AusNet Gas Services Pty Ltd

Gas Access Arrangement Review 2018–2022

Appendix 9D: Inflation compensation- addendum to September report – 14 December 2016

Submitted: 16 December 2016

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COMPETITION ECONOMISTS GROUP

Memorandum

To:	AusNet Services, Multinet Gas and AGN
From:	CEG – Asia Pacific
Date:	14 December 2016
Subject:	**Inflation compensation – addendum to September report**

1. This memorandum provides supplementary analysis to our September report for AusNet Services, Multinet Gas and AGN.[1] Section 1 provides a summary of the academic literature that was referred to by the AER in its Final Decision for AusNet distribution in support of the potential existence of bias in breakeven inflation (our original report was limited to those papers discussed by the AER in Table 3-25). It concludes that of the overwhelming evidence in those papers is that any such bias is likely to be positive (such that breakeven inflation overstates expected inflation).

2. Section 2 addresses the optimal regulatory design to give effect to the objective of accurately compensating for efficient financing costs. It begins by recapping how the regulatory regime delivers realised returns to investors and explains why the operation of the PTRM and the RAB RFM must be analysed jointly for this purpose.

3. Section 2 goes onto explain that application of the AER's PTRM and RAB RFM will, absent any cost pass through for the impact of unexpected inflation, cause compensation to systematically deviate from efficient costs when there is a divergence between actual and previously expected inflation. It is explained that this is because the AER's proposed framework treats all financing costs as real (i.e., varying with inflation) but, in reality, efficient debt financing costs are nominal. Amendments to the AER's regime are suggested that would mean that compensation matched benchmark efficient costs even in the presence of unexpected inflation.

4. In this context we agree with the AER that the cost of equity is a real cost and should be compensated as such by deducting the expected inflation that is built into nominal 10 year CGS yields during the equity averaging period. However, we explain that, given that debt is a nominal cost, a different approach is appropriate for debt.

[1] CEG, Best estimate of expected inflation, September 2016.

1 Bias in breakeven inflation

1.1 AER cited literature supports, if anything, a positive estimate of bias

5. In our September report we analysed, *inter alia*, academic papers referred to by the AER (in Table 3-25 of its AusNet Services final decision) in support of the existence of bias. We revisit that analysis below, adding papers referred to elsewhere by the AER in the same decision.

6. In total the AER cites 9 academic papers[2] that deal with the existence of potential sources of bias in breakeven inflation estimates. Of these, only 6 have actual estimates of the sign of any net bias with the focus of the other 3 papers being elsewhere (and generally simply mentioning the theoretical potential for bias). Five of the six papers with empirical estimates present evidence consistent with the conclusion that 10 year breakeven inflation was more likely to overestimate expected inflation than underestimate it. The only paper with the opposite conclusion (Shen and Corning (2001)) relates only to the first four years of the operation of the US indexed bond market.

[2] These references can be found in footnotes 600, 601, 602, 603, 604, 605, 610 611, 613, 614, of the AusNet Distribution Final Decision, Attachment 3, at pages 3-156 to 3-3-159.

Table 1: Literature summary

Finding	Article references
Magnitude and sign of potential bias – discussed in detail in Appendix A	
Positive net bias (overestimation)	Grishchenko and Huang (2012); Finlay and Wende (2011); D'Amico, Kim and Wei (2009); Gurkaynak, R., Sack, B., Wright, J. (2010); Campbell, Shiller and Viceira (2009).
Negative net bias (underestimation)	Shen and Corning (2001). This paper only had 4 years of data available from the first issuance of indexed bonds (see page 68).
No estimate of bias provided	Scholtes (2002) - While not providing any estimates of potential bias in long term breakeven rates, Scholtes states on page 74: "Breakeven inflation rates are useful in providing an indication of investors' views of the longer-term inflation outlook that is unavailable elsewhere." Barnes, Bodie, Triest and Wang (2015) - The authors raise potential sources of bias (at page 70) but make no attempt to measure these. Devlin and Patwardhan (2012) - The authors note the existence of potential sources of bias but do not attempt to measure them.
Sources of potential bias – discussed in detail in Appendix B	
Convexity bias	Grishchenko and Huang (2012), at page 18, cite literature that puts this bias at less than -1bp.
Inflation risk premium	Grishchenko and Huang (2012), at page 30 state that their preferred estimate of inflation risk premium is +14bp to +19bp over the period 2004 to 2008 and also survey the literature which typically estimates a higher inflation risk premium.
Liquidity premium	Grishchenko and Huang (2012), at page 3, estimate the average liquidity premium at 6bp (less than the average inflation risk premium implying the net effect is that breakeven inflation overestimates inflation expectations). D'Amico, Kim, and Wei (2009), at page 64, similarly show a time series for the liquidity premium which has hovered around zero since 2004. Devlin and Patwardhan (2012), at page 8, note that the Australian "relative liquidity difference appears to have narrowed over recent years". Campbell, Shiller and Viceira (2009), at page 115, state that indexed bonds are "extremely cheap to trade".
Impact of indexation lag	The literature notes that the impact of indexation lag is predominantly an issue for short term measures of breakeven inflation: D'Amico, Kim, and Wei (2009), at page 36; Shen and Corning (2001), at page 86, in footnote 29; Scholtes (2002), at page 70. In any event, the sign of any bias is indeterminate.

1.2 No adjustment for bias previously made by the AER

7. It relevant to note that, when using breakeven inflation to determine expected inflation prior to late 2008, the AER and its forerunner the ACCC, did not make any adjustments for inflation risk or any of the other potential sources of bias, for which it now argues adjustments must be made.[3] Following submissions, including by the author of this report that, at that time, breakeven inflation was upward biased by a lack of supply of indexed CGS, the AER in its 2007 Final Decision for Powerlink stated:[4]

> *The use of the Fisher equation to derive inflation forecasts is a well established practice among Australian regulators. It has been widely accepted as an appropriate method of forecasting inflation. The AER considers that until a thorough analysis of NERA's study has been undertaken, the forecast inflation rate used in revenue caps should continue to be determined by the difference between nominal and indexed CGS yields obtained from the financial market. The use of the latest market based data is objective and transparent and avoids the need for assumptions regarding future inflation. The inflation forecast derived from the Fisher equation also maintains consistency with other financial parameters used in the regulatory framework. Accordingly, the AER considers that its inflation forecast of 3.15 per cent in the draft decision is consistent with the capital market conditions that applies when the CGS yields were sampled.141 For this final decision, the AER has decided to apply a forecast inflation rate of 3.15 per cent per annum based on market determined nominal and indexed CGS yields.*

1.3 Breakeven inflation in 2007

8. There are two important points to note in relation to the experience with breakeven inflation around 2007. The first is that breakeven inflation was widely accepted to be overstating expected inflation (including in subsequent AER decisions). That is, breakeven inflation was accepted as being biased upwards.

9. For a period the AER made no adjustment for this bias but, when it eventually did, it adopted an estimate of expected inflation that was *lower* than breakeven inflation. That is, consistent with adjusting for an *upward bias* in breakeven inflation. This is entirely consistent with the academic literature which suggests that breakeven inflation tends to, if anything, overstate expected inflation.

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3 For example, see ACCC, Final Decision, NSW and ACT Transmission Network Revenue Cap, TransGrid 2004–05 to 2008–09, p. 139.

4 AER, Powerlink Final Decision, 2007, p. 105.

10. This was entirely appropriate in 2007 when the indexed CGS were in short supply and the Government policy was not to issue any new indexed CGS. At that time there were only 3 indexed bonds on issue with maturity horizons of 2, 7 and 13 years.[5] Currently, there are 7 indexed CGS on issue[6] with maturity horizons from 2 to 24 years and a firm Government commitment to continue issuance.[7]

11. Devlin and Hardin (2012), one of the papers cited by the AER, states:[8]

> *The issuance of Treasury indexed bonds was halted in 2003, and maturing bond lines saw the market shrink to a low of around $6 billion outstanding in 2008. In late 2009, however, the AOFM resumed its indexed bond issuance program and the market has since grown to just over $16 billion outstanding. At the 2011-12 Budget the Government announced it would support liquidity in the indexed bond market by maintaining around 10 to 15 per cent of the total CGS market in indexed securities. There are currently five indexed bond lines on issue, with maturities ranging from 2015 to 2030.*

12. Since then the issuance of indexed CGS has expanded still further (indeed doubled in dollar value). This is illustrated in Figure 1 below.

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5 Treasury Indexed Bonds numbered 404, 405, 404. As set out in RBA table F16 Indicative Mid Rates Of Selected Australian Government Securities (available on the RBA website).

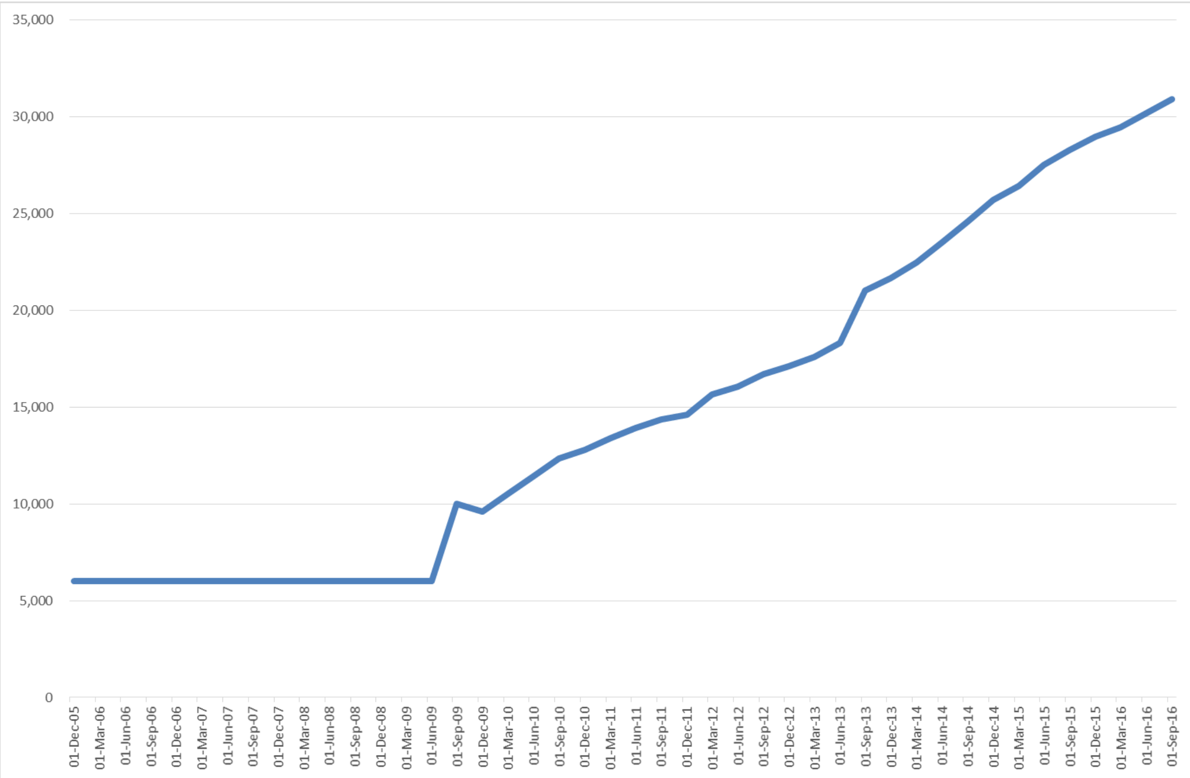
6 Treasury Indexed Bonds numbered 406, 407, 408, 409, 410, 412, and 413. As set out in RBA table F16 Indicative Mid Rates of Selected Australian Government Securities (available on the RBA website).

7 In a 26 May 2015 speech "*Australian Government Sovereign Debt: Are we there yet? What more can be expected in terms of developing the market? – Presentation to the Australian Business Economists luncheon*" the CEO of the AOFM stated:

> *From a modest starting point in 2009 when we recommenced indexed issuance (with $6 billion on issue spread across 3 lines), we now have around $27 billion in stock outstanding ($33 billion when adjusted for inflation indexation). This is spread across 7 lines with a curve extending 20 years.*

8 Devlin and Hardin (2012), p. 8.

Figure 1: Indexed CGS on issue



AOFM data, CEG analysis

13. In relation to the market imperfections in and around 2007 and 2008, the AER refers to two reports authored by the author of this report (Dr Hird for NERA and CEG in 2007 and 2008 respectively).[9] In these reports, it was observed that a lack of supply in indexed government bond yields were, at that time, causing breakeven inflation to *overestimate* expected inflation.

14. As is clear from the findings in the literature relied on by the AER and from Dr Hird's 2007 report, the effect of any inflation risk premium is to render breakeven estimates of inflation expectations *conservative* in that breakeven inflation overstates true inflation expectations, and any adjustment for this issue would lower the estimate of inflation expectations below breakeven inflation. This is made clear in the below quote from Dr Hird's 2007 report:

> *It is important to note that the bias in CGS examined here is a separate issue to any inflation risk premium. An inflation risk premium exists where investors require more than just expected inflation to compensate them for the exposure to inflation associated with nominally defined debt repayments. …*

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9 NERA, Bias in Indexed CGS Yields as a Proxy for the CAPM Risk Free Rate, March 2007; CEG, Expected inflation estimation methodology A report for Country Energy, April 2008.

That does not mean to say that there is no inflation risk premium. Our work is not intended to shed any light on that issue one way or the other.

15. Any failure to adjust for bias by lowering the estimate of inflation below breakeven inflation can, in no way, provide a rationale for the AER's preference for its own (higher) estimate.

1.4 Estimates of bias are not reliable especially over short windows

16. In order to make an adjustment for bias in expected inflation, one needs to have at hand a better, more accurate, measure of expected inflation. If such a measure was at hand then, obviously, it would be used in preference to breakeven inflation. In other words, all estimates of bias (positive or negative) in the breakeven rate must ultimately be based on a comparison to an alternative measure of expected inflation that is assumed to be more accurate.

17. The alternative estimates used in the literature are commonly surveys of economist forecasts, actual inflation outcomes or some sort of model that defines inflation expectations in terms of past inflation and real economic activity. Grishchenko and Huang (2012) use all three alternative measures.[10] Naturally, the results are only a true measure of bias if it is the case that the alternative measure of expectations is accurate. If the alternative estimate is not accurate, then the results can reasonably be interpreted as bias in the alternative measures of inflation expectations and not in breakeven inflation.

18. Importantly, our September 2016 report carefully explains that surveys of inflation forecasts are typically measures of 'likely' inflation while market based measures reflect actuarially expected inflation. We also explain that the expected inflation that must be used in the PTRM (and which is built into observed bond yields) is actuarially expected inflation. Actuarially expected and most likely inflation can, and do, diverge. Therefore, when a research paper identifies a 'bias' in a market based measure of inflation expectations (such as breakeven inflation) relative to survey inflation expectations this is not necessarily (or even likely) a measure of bias relative to the inflation expectation that the AER should be targeting. Rather, it is just as likely a measure of bias in survey inflation relative to the measure that the AER should be targeting.

19. In our view, in a mature indexed government bond market where ongoing supply is not in question, there is no alternative measure of actuarially expected 10 year inflation expectations built into government bond rates than the breakeven inflation implied by government bond rates. Given that the purpose of inflation expectations in the PTRM is to back out the former measure of inflation expectations, then the latter source of that estimate is best. It is possible that this will be a biased measure but it is not

[10] See discussion beginning in the second paragraph on page 9

possible to reliably estimate the magnitude of any bias over a short horizon (such as a cost of equity averaging period).

20. These considerations are, presumably, why the AER did not make any attempt to adjust breakeven inflation in its 2007 decision for Powerlink quoted above. Namely, having failed to determine a better estimate the AER did not have a reliable basis upon which to make an adjustment.

21. It is, however, possible to, more reliably, arrive at estimates of the average bias over longer periods of time. That does not mean that all such measures will be accurate because, as already discussed, any measure of bias is only as good as the alternative expectation estimate used. However, it is notable that the literature is clear that the best estimate of any such bias is positive (i.e., breakeven inflation is biased upwards).

1.5 Government issuance of indexed bonds implies they believe any bias is positive

22. An important confirmation of the existence of a positive bias is the very existence of CPI indexed bonds. If the bias was negative then this is just another way of saying that CPI indexed bonds are expected to be a more costly form of borrowing by the government in question. The Australian Government's decision to cease issuing indexed CGS in the mid 2000s was based on a projected dwindling of Government debt (due to prolonged budget surpluses) such that even the nominal CGS market was under threat of closure. The cessation of issuance of indexed bonds (and Treasury Notes) reflected the need to concentrate the limited issuance available (at that time) in a single market in order to maintain that market's overall viability.[11]

23. However, as soon as budgetary circumstances allowed, following the GFC, the Government recommenced issuance of indexed CGS. The fact that the Government did so is evidence that it believed that the expected cost of issuing indexed CGS was, at a minimum, not higher than the cost of issuing nominal CGS. By definition, this can only be the case if break even inflation exceeds (or is not less than) actuarially expected

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[11] As noted in the 2002-03 AOFM Annual Report

"The Government publicly reviewed the future of the Commonwealth Government securities market during the year against a backdrop of financial market concern about the future viability of the market. The review concluded that sufficient Treasury Bonds should be issued to support the Treasury Bond futures market. Without a Treasury Bond futures market, higher costs associated with managing interest rate risk would lead to slightly higher interest rates across the economy.

The outcome of the review, as set out in the 2003 Budget papers, establishes a clear medium-term framework for the AOFM's debt management operations. While recent borrowing and repurchase programs have been structured to a broad objective of maintaining the viability of the Commonwealth Government securities market, programs going forward will be tightly targeted to support the Treasury Bond futures market. Accordingly, the AOFM has suspended" inflation outcomes. That is, mathematically, the difference in expected costs of issuing nominal and indexed CGS is equal to:

- inflation compensation built into nominal CGS (i.e., breakeven inflation); and
- actuarially expected inflation.

24. If the former exceeds the latter then the expected cost of indexed CGS are lower than nominal CGS and it makes sense to issue indexed CGS. The Australian Government's keenness to return to issuing indexed CGS post GFC provides a useful indication that it believes than any bias in breakeven inflation is likely positive.

25. The same conclusion has been made explicitly in one of the papers relied on by the AER, namely, Campbell, Shiller and Viceira (2009). The key findings of interest in the current context is that indexed bonds (TIPS, "Treasury inflation-protected securities") are lower expected cost precisely because investors in nominal bonds require compensation for risk above and beyond inflation expectations:[12]

> *"Governments should expect inflation-indexed bonds to be a relatively cheap form of debt financing in the future, even though they have offered high returns over the past decade."*

26. Similarly, on page 115, the authors state:

> *"…our analysis implies that the cost of TIPS should be lower than that of Treasury bills ex ante, because TIPS offer investors desirable insurance against future variation in real interest rates."*

1.6 Conclusion

27. We are aware of no evidence from which the AER can reach a positive state of satisfaction that a better forecast than breakeven inflation is possible in the circumstances (the only other possible forecast before the AER being the AER's estimate). In particular, there is no evidence to suggest that potential biases in the breakeven methodology currently exist (on the contrary, the short term accuracy of the breakeven methodology suggests otherwise) or that, if those biases exist, they would result in an underestimate of inflation. Further, as discussed above, there is clear evidence that the AER's methodology results in an upwardly biased estimate even over a 10 year horizon, given that in the current low inflation and low interest rate environment, investor expectations are that there is an asymmetry of risk in inflation being less than the midpoint of the RBA's forecast and target inflation bands over 10 years than exceeding it.

12 Campbell, Shiller and Viceira (2009), p. 79.

2 Regulatory design issues – eliminating inflation forecast error for the debt portion of the RAB

28. Under the current regulatory design, any deviation of actual from expected inflation results in a corresponding change in the return on the RAB (both real and nominal) paid by customers and received by investors.[13] This means that adopting the most accurate estimate of expected inflation is critical to correctly compensating investors. For the reasons set out above, and in our September 2016 report, we consider that this is achieved by the adoption of breakeven inflation.

29. This section describes reforms to the regulatory design that would have the effect of reducing the potential impact of deviations of actual inflation from expected inflation. Justification for such reform exists absent any disagreement on the best estimate of expected inflation. However, where such disagreement remains these reforms provide a critical means of also defusing such disagreement. This is because these reforms materially reduce, for both investors and customers, the impact of an inaccurate estimate of expected inflation. .

2.1 How the regulatory regime delivers returns to investors

30. Before analysing how inflation is/should be compensated in the regulatory design, it is critical to understand that financing costs are compensated via a combination of both revenues (set in the PTRM) and rolling forward the RAB (in the RAB RFM). That is, the internal rate of return (IRR) actually received on the investment in the RAB must be calculated by reference to:

- The opening RAB in regulatory period T
- The net cash-flows before interest during the regulatory period T; and
- The opening RAB in regulatory period T+1 (i.e., the "Terminal Value" in the cash-flow analysis).

31. Similarly, from the perspective of equity investors (i.e., owners) the IRR must be calculated by reference to:

- The equity portion of the opening RAB in regulatory period T
- The cash-flows *after interest* during the regulatory period T; and
- The equity portion of the opening RAB in regulatory period T+1 (i.e., the "Terminal Value" in the cash-flow analysis).

13 For any given actual inflation, a 1.0% lower/higher estimate of expected inflation will flow through automatically into a 1.0% higher/lower real return on the RAB.

32. In order to analyse the role of inflation in the regulatory design it is impossible to do so without simultaneously analysing the operation of both the PTRM and the RAB RFM.

2.2 Inflation risk and regulatory design

33. The AER has expressed its view that under the current regime regulated businesses face "no inflation risk"[14] which is less than the risks faced by competitive businesses.

> *Regulated service providers face less inflation risk than unregulated businesses. Under the regulatory framework, they effectively expect to receive a real return on their investments in their RABs and to also have their RABs indexed for actual inflation.*

34. However, the AER conflates maintaining the real value of the RAB with eliminating inflation risk. These two concepts are only the same if all financing costs are incurred in real (inflation adjusted) terms. This is clearly not the case for debt financing costs which are efficiently incurred in fixed nominal contracts (i.e., such that repayments to debt providers are independent of the level of subsequent inflation after the contract is entered into).

35. Given that the benchmark entity has fixed nominal financing costs for 60% of its RAB, maintaining a fixed real return on the RAB creates, rather than eliminates, inflation risk. By way of example, imagine a business with a RAB of $10bn financed with $6bn in debt and $4bn in equity. Now, let a period of unexpected deflation occur such that the price level halves. The RAB would need to halve to $5bn in order to maintain the real value of the RAB. However, total outstanding debt, specified in nominal terms, would remain at $6bn and the benchmark business would be bankrupted ($1bn (or 20%) more debt than gross assets).

36. Similarly, if there was a period of unexpectedly very high inflation, such that the price level doubled, the businesses' debt would remain fixed in nominal terms at 6bn but the value of the assets would double to $20bn – causing the equity stake to more than triple (from $4bn to $14). Given the price level only doubled in this example the equity stake would only need to double to $8bn in order to maintain its real value. The additional $6bn increase in the equity stake is a pure windfall for the equity owners.

37. Neither of these impacts (bankruptcy or a $6bn dollar windfall) is as a result of any inefficient/efficient action taken by the business. Rather, these result from forces that are outside the control of the business, economy wide inflation levels, interacting with a regulatory design that does not accurately reflect the impact of unexpected inflation on costs.

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14 See Final Decision for AusNet distribution p. 3-157.

38. The above examples are extreme in order to provide a clear illustration of the nature of the problem. However, the same effect is produced for smaller divergences between expected and actual inflation. More generally, compensating debt financing costs 'as if' they were real (rather than nominal) costs means that debt costs will be over/undercompensated whenever inflation is higher/lower than the expected inflation used to set the real revenue path.

2.3 Correction if objective is to remove inflation risk

39. If one accepts that debt costs are efficiently incurred in nominal terms, there are a number of ways that this mismatch between efficient costs and compensation can be corrected. All of them involve ensuring that, for the debt funded 60% of the RAB, the revenue reduction associated with inflation is the same as the RAB increase in the RFM. This can be achieved by:

- Retaining the current approach to the 2018-22 PTRM but using a 60/40 weighted average of PTRM/actual inflation in the 2018-22 RAB RFM;
- Retain the current 2018-22 RAB RFM but amend the 2018-22 PTRM such that annual updates of the PTRM correct for 60% of divergences between actual and expected inflation.
- A cost pass through measure corresponding to the difference between nominal compensation actually provided for the cost of debt (via both PTRM revenues and RAB RFM) and the nominal cost of debt (as per the trailing average calculations).

40. Correctly implemented, all of these approaches would have the same result, namely, ensuring that the nominal compensation for the cost of debt matches the nominal cost of debt which is the regulator's best estimate of efficient debt financing costs and which is used as an input to the PTRM.

2.4 Implication for measuring inflation expectations

41. The AER's current approach to inflation forecasting is to forecast inflation over a 10 year horizon where the start date of that horizon is the beginning of the regulatory period.[15] In our view, the adoption of a 10 year horizon only makes sense in the context of attempting to derive a real return on equity. If debt costs are efficiently incurred in nominal terms then the forecast horizon should be the five year regulatory period

15 This is the AER's practice and it is consistent with the approach described in AER *Final decision, TransGrid transmission determination 2009–10 to 2013–14*, p.64 where the AER states: "The AER has updated the inflation forecast **for the first two years of the next regulatory control period** using the latest published RBA inflation expectations as shown in table 4.5." (emphasis added). The AER references this document in its PTRM transmission handbook as a description of its methodology.

(because this is what maximises the probability that the deduction from revenues for inflation in the PTRM will match the increment to the RAB in the RFM for inflation).

42. However, putting this issue aside, even if the objective was to estimate the expected real return on both equity and debt, then the correct measure of 10 year inflation expectations is the expected inflation in the equity and debt averaging periods. This is the inflation expectation that will be embedded in the bond returns that are used by the AER to set the cost of debt and equity.

43. The averaging periods for debt and equity can be materially different both from each other and from the start of the regulatory period. Indeed, there are 10 different averaging periods for the cost of debt under a trailing average which are spread over 10 different years. There is no reason to believe that inflation expectations for 10 years starting on the first day of the regulatory period has any bearing whatsoever on the inflation expectations built into the nominal cost of debt. It follows that, even if one were interested in removing the inflation expectation built into nominal debt costs, one would need 10 different inflation expectations – one to match each relevant averaging period in the trailing average.

44. Focussing on equity costs, which is the only element of financing costs it makes sense to attempt to remove expected inflation, the required measure is the 10 year inflation expectation that:

   a. is held by investors in the 10 year government bond market;

   b. reflects the same 10 year horizon (starting in the averaging period and ending 10 years hence); and

   c. is measured over the equity averaging period (i.e., over the period that the 10 year nominal government bond yield is measured as an input into the cost of equity).

45. Clearly, 10 year breakeven inflation measured over the regulatory period provides a measure that is consistent with all of these requirements: a) derived from the relevant bond market; b) reflects a 10 year horizon from the equity averaging period; and b) measurable over the equity averaging period. The AER's method does not: a) attempt to measure bond market investor expectations; b) cover a 10 year horizon starting in the equity averaging period; c) reflect an average of expectations during the equity averaging period.

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Appendix A: Summary of empirical estimates

46. This appendix summarises the key results of the 6 articles referred to by the AER that have empirical estimates of bias.

Introductory comments

The term 'liquidity premium' does not mean the same thing in all studies

47. Before proceeding with a discussion of each individual paper it is useful to make a few observations about the existence or otherwise of a 'liquidity premium'. The first point to note is that in much of the literature the reported 'liquidity premium' is, in reality, an error term in the analysis. It is the term given to the amount of the difference between nominal and indexed government bonds that is not explained by the other factors in the researchers' models. For example, D'Amico, Kim and Wei (2009) estimate a TIPS[16] "liquidity premium" that causes breakeven inflation to overestimate expected inflation in early 2005[17] (i.e., associated with breakeven inflation overestimating expected inflation). If one attempted to truly relate this back to differential liquidity as a cause it would imply that investors in that period preferred indexed bonds (paid a higher price/accepted a lower yield) because they valued relative illiquidity.

48. There is no reason to believe that investors would pay more for index linked Treasury bonds because they are less liquid. Therefore, there is no reason to assign an upward bias in breakeven inflation that is due to the relative liquidity of the instruments. However, if the liquidity premium is simply the name given to an error term (residual) in the researchers' model then this, naturally, can be negative. Given that many of the papers surveyed use surveys of inflation expectations as the benchmark against which breakeven inflation is measured what is really being measured are potential explanations for why breakeven inflation is different to the average of survey information.

[16] US Treasury Inflation Protected Securities.

[17] See Figure 11 of D'Amico, Kim and Wei (2009). The Authors updated (and modified) their estimates for a 2016 published version of the same paper. In that paper the TIPS "liquidity premium" is associated with breakeven inflation exceeding expected inflation from 2012 onwards – as can be seen in the reproduction at Figure 24 of our September 2016 report. (Note that in the 2016 paper the authors have assigned a different sign to the "liquidity premium". In the 2009 paper a negative "liquidity premium" implied upward bias in breakeven inflation while in the 2016 paper a positive "liquidity premium" implies upward bias in breakeven inflation).

Potential for 'true' liquidity premium is small

49. The theoretical reason for the existence of a liquidity premium is that investors will have a preference for assets that are more liquid because those assets allow them to optimise their portfolios at lowest cost. Specifically, a 'liquid' market is one where an individual investor can expect to be able to buy or sell into the market without their personal transaction having a significant impact on the price paid/received in the transaction.

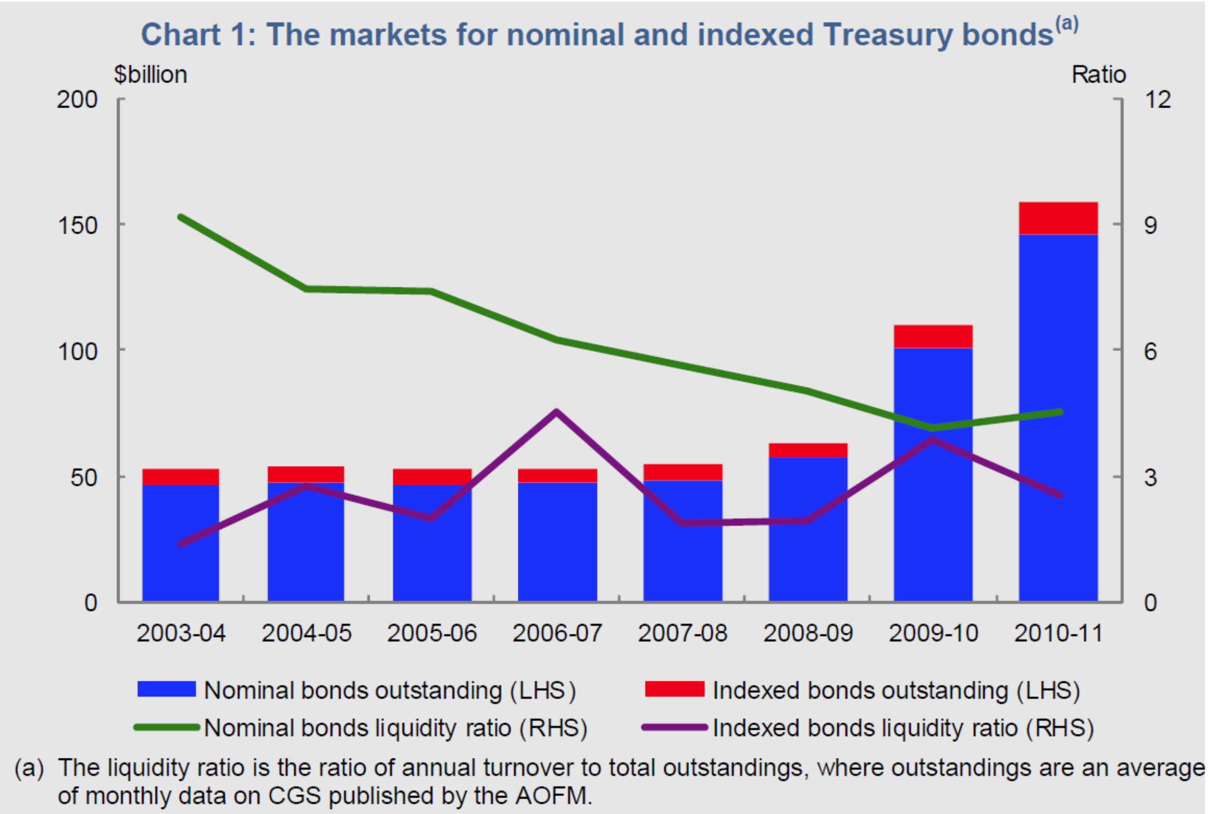
50. In reality, both indexed and nominal CGS are highly liquid. This means that the value investors place on any differential in liquidity is likely to be trivial. Both the nominal and indexed CGS markets are highly liquid with turnover of around $1,000bn and $50bn respectively. While the turnover in nominal bonds is around 20 times larger, both are very large in absolute magnitude.

51. Moreover, liquidity is a function of the ability of an investor to divest their holding without moving the market and, given that investors' holdings on nominal CGS tend to be larger, the absolute turnover must be adjusted for the average holding of these bonds in an investor's portfolio. A standard way to do so is to divide turnover rates by total outstanding stock in order to provide the 'turnover ratio'. The Australian Financial Markets Association produces this metric for nominal CGS and it has fallen from 5.2 in 2007/08 to 3.2 in 2014/15. [18] A similar metric for indexed CGS was around 1.2 in 2007/08 and 2.0 in 2014/15.[19] On this metric, liquidity in nominal CGS is only modestly higher than for indexed CGS. Notably, this is the metric that is used in the Devlin and Patwardhan (2012) when they note on page 8 that "relative liquidity difference appears to have narrowed over recent years". The relevant chart on which this statement is based is produced below.

18 AFMA, 2008 and 2015 Australian Financial Markets Report.

19 AFMA does not explicitly present this ratio but it can be calculated as total turnover in index linked CGS (e.g., $51bn in 2014-15) divided by total bonds outstanding available from AOFM ($25.5bn average of beginning and end of year outstanding in 2014-15).

Figure 2: Reproduction of Chart 1 from Devlin and Patwardhan (2012)



Source: AOFM, Australian Financial Markets Association and Treasury.

52. Notably the AER cites Devlin and Patwardhan (2012) in support of the AER's view that '*the size and liquidity of the indexed CGS market is still limited*'.[20] However, the AER cites to page 7 of Devlin and Patwardhan (2012) in support. On the relevant page Devlin and Patwardhan (2012) make the following statement:

> *The use of bond market break-evens is also made somewhat problematic by the limited size and liquidity of the indexed bond market in Australia. While the market for (nominal) Treasury bonds is quite liquid, the market for Treasury indexed bonds is significantly less liquid (see Box 1).*

53. In our view, this quote, and the reference to Box 1 in which Chart 1 above is found, is clearly referencing historical average differences in liquidity – not prevailing estimates (for which the authors note relative liquidity difference appears to have

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20 AER, Ausnet Distribution, Final Decision, May 2016, p. 3-159.

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narrowed over recent years). Moreover, this is before factoring in the increased issuance since publication of the article.[21]

54. Moreover, having cited Devlin and Patwardhan (2012) (incorrectly) in support of a conclusion that '*the size and liquidity of the indexed CGS market is still limited',* the AER goes onto use a measure of relative liquidity which is not that used by Devlin and Patwardhan (2012). Instead, they use absolute trading volume (not volume relative to outstandings).[22]

> *Trading volume of indexed CGS expressed share of total indexed and nominal CGS can be used as a measure of the relative liquidity. According to this metric, there has only been a minor improvement to relative liquidity of the indexed CGS since early 2008.*

55. Even if we were to accept the AER's use of absolute trading volumes as an appropriate measure of absolute 'liquidity',[23] it is critical to differentiate between this measure of liquidity and the value that investors place on liquidity. The AER, in the above quote, proceeds as if the marginal value to investors of liquidity (so measured) does not decline with absolute liquidity. This is a critical theoretical error.

56. Investors' valuation of additional liquidity falls to zero as soon as they are confident that their own trading will not move the market against themselves. That is, if I am already confident that I will not move the CGS market against myself when trading, then I receive no advantage, and will not value CGS any higher, if the turnover in the market doubles or quadruples. Both nominal and indexed CGS are homogenous products that are very easy to value. This means that there are not the same 'inside information issues' that arise with trading corporate equity and debt. This fact, when combined with the very large in size (and turnover relative to size) markets means

21 Thus, the reference to 'still' in the AER quote, made in 2016, should, at best, be 'was limited in 2010-11'. This is particularly important given that the authors of that paper note (on p. 8) "In late 2009, however, the AOFM resumed its indexed bond issuance program and the market has since grown to just over **$16 billion** outstanding. At the 2011-12 Budget the Government announced it would support liquidity in the indexed bond market by maintaining around 10 to 15 per cent of the total CGS market in indexed securities. There are currently **five indexed bond lines on issue**, with maturities ranging from 2015 **to 2030**." [Emphasis added.] At the time of the AER's final decision there were **seven indexed bond lines** on issue (see AER, AusNet Distribution Final Decision, 2016 3-159) which is 2 more than the five referred to by Devlin and Patwardha. Similarly, the amount outstanding was at least **$33 billion** outstanding (see CEG, report for SAPN, p.7 FN 4) more than double the $16bn in 2010-11 referred to by Devlin and Patwardha. Similarly, the maturity range extended out to **2040 or 2045** (see CEG, report for SAPN, p.7 FN 5) which is 10 to 15 years longer than referred to by Devlin and Patwardha. Moreover, the expanded issuance of indexed CGS was foreshadowed by Devlin and Patwardha in the above quote. The AER's reliance on Devlin and Patwardha to conclude that liquidity of the indexed CGS market is "still" limited is an important factual error.

22 AER, Ausnet Distribution, Final Decision, May 2016, p. 3-159.

23 Indeed, the following logic applies to any measure of liquidity – including turnover adjusted for outstandings.

that it is therefore reasonable to assume that the potential value of incremental increases in turnover/liquidity ratio when moving from indexed CGS to nominal CGS are very small.

57. Contrary to the AER's position, a material absolute increase in turnover for indexed bonds will, even if it is matched by higher turnover for nominal bonds, materially reduce any liquidity bias because the marginal 'liquidity value' of incremental turnover will be higher for the less liquid instrument. In this context it is relevant to note that, Campbell, Shiller and Viceira (2009, p.115) state that indexed bonds are "extremely cheap to trade". Once an instrument is 'extremely cheap to trade' there is a limit to any difference in the cost of trading that instrument and a lower cost instrument.

58. That is not to say that there might be a more material liquidity premium when moving from CGS to less liquid assets (such as corporate debt/equity or real-estate). However, there is no reason to believe that a material liquidity premium exists when moving from indexed to nominal CGS.

Grishchenko and Huang (2012)

59. The relevant finding from Grishchenko and Huang (2012, p. 30) is as follows

> *"...we conclude that the 10-year inflation risk premium ranges between 14 and 19 b.p., depending on the proxy used for expected inflation, based on our empirical analysis and when we correct for liquidity using a liquidity adjustment".*

60. That is, the authors estimate that exposure to inflation risk in nominal government bonds causes these bonds to include a risk premium of 14 to 19bp such that breakeven inflation is overstated (i.e., nominal yields are elevated relative to inflation protected yields).

61. Grishchenko and Huang (2012) also examine the existence of a liquidity premium that might have the opposite effect (raising the relatively less liquid indexed bond yields relative to the nominal bond yields). Figure 4 of Grishchenko and Huang (2012) demonstrates that, from 2000 to 2009, any impact of a liquidity premium on breakeven inflation is below 10bp outside the GFC and a single month in 2003. The authors' average liquidity premium estimate is 6bp (see page 3).

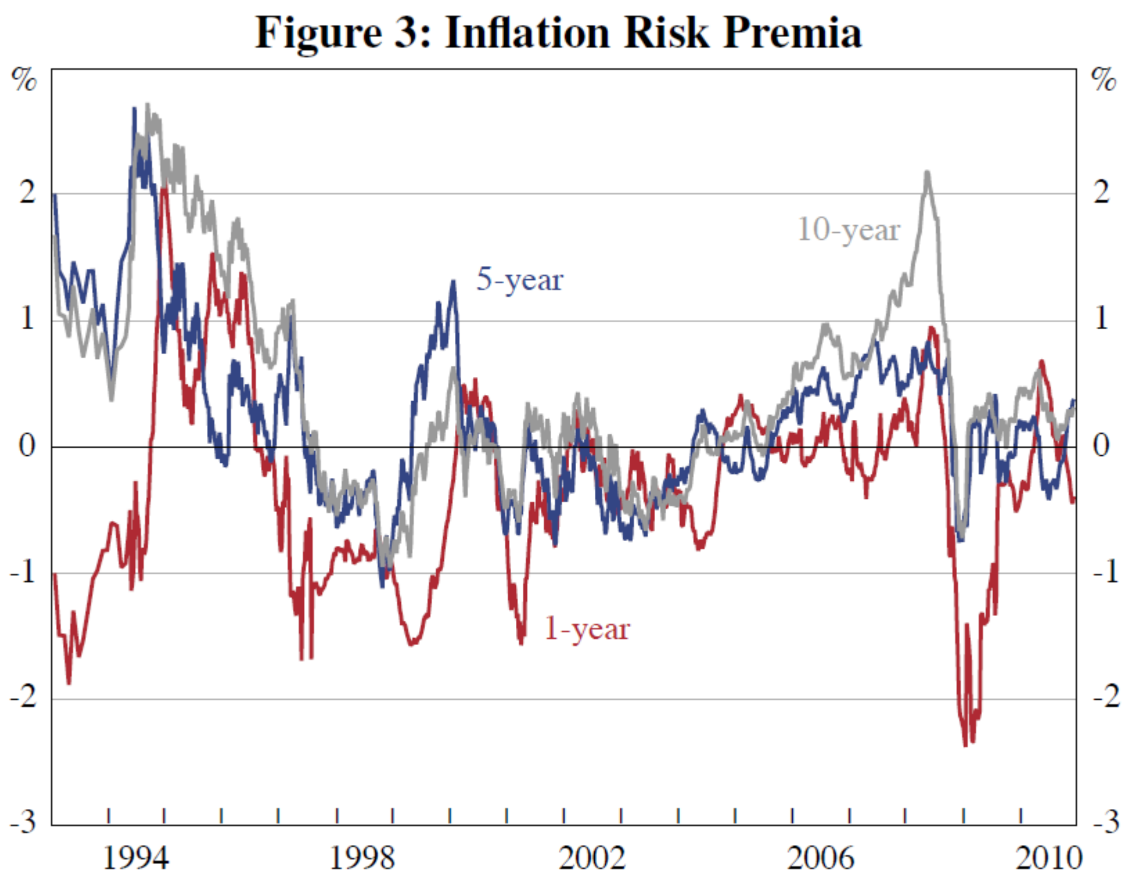
62. Subtracting this from the 14-19bp range gives a net bias estimate of 8-13bp. This implies breakeven inflation overestimates expected inflation by 8-13bp.

Finlay and Wende (2011)

63. The most relevant findings are presented in Figure 3 on page 16, which shows that the inflation risk premia (which incorporates any liquidity premia) for 10 year maturity

(grey line) is positive for the majority of the sample period in Australia and for all of the period post GFC.

Figure 3: Reproduction of Figure 3 from Finlay and Wende (2011)



64. Similar results presented for the UK in the bottom panel of Figure 5 on page 19.

D'Amico, Kim and Wei (2009)

65. The key summary chart is the bottom panel of Figure 11 on page 64 which shows that, since 2003, the 10 year breakeven inflation has been typically higher than or hovered around the authors' alternative estimate of inflation expectations.

Figure 4: Reproduction of Figure 11 from D'Amico, Kim and Wei (2009)

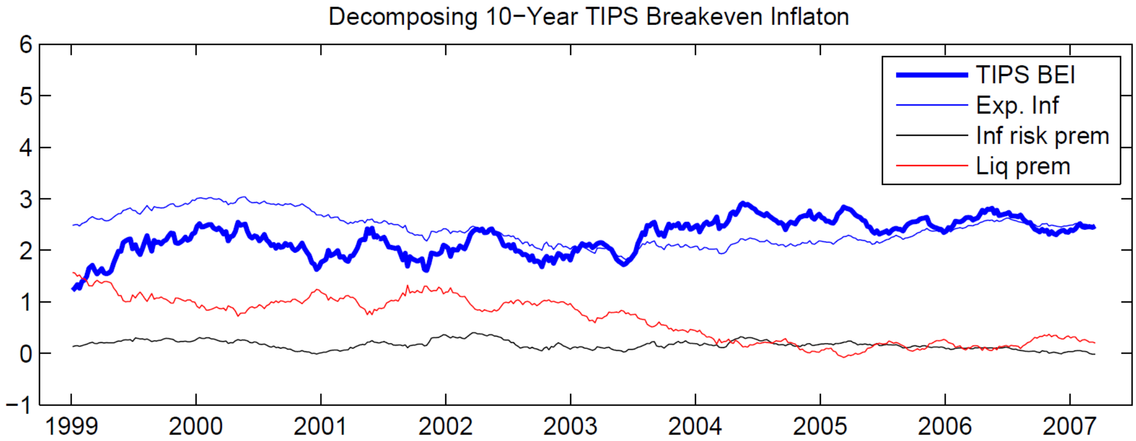
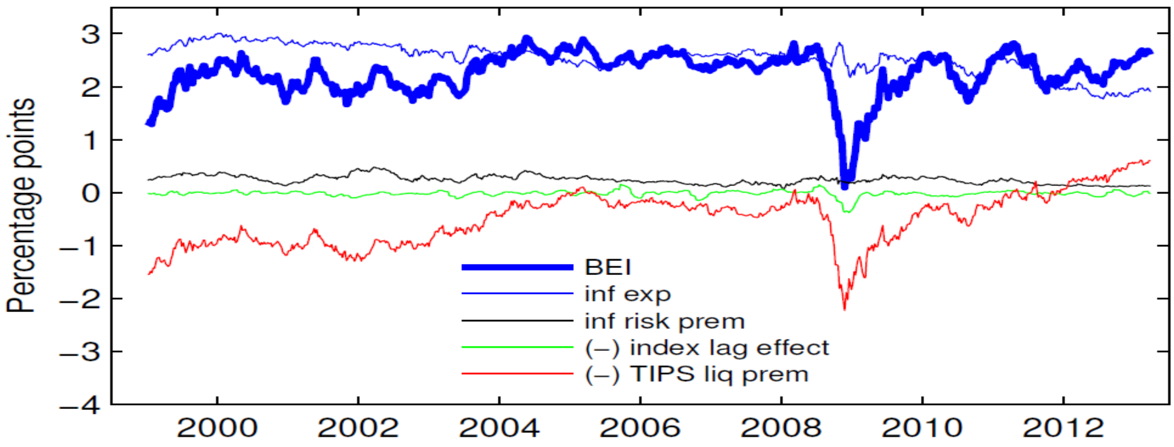


Figure 11: Decomposing TIPS Yields and TIPS Breakeven Inflation

66. As noted in our September report, the same authors have a 2016 update[24] which shows that, but for the GFC, the same results held.

Figure 5: Decomposing 10-year TIPS Breakeven Inflation D'Amico, Kim and Wei (2016)



24 D'Amico, S., Kim, D. H., and Wei, M., "Tips from TIPS: the Informational Content of Treasury Inflation-Protected Security Prices," FEDS Working Paper 2014-24 (Draft Version February 19, 2016)

Gurkaynak, R., Sack, B., Wright, J. (2010)[25]

67. Gurkaynak, R., Sack, B., Wright, J. (2010, p. 85) state:

> *"Since 2002, survey expectations have been consistently below inflation compensation, suggesting that the inflation risk premium (which pushes inflation compensation up) now outweighs the TIPS liquidity premium (which pushes inflation compensation down)."*

Campbell, Shiller and Viceira (2009)

68. The authors are primarily concerned with the utility of issuing/holding indexed bonds from the perspective of the government/investors. The key findings of interest in the current context are where the authors state (at page 79) that:

> *"Governments should expect inflation-indexed bonds to be a relatively cheap form of debt financing in the future, even though they have offered high returns over the past decade."*

69. Similarly, on page 115, the authors state:

> *"…our analysis implies that the cost of TIPS should be lower than that of Treasury bills ex ante, because TIPS offer investors desirable insurance against future variation in real interest rates."*

70. TIPS are "Treasury inflation-protected securities." These statements that the costs of issuing TIPS are lower than nominal bonds can only be true if inflation compensation built into nominal bonds is higher than the expected level of inflation (i.e., nominal rates are elevated by an inflation risk premium).

71. The AER (Ausnet distribution Final Decision, page 3-157, in footnote 602) also refers to Campbell and Shiller to the effect that:

> *"Campbell and Shiller also found that with inflation positively correlated with stock prices during the US economic downturn (2009), the inflation risk premium in nominal Treasury bonds is likely negative."*

72. The AER's reference is to page 115 - the same page of Campbell, Shiller and Viceira (2009) where they state that TIPS are lower expected cost to Governments than nominal bonds. That finding, omitted from the AER's analysis, is the most relevant.

73. The AER (AusNet Distribution Final Decision, Attachment 3, page 3-157) argues that the inflation risk premium may be negative if there are fears of deflation.

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[25] The authors state on page 85: "Since 2002, survey expectations have been consistently below inflation compensation, suggesting that the inflation risk premium (which pushes inflation compensation up) now outweighs the TIPS liquidity premium (which pushes inflation compensation down)."

However, if there are concerns about deflation, the inflation risk premium may become negative and the breakeven inflation rate may underestimate expected inflation.

74. The only way that this can be true is if investors in nominal bonds view them as having negative risk (i.e., investors prefer to be exposed to inflation risk via holding a nominal bond than not to be exposed to inflation risk). If this is true then breakeven inflation will tend to underestimate 'pure' expected inflation. However, it also follows logically that the nominal bond rate will be depressed below the true risk free rate by the presence of such negative risk (and by exactly the same amount as breakeven inflation underestimates actual inflation).

75. It follows that, even if this speculative scenario were actually true, the AER must have made an equal and offsetting error in its estimation of the nominal risk free rate – such that using breakeven inflation will arrive at the correct real risk free rate (one that removes the impact of the negative risk premium the AER speculates could be embedded in nominal yields). That is, arguments that imply breakeven inflation is biased because the nominal bond rate has positive/negative risks are, in reality, arguments in favour of the use of breakeven inflation because any bias so created will offset the bias in the proxy for the risk free rate.

Shen and Corning (2001)

76. Shen and Corning (2001) concludes that breakeven inflation tended to underestimate expected inflation in the very early period of the indexed bond market. However, this paper had only had 4 years of data available from the first issuance of indexed bonds (see page 68) and sheds no light on the magnitude of any bias in a mature market for indexed bonds.

Appendix B: Potential sources of bias

77. The AER discusses four different potential sources of bias in breakeven inflation. The AER does not seek to put any value on these. Table 2 summarises what that literature said about those sources of bias.

Table 2: Literature relating to individual sources of bias

Convexity bias	Grishchenko and Huang (2012), at page 18, cite literature that puts this bias at less than -1bp.
Inflation risk premium	Grishchenko and Huang (2012), at page 30 state that their preferred estimate of inflation risk premium is +14bp to +19bp over the period 2004 to 2008 and also survey the literature which typically estimates a higher inflation risk premium.
Liquidity premium	Grishchenko and Huang (2012), at page 3, estimate the average liquidity premium at 6bp (less than the average inflation risk premium implying the net effect is that breakeven inflation overestimates inflation expectations). D'Amico, Kim, and Wei (2009), at page 64, similarly show a time series for the liquidity premium which has hovered around zero since 2004. Devlin and Patwardhan (2012), at page 8, note that the Australian "relative liquidity difference appears to have narrowed over recent years". Campbell, Shiller and Viceira (2009), at page 115, state that indexed bonds are "extremely cheap to trade".
Impact of indexation lag	The literature notes that the impact of indexation lag is predominantly an issue for short term measures of breakeven inflation: D'Amico, Kim, and Wei (2009), at page 36; Shen and Corning (2001), at page 86, in footnote 29; Scholtes (2002), at page 70. In any event, the sign of any bias is indeterminate.

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The Term Structure of Real Rates and Expected Inflation

ANDREW ANG, GEERT BEKAERT, and MIN WEI*

ABSTRACT

Changes in nominal interest rates must be due to either movements in real interest rates, expected inflation, or the inflation risk premium. We develop a term structure model with regime switches, time-varying prices of risk, and inflation to identify these components of the nominal yield curve. We find that the unconditional real rate curve in the United States is fairly flat around 1.3%. In one real rate regime, the real term structure is steeply downward sloping. An inflation risk premium that increases with maturity fully accounts for the generally upward sloping nominal term structure.

THE REAL INTEREST RATE AND EXPECTED INFLATION are two key economic variables; yet, their dynamic behavior is essentially unobserved. A large empirical literature has yielded surprisingly few generally accepted stylized facts. For example, while theoretical research often assumes that the real interest rate is constant, empirical estimates for the real interest rate process vary between constancy as in Fama (1975), mean-reverting behavior (Hamilton (1985)), or a unit root process (Rose (1988)). There seems to be more consensus on the fact that real rate variation, if it exists at all, should only affect the short end of the term structure whereas the variation in long-term interest rates is primarily affected by shocks to expected inflation (see, among others, Fama (1990) and Mishkin

*Ang is with Columbia University and NBER. Bekaert is with Columbia University, CEPR and NBER. Wei is with the Federal Reserve Board of Governors. We thank Kobi Boudoukh, Qiang Dai, Rob Engle, Martin Evans, Rene Garcia, Bob Hodrick, Refet Gürkaynak, Monika Piazzesi, Bill Schwert, Ken Singleton, Peter Vlaar, Ken West, and Mungo Wilson for helpful discussions, and seminar participants at the American Finance Association, Asian Finance Association, Barclays Capital Annual Global Inflation-Linked Conference, CIREQ and CIRANO-MITACS conference on Macroeconomics and Finance, Empirical Finance Conference at the LSE, European Finance Association, FRBSF-Stanford University conference on Interest Rates and Monetary Policy, HKUST Finance Symposium, Washington University-St. Louis Federal Reserve conference on State-Space Models, Regime-Switching and Identification, Bank of England, Bank of Norway, Campbell and Company, University of Amsterdam, Columbia University, Cornell University, Erasmus University, European Central Bank, Federal Reserve Bank of Kansas, Federal Reserve Board of Governors, Financial Engines, HEC Lausanne, Indiana University, IMF, London Business School, National University of Singapore, NYU, Oakhill Platinum Partners, PIMCO, Singapore Management University, Tilburg University, UCL-CORE at Louvain-la-Neuve, University of Gent, University of Illinois, University of Michigan, University of Rochester, University of Washington, UCLA, UC Riverside, UC San Diego, USC, and the World Bank. Andrew Ang and Geert Bekaert both acknowledge funding from the National Science Foundation. Additional results and further technical details are available in the NBER working paper version of this article.

(1990)), although this is disputed by Pennacchi (1991). Another phenomenon that has received wide attention is the Mundell (1963) and Tobin (1965) effect: The correlation between real rates and (expected) inflation appears to be negative.

In this article, we seek to establish a comprehensive set of stylized facts regarding real rates, expected inflation, and inflation risk premiums, and to determine their relative importance for determining the U.S. nominal term structure. To infer the behavior of these variables, we use a model with three distinguishing features. First, we specify a no-arbitrage term structure model with both nominal bond yields and inflation data to efficiently identify the term structure of real rates and inflation risk premia. Second, our model accommodates regime-switching (RS) behavior, but still produces closed-form solutions for bond prices. We go beyond the extant RS literature by attempting to identify the real and nominal sources of the regime switches. Third, the model accommodates flexible time-varying risk premiums crucial for matching time-varying bond premia (see, for example, Dai and Singleton (2002)). These features allow our model to fit the dynamics of inflation and nominal interest rates.

This paper is organized as follows. Section I develops the model and discusses the effect of regime switches on real yields and inflation risk premia. In Section II, we detail the specification tests used to select the best model, analyze factor dynamics, and report parameter estimates. Section III contains the main economic results, which can be summarized as follows:

1. Unconditionally, the term structure of real rates assumes a fairly flat shape around 1.3%, with a slight hump, peaking at a 1-year maturity. However, there are some regimes in which the real rate curve is downward sloping.
2. Real rates are quite variable at short maturities but smooth and persistent at long maturities. There is no significant real term spread.
3. The real short rate is negatively correlated with both expected and unexpected inflation, but the statistical evidence for a Mundell–Tobin effect is weak.
4. The model matches an unconditional upward-sloping nominal yield curve by generating an inflation risk premium that is increasing in maturity.
5. Nominal interest rates do not behave procyclically across NBER business cycles but our model-implied real rates do.
6. The decompositions of nominal yields into real yields and inflation components at various horizons indicate that variation in inflation compensation (expected inflation and inflation risk premia) explains about 80% of the variation in nominal rates at both short and long maturities.
7. Inflation compensation is the main determinant of nominal interest rate spreads at long horizons.

Finally, Section IV concludes.

I. A Real and Nominal Term Structure Model with Regime Switches

A. Decomposing Nominal Yields

The nominal yield on a zero-coupon bond of maturity n, y_t^n, can be decomposed into a real yield, $\hat{y}_t^n$, and inflation compensation, $\pi_{t,n}^e$. The real yield represents the yield on a zero-coupon bond perfectly indexed against inflation. Inflation compensation reflects expected inflation, $\mathrm{E}_t(\pi_{t+n,n})$, and an inflation risk premium, $\varphi_{t,n}$ (ignoring Jensen's inequality terms):

$$\begin{aligned} y_t^n &= \hat{y}_t^n + \pi_{t,n}^e \\ &= \hat{y}_t^n + \mathrm{E}_t(\pi_{t+n,n}) + \varphi_{t,n}, \end{aligned} \tag{1}$$

where $\mathrm{E}_t(\pi_{t+n,n})$ is expected inflation from t to $t+n$, that is,

$$\mathrm{E}_t(\pi_{t+n,n}) = \frac{1}{n}\mathrm{E}_t(\pi_{t+1} + \cdots + \pi_{t+n}),$$

and π_{t+1} is one-period inflation from t to $t+1$.

The goal of this article is to achieve this decomposition of nominal yields, y_t^n, into real and inflation components ($\hat{y}_t^n$, $\mathrm{E}_t(\pi_{t+n,n})$, and $\varphi_{t,n}$) for U.S. data. Unfortunately, we do not observe real rates for most of the U.S. sample. Inflation-indexed bonds (the Treasury Income Protection Securities or TIPS) have traded only since 1997 and the market faced considerable liquidity problems in its early days (see Roll (2004)). Consequently, our endeavor faces an identification problem as we must estimate two unknown quantities—real rates and inflation risk premia—from only nominal yields. We obtain identification by using a no-arbitrage term structure model that imposes restrictions on the nominal yields. That is, the movements of long-term yields are linked to the dynamics of both short-term yields and inflation. These pricing restrictions uniquely identify the dynamics of real rates and inflation risk premiums using data on inflation and nominal yields. To pin down the average level of real rates, we further restrict the one-period inflation risk premium to be zero.

The remainder of this section sets up the model to identify the various components of nominal yields. Section I.B presents the term structure model and discusses the economic background of our factors and parametric assumptions. Importantly, both the empirical literature and economic logic suggest that the process generating inflation and real rates may undergo discrete shifts over time, which we model using an RS model following Hamilton (1989). We present solutions to bond prices in Section I.C and discuss how regime switches affect our decomposition in Section I.D. Section I.E briefly covers econometric and identification issues. Finally, Section I.F discusses how our work relates to the literature.

B. The Model

B.1. State Variable Dynamics

We employ a three-factor representation of yields, which is the number of factors often used to match term structure dynamics in the finance literature (see, for example, Dai and Singleton (2000)). We incorporate an observed inflation factor, denoted by π_t, which switches regimes. The other two factors are unobservable term structure factors. One factor, f_t, represents a latent RS term structure factor. The other latent factor is denoted by q_t and represents a time-varying but regime-invariant price of risk factor, which directly enters into the risk prices (see below). The factor q_t plays two roles. First, it helps time-varying expected excess returns on long-term bonds, as demonstrated by Dai and Singleton (2002).[1] Second, q_t also accounts for part of the time variation of inflation risk premia, as we show below.

We stack the state variables in the 3×1 vector $X_t = (q_t\ f_t\ \pi_t)'$, which follows

$$X_{t+1} = \mu(s_{t+1}) + \Phi X_t + \Sigma(s_{t+1})\varepsilon_{t+1}, \tag{2}$$

where s_{t+1} indicates the regime prevailing at time $t+1$ and

$$\mu(s_t) = \begin{bmatrix} \mu_q \\ \mu_f(s_t) \\ \mu_\pi(s_t) \end{bmatrix}, \quad \Phi = \begin{bmatrix} \Phi_{qq} & 0 & 0 \\ \Phi_{fq} & \Phi_{ff} & 0 \\ \Phi_{\pi q} & \Phi_{\pi f} & \Phi_{\pi\pi} \end{bmatrix}, \quad \Sigma(s_t) = \begin{bmatrix} \sigma_q & 0 & 0 \\ 0 & \sigma_f(s_t) & 0 \\ 0 & 0 & \sigma_\pi(s_t) \end{bmatrix}. \tag{3}$$

The regime variable represents K different regimes, $s_t = 1, \ldots, K$, and follows a Markov chain with a constant transition probability matrix $\Pi = \{p_{ij} = Pr(s_{t+1} = j \mid s_t = i)\}$. These regimes are independent of the shocks ε_{t+1} in equation (2).

In equation (3), the conditional mean and volatility of f_t and π_t switch regimes, but the conditional mean and volatility of q_t do not. The feedback parameters for all variables in the companion form Φ also do not switch across regimes. These restrictions are necessary to permit closed-form solutions for bond prices.

We order the factors so that the latent factors appear first. As a consequence, expected inflation depends on lagged inflation, other information captured by the latent variables, as well as a nonlinear drift term. The inflation forecasting literature strongly suggests that expected inflation depends on more than just lagged inflation (see, for example, Stockton and Glassman (1987)). In addition, by placing inflation last in the system, the reduced-form process for inflation involves moving average terms. The autocorrelogram of inflation in data is well approximated by a low order ARMA process.

B.2. Real Short Rate Dynamics

We specify the real short rate, $\hat{r}_t$, to be affine in the state variables:

$$\hat{r}_t = \delta_0 + \delta_1' X_t. \tag{4}$$

[1] Fama and Bliss (1987), Campbell and Shiller (1991), Bekaert, Hodrick, and Marshall (1997), and Cochrane and Piazzesi (2005), among many others, document time variation in expected excess holding period returns of long-term bonds.

For reference, we let $\delta_1 = (\delta_q\, \delta_f\, \delta_\pi)'$. The real rate process nests the special cases of a constant real rate ($\delta_1 = 0_{3\times1}$), advocated by Fama (1975), and mean-reverting real rates within a single regime ($\delta_f = \delta_\pi = 0$), following Hamilton (1985). Allowing nonzero δ_f or δ_π causes the real rate to switch regimes. If $\delta_q \neq 0$, then the time-varying price of risk can directly influence the real rate, as it would in any equilibrium model with growth. In general, if $\delta_\pi \neq 0$, then money neutrality is rejected and real interest rates are functions of inflation.

The model allows for arbitrary correlation between the real rate and inflation. To gain some intuition, we compute the conditional covariance between real rates and actual or expected inflation for an affine model without regime switches. First, δ_π primarily drives the covariance between real rates and unexpected inflation. That is, $\text{cov}_t(\hat{r}_{t+1}, \pi_{t+1}) = \delta_\pi \sigma_\pi^2$. Second, without regimes, the covariance between expected inflation and real rates is given by

$$\text{cov}_t(\hat{r}_{t+1}, \text{E}_{t+1}(\pi_{t+2})) = \delta_q \Phi_{\pi q} \sigma_q^2 + \delta_f \Phi_{\pi f} \sigma_f^2 + \delta_\pi \Phi_{\pi\pi} \sigma_\pi^2.$$

The Mundell–Tobin effect predicts this covariance to be negative, whereas an activist Taylor (1993) rule would predict it to be positive, as the monetary authority raises real rates in response to high expected inflation (see, for example, Clarida, Galí, and Gertler (2000)). Clearly, the sign of the covariance is parameter dependent, and a negative δ_π does not suffice to obtain a Mundell–Tobin effect.

To compare the conditional covariance between real rates and expected inflation in our model with regimes, we derive $\text{cov}_t(\hat{r}_{t+1}, \text{E}_{t+1}(\pi_{t+2}) | s_t = i)$ for $K = 2$ regimes to be

$$\begin{aligned}\text{cov}_t(\hat{r}_{t+1}, \text{E}_{t+1}(\pi_{t+2}) | s_t = i) = {} & \delta_q \Phi_{\pi q} \sigma_q^2 \\ & + \delta_f \Phi_{\pi f} \left[\textstyle\sum_{j=1}^{2} p_{ij} \sigma_f^2(j) + p_{i1} p_{i2} (\mu_f(1) - \mu_f(2))^2 \right] \\ & + \delta_\pi \Phi_{\pi\pi} \left[\textstyle\sum_{j=1}^{2} p_{ij} \sigma_\pi^2(j) + p_{i1} p_{i2} (\mu_\pi(1) - \mu_\pi(2))^2 \right] \\ & + \delta_f \delta_\pi \Phi_{\pi f} \Phi_{\pi\pi} p_{i1} p_{i2} [(\mu_\pi(1) - \mu_\pi(2))(\mu_f(1) - \mu_f(2))].\end{aligned}$$

Relative to the one-regime model, the contribution of the factor variances for the RS factors now depends on the regime prevailing at time t and has two components namely, an average of the two regime-dependent factor variances and a term measuring the volatility impact of a change in the regime-dependent drifts. In addition, there is a new factor contributing to the covariance that comes from the covariance between these regime-dependent drifts for f_t and π_t.

B.3. Pricing Kernel and Prices of Risk

We specify the real pricing kernel to take the form

$$\widehat{m}_{t+1} = \log \widehat{M}_{t+1} = -\hat{r}_t - \frac{1}{2} \lambda_t(s_{t+1})' \lambda_t(s_{t+1}) - \lambda_t(s_{t+1})' \varepsilon_{t+1}, \tag{5}$$

where the vector of time-varying and RS prices of risk $\lambda_t(s_{t+1})$ is given by

$$\lambda_t(s_{t+1}) = (\gamma_t \;\; \lambda(s_{t+1})')',$$

where $\lambda(s_{t+1})$ is a 2×1 vector of RS prices of risk $\lambda(s_{t+1}) = (\lambda_f(s_{t+1})\, \lambda_\pi(s_{t+1}))'$ and the scalar γ_t takes the form

$$\gamma_t = \gamma_0 + \gamma_1 q_t = \gamma_0 + \gamma_1 e_1' X_t, \tag{6}$$

where e_i represents a vector of zeros with a "1" in the ith position. In this formulation, the prices of risk of f_t and π_t change across regimes. The variable q_t controls the time variation of the price of risk associated with γ_t in equation (6) but does not switch regimes. Allowing γ_t to switch across regimes results in the loss of closed-form solutions for bond prices.

We formulate the nominal pricing kernel in the standard way as $M_{t+1} = \widehat{M}_{t+1} P_t / P_{t+1}$:

$$m_{t+1} = \log M_{t+1} = -\hat{r}_t - \frac{1}{2}\lambda_t(s_{t+1})'\lambda_t(s_{t+1}) - \lambda_t(s_{t+1})'\varepsilon_{t+1} - e_3' X_{t+1}. \tag{7}$$

B.4. Real Factor and Inflation Regimes

We introduce two different regime variables, $s_t^f \in \{1, 2\}$, affecting the drift and variance of the f_t process, and $s_t^\pi \in \{1, 2\}$, affecting the drift and variance of the inflation process. Since both the f_t and π_t factors enter the real short rate in equation (4), the real short rate contains both f_t and π_t regime components. This modeling choice accommodates the possibility that s_t^f captures changes of regimes in real factors. Since f_t enters the conditional mean of inflation in equation (2), the f_t regime also potentially affects expected inflation and can capture nonlinear expected inflation components not directly related to past inflation realizations.

The model with s_t^f and s_t^π can be rewritten using an aggregate regime variable $s_t \in \{1, 2, 3, 4\}$ to account for all possible combinations of $\{s_t^f, s_t^\pi\} = \{(1, 1), (1, 2), (2, 1), (2, 2)\}$. Hence, our model has $K = 4$ regimes. To reduce the number of parameters in the 4×4 transition probability matrix, we consider two restricted models of the correlation between s_t^f and s_t^π. Case A represents the simplest case of independent regimes.[2]

In an alternative case C, we specify a restricted form of the transition probability matrix so that the inflation regime at $t + 1$ depends on the stance of the f_{t+1} regime as well as the previous inflation environment, but we restrict future f_{t+1} regimes to depend only on current f_t regimes. Intuitively, this specification can capture periods in which aggressive real rates, for example, captured by a regime with high f_t, could successfully stave off a regime of high

[2] Ang, Bekaert, and Wei (2007) consider another restricted case of correlated s_t^f and s_t^π regimes. This fits the data less well than Case C presented here.

inflation. This leads to the following conditional transition probability:

$$
\begin{aligned}
&Pr\left(s^f_{t+1} = j, s^\pi_{t+1} = k | s^f_t = m, s^\pi_t = n\right) \\
&= Pr\left(s^\pi_{t+1} = k | s^f_{t+1} = j, s^f_t = m, s^\pi_t = n\right) \times Pr\left(s^f_{t+1} = j | s^f_t = m, s^\pi_t = n\right) \\
&= Pr\left(s^\pi_{t+1} = k | s^f_{t+1} = j, s^\pi_t = n\right) \times Pr\left(s^f_{t+1} = j | s^f_t = m\right),
\end{aligned} \tag{8}
$$

where we assume that $Pr(s^\pi_{t+1} | s^f{}_{t+1}, s^f_t, s^\pi_t) = Pr(s^\pi_{t+1} | s^f{}_{t+1}, s^\pi_t)$ and $Pr(s^f{}_{t+1} | s^f_t, s^\pi_t) = Pr(s^f{}_{t+1} | s^f_t)$. We denote $Pr(s^f{}_{t+1} = 1 | s^f_t = 1) = p^f$ and $Pr(s^f{}_{t+1} = 2 | s^f_t = 2) = q^f$ and parameterize $Pr(s^\pi_{t+1} = k | s^f_t = m, s^\pi_t = n)$ as $p^{\text{“}j\text{”},\text{“}m\text{”}}$, where

$$
j = \begin{cases} A & \text{if } s^\pi_{t+1} = s^f_{t+1} = 1 \\ B & \text{if } s^\pi_{t+1} = s^f_{t+1} = 2. \end{cases}
$$

The “j”-component captures (potentially positive) correlation between the f_t and π_t regimes. The “m”-component captures persistence in π_t regimes:

$$
m = \begin{cases} A & \text{if } s^\pi_t = 1 \\ B & \text{if } s^\pi_t = 2. \end{cases}
$$

This formulation can capture instances in which a high real rate regime, as captured by the high f_t regime, contemporaneously influences the inflation regime. Using the notation introduced above, the transition probability matrix Π for Case C takes the form:

$$
\begin{array}{c}
[s_t = 1] \\ [s_t = 2] \\ [s_t = 3] \\ [s_t = 4]
\end{array}
\overset{\begin{array}{cccc} [s_{t+1} = 1] & [s_{t+1} = 2] & [s_{t+1} = 3] & [s_{t+1} = 4] \end{array}}{
\begin{bmatrix}
p^f p^{AA} & p^f(1 - p^{AA}) & (1 - p^f)(1 - p^{BA}) & (1 - p^f)p^{BA} \\
p^f p^{AB} & p^f(1 - p^{AB}) & (1 - p^f)(1 - p^{BB}) & (1 - p^f)p^{BB} \\
(1 - q^f)p^{AA} & (1 - q^f)(1 - p^{AA}) & q^f(1 - p^{BA}) & q^f p^{BA} \\
(1 - q^f)p^{AB} & (1 - q^f)(1 - p^{AB}) & q^f(1 - p^{BB}) & q^f p^{BB}
\end{bmatrix}}
$$

This model has four additional parameters relative to the model with independent real and inflation regimes. We can test Case C against the null of the independent regime Case A by testing the restrictions

$$
H_0 : p^{BA} = 1 - p^{AA} \text{ and } p^{BB} = 1 - p^{AB}.
$$

We find evidence to reject the case of independent regimes in favor of this case with a p-value of 0.033. Thus, our benchmark specification uses the probability transition matrix of Case C.

C. Bond Prices

Our model produces closed-form solutions for bond prices, enabling both efficient estimation and the ability to fully characterize real and nominal yields at all maturities without discretization error.

C.1. Real Bond Prices

In our model, the real zero-coupon bond price of maturity n conditional on regime $s_t = i$, $\widehat{P}_t^n(s_t = i)$, is given by

$$\widehat{P}_t^n(i) = \exp(\widehat{A}_n(i) + \widehat{B}_n X_t), \tag{9}$$

where $\widehat{A}_n(i)$ is dependent on regime $s_t = i$, $\widehat{B}_n$ is a $1 \times N$ vector, and N is the total number of factors in the model, including inflation. The expressions for $\widehat{A}_n(i)$ and $\widehat{B}_n$ are given in Appendix A. Since the real bond prices are given by (9), it follows that the real yields $\hat{y}_t^n(i)$ conditional on regime i are affine functions of X_t:

$$\hat{y}_t^n(i) = -\frac{\log(\widehat{P}_t^n)}{n} = -\frac{1}{n}(\widehat{A}_n(i) + \widehat{B}_n X_t). \tag{10}$$

While the expressions for $\widehat{A}_n(i)$ and $\widehat{B}_n$ are complex, some intuition can be gained on how the prices of risk affect each term. The prices of risk γ_0 and $\lambda(s_t)$ enter only the constant term in the yields $\widehat{A}_n(s_t)$, but affect this term in all regimes. More negative values of γ_0 or $\lambda(s_t)$ cause long maturity yields to be, on average, higher than short maturity yields. In addition, since the $\lambda(s_t)$ terms differ across regimes, $\lambda(s_t)$ also controls the regime-dependent level of the yield curve away from the unconditional shape of the yield curve. Thus, the model can accommodate the switching signs of term premiums documented by Boudoukh et al. (1999). The prices of risk affect the time variation in the yields through the parameter γ_1. This term only enters the $\widehat{B}_n$ terms. A more negative γ_1 means that long-term yields respond more to shocks in the price of risk factor q_t.

The pricing implications of (10), together with the assumed dynamics of X_t in (2), imply that the autoregressive dynamics of inflation and bond yields are constant over time, but the drifts vary through time, and shocks to inflation and real yields are heteroskedastic. Hence, our model is consistent with the macro models of Sims (1999, 2001) and Bernanke and Mihov (1998), who stress changing drifts, induced for example by changes in monetary policy, and heteroskedastic shocks. On the other hand, Cogley and Sargent (2001, 2005) advocate models with changes in the feedback parameters, induced for example by changes in systematic monetary policy, which we do not accommodate.

C.2. Nominal Bond Prices

Nominal bond prices take the form

$$P_t^n(i) = \exp(A_n(i) + B_n X_t) \tag{11}$$

for $P_t^n(i)$, the zero-coupon bond price of a nominal n-period bond conditional on regime i. The scalar $A_n(i)$ is dependent on regime $s_t = i$ and B_n is a $1 \times N$ vector. It follows that the nominal n-period yield conditional on regime i, $y_t^n(i)$, is an affine function of X_t:

$$y_t^n(i) = -\frac{\log(P_t^n)}{n} = -\frac{1}{n}(A_n(i) + B_n X_t). \tag{12}$$

Appendix B shows that the only difference between the $\widehat{A}_n(i)$ and $\widehat{B}_n$ terms for real bond prices and the $A_n(i)$ and B_n terms for nominal bond prices are due to terms that select inflation from X_t. Positive inflation shocks decrease nominal bond prices.

D. The Effect of Regime Switches

The key ingredient differentiating our model from the standard affine term structure paradigm is the presence of regimes. In this section, we develop intuition on how regimes affect the decomposition of nominal rates into real rate and inflation components.

D.1. Expected Inflation

In our model, one-period expected inflation, $\mathrm{E}_t(\pi_{t+1})$, takes the form

$$\begin{aligned} \mathrm{E}_t(\pi_{t+1}|s_t = i) &= e_3' \mathrm{E}[\mu(s_{t+1})|s_t = i] + e_3' \Phi X_t \\ &= \left(\sum_{j=1}^{K} p_{ij}\ \mu_\pi(j) \right) + e_3' \Phi X_t. \end{aligned} \tag{13}$$

This process is only different from a simple linear process because of the nonlinear drift, which can accommodate sudden discrete changes in expected inflation. Because expected inflation depends on f_t and π_t, the contemporaneous s_t^f and s_t^π regimes also both affect expected inflation.

D.2. Inflation Compensation

With only one regime, one-period inflation compensation, $\pi_{t,1}^e = y_t^1 - \hat{r}_t$, is given by

$$\pi_{t,1}^e = \left(\mu_\pi - \frac{1}{2}\sigma_\pi^2 - \sigma_\pi \lambda_\pi \right) + e_3' \Phi X_t.$$

With multiple regimes, inflation compensation is more complex:

$$\pi_{t,1}^e(i) = -\log\left[\sum_{j=1}^{K} p_{ij} \exp\left(-\mu_\pi(j) + \frac{1}{2}\sigma_\pi^2(j) + \sigma_\pi(j)\lambda_\pi(j) \right) \right] + e_3' \Phi X_t. \tag{14}$$

The last term in the exponential represents the one-period inflation risk premium, which is zero by assumption in our model. The $\frac{1}{2}\sigma_\pi^2(j)$ term is the standard Jensen's inequality term, which now becomes regime dependent. The

$-\mu_\pi(s_t)$ term represents the nonlinear, regime-dependent part of expected inflation. The last term, $e_3{}'\Phi\ X_t$, represents the time-varying part of expected inflation, which does not switch across regimes, and is the only term that is the same as in the affine model.

In comparing expected inflation in equation (13) with inflation compensation in equation (14), we see that the constant terms for $\pi^e_{t,1}$ and $E_t(\pi_{t+1}\,|s_t)$ are different. The constants in the inflation compensation expression (14) reflect both a Jensen's inequality term $\frac{1}{2}\sigma^2_\pi(s_t)$ and a nonlinear term, driven by taking the log of a sum that is weighted by transition probabilities. Because exp (.) is a convex function, Veronesi and Yared (1999) call this effect a "convexity bias." Like the Jensen's term, this also makes $\pi^e_{t,1} < E_t(\pi_{t+1})$. In our estimations, both the Jensen's term and the convexity bias amount to less than one basis point, even for longer maturities.

D.3. Real Term Spreads

The intuition for how regimes affect real term spreads can be readily gleaned from considering a two-period real bond. We first analyze the case of the real term spread, $\hat{y}^2_t - \hat{r}_t$, in an affine model without regime switches:

$$\hat{y}^2_t - \hat{r}_t = \frac{1}{2}\left(\mathrm{E}_t(\hat{r}_{t+1}) - \hat{r}_t\right) - \frac{1}{4}\mathrm{var}_t\left(\hat{r}_{t+1}\right) + \frac{1}{2}\mathrm{cov}_t\left(\widehat{m}_{t+1}, \hat{r}_{t+1}\right). \tag{15}$$

The first term, $(\mathrm{E}_t(\hat{r}_{t+1}) - \hat{r}_t)$, is an Expectations Hypothesis (EH) term, the second term, $\mathrm{var}_t(\hat{r}_{t+1})$, is a Jensen's inequality term, and the last term, $\mathrm{cov}_t(\widehat{m}_{t+1}, \hat{r}_{t+1})$, is the risk premium. In the single-regime affine setting, the last term is given by

$$\mathrm{cov}_t(\widehat{m}_{t+1}, \hat{r}_{t+1}) = -\gamma_0\sigma_q - \lambda_f\sigma_f - \gamma_1\sigma_q q_t. \tag{16}$$

Hence, the price of risk factor q_t determines the time variation in the term premium.

The RS model has a more complex expression for the two-period real term spread:

$$\begin{aligned}\hat{y}^2_t(i) - \hat{r}_t = {} & \frac{1}{2}(\mathrm{E}_t(\hat{r}_{t+1}|s_t = i) - \hat{r}_t) - \frac{1}{2}\left(\gamma_0\sigma_q + \gamma_1\sigma_q q_t\right) \\ & -\frac{1}{2}\log\left(\sum_{j=1}^{K} p_{ij}\exp\Big[-\delta_1'\Big(\mu(j) - \mathrm{E}\left[\mu(s_{t+1})|s_t = i\right]\Big)\right. \\ & \left. + \frac{1}{2}\delta_1'\Sigma(j)\Sigma(j)'\delta_1 + \lambda_f(j)\sigma_f(j)\Big]\right),\end{aligned} \tag{17}$$

for K regimes. First, the term spread now switches across regimes, explicitly shown by the dependence of $\hat{y}^2_t(i)$ on regime $s_t = i$. Not surprisingly, the EH term $(\mathrm{E}_t(\hat{r}_{t+1}|s_t = i) - \hat{r}_t)$ now switches across regimes. The time-varying price of risk term, $-\frac{1}{2}(\gamma_0\sigma_q + \gamma_1\sigma_q q_t)$, is the same as in (16) because the process for q_t does not switch regimes. The remaining terms in (17) are nonlinear, as they involve the log of the sum of an exponential function of regime-dependent terms that are weighted by transition probabilities. Within the nonlinear expression, the term $\frac{1}{2}\delta_1'\Sigma(j)\Sigma(j)'\delta_1$ represents a Jensen's inequality term, which is regime-dependent, and $\lambda_f(j)\sigma_f(j)$ represents a RS price of risk term. Thus, the average slope of the real yield curve can potentially change across regimes and produce a variety of regime-dependent shapes of the real yield curve, including flat, inverse-humped, upward-sloping, or downward-sloping yield curves. A new term in (17) that does not have a counterpart in (16) is $-\delta'_1(\mu(j) - \mathrm{E}\,[\mu\,(s_{t+1})\,|s_t = i])$, reflecting the "jump risk" of a change in the regime-dependent drift.

D.4. Inflation Risk Premia

The riskiness of nominal bonds is driven by the covariance between the real kernel and inflation: If inflation is high (purchasing power is low) when the pricing kernel realization (marginal utility in an equilibrium model) is high, nominal bonds are risky and the inflation risk premium is positive. It is tempting to conclude that the sign of the inflation risk premium determines the correlation between expected inflation and real rates. For example, a Mundell–Tobin effect implies that when a bad shock is experienced (an increase in real rates), the holders of nominal bonds experience a countervailing effect, namely, a decrease in expected inflation, which increases nominal bond prices. This intuition is not completely correct as we now discuss.

Consider the two-period pricing kernel, which depends on real rates both through its conditional mean and through real rate innovations. Interestingly, the effects of these two components are likely to act in opposite directions. High real rates decrease the conditional mean of the pricing kernel; but, if the price of risk is negative, positive shocks to the real rate should increase marginal utility. We first focus on the affine model. By splitting inflation into unexpected and expected inflation, we can decompose the two-period inflation risk premium, $\varphi_{t,2}$, into four components (ignoring the Jensen's inequality term):

$$\varphi_{t,2} = \frac{1}{2}\big[-\mathrm{cov}_t(\hat{r}_{t+1}, \mathrm{E}_{t+1}(\pi_{t+2})) - \mathrm{cov}_t(\hat{r}_{t+1}, \pi_{t+1}) \\ + \mathrm{cov}_t(\widehat{m}_{t+1}, \mathrm{E}_{t+1}(\pi_{t+2})) + \mathrm{cov}_t(\widehat{m}_{t+1}, \pi_{t+1})\big]. \tag{18}$$

The first two terms reveal that a negative correlation between real rates and both expected and unexpected inflation actually implies a positive risk premium. Nevertheless, a Mundell–Tobin effect does not necessarily imply a positive inflation risk premium because of the last two terms, which involve the innovations of the pricing kernel. In the affine model equivalent of our RS model, the last term is zero by assumption, but the third term is not and may swamp the others. In particular, for the affine specification:

$$\varphi_{t,2} = -\frac{1}{2}\left[\delta_\pi \sigma_\pi^2 (1 + \Phi_{\pi\pi}) + \Phi_{\pi q}(\sigma_q^2 + \gamma_1 \sigma_q q_t) + \Phi_{\pi f}(\sigma_f^2 + \lambda_f \sigma_f)\right]. \quad (19)$$

Hence, the time variation in the inflation risk premium depends on q_t, and the mean premium depends on parameters that also determine the correlation between real rates and inflation. In particular, if the correlation between real rates and inflation is zero (requiring $\delta_\pi = \Phi_{\pi,q} = \Phi_{\pi,f} = 0$), then the inflation risk premium is also zero. Note that the price of risk λ_f plays a role in determining the inflation risk premium whereas it does not play a role in determining the correlation between real rates and expected inflation.

Naturally, the RS model has a richer expression for the inflation risk premium than equation (19).[3] Regime switches affect the inflation risk premium in two ways, through the RS price of risk, $\lambda_f(s_{t+1})$ and also through the RS means. This gives the inflation risk premium the ability to capture sudden shifts due to changing inflation environments.

E. Econometrics and Identification

We derive the likelihood function of the model in Appendix C. Our model implies a RS-VAR for inflation and yields with complex cross-equation restrictions imposed by the term structure model. Since the model has latent factors, identification restrictions must be imposed to estimate the model. We also discuss these issues in Appendix C. An important identification assumption is that we set the one-period inflation risk premium equal to zero, $\lambda_\pi(s_{t+1}) = 0$. This parameter identifies the average level of real rates and the inflation risk premium, and is very hard to identify without using real yields in the estimation. This restriction does not undermine the ability of the model to fit the dynamics of nominal interest rates and inflation well, as we show below. Models with nonzero λ_π give rise to lower and more implausible real rates than our estimates imply and have a poorer fit with the data.

Finally, we specify the dependence of the prices of risk for the f_t and π_t factors on s_t. Because we set $\lambda_\pi = 0$, we only need to model $\lambda_f(s_{t+1})$. In general, there are four possible λ_f parameters across the four s_{t+1} regimes. This potentially allows real and nominal yield curves to take on different unconditional shapes in different inflationary environments. When estimating a model where $\lambda(s_{t+1})$ varies over all regimes, a Wald test on the equality of $\lambda(s_{t+1})$ across s^π_{t+1} regimes is strongly rejected with a p-value less than 0.001, while a Wald test on the equality of $\lambda(s_{t+1})$ across $s^f{}_{t+1}$ regimes is not rejected at the 5% level. Hence, in our benchmark model, we consider prices of f risk to vary only across inflation regimes, s^π_{t+1}.

[3] The RS inflation risk premium is reported in Ang, Bekaert, and Wei (2007).

F. Related Models

To better appreciate the relative contribution of the model, we link it to three distinct literatures: (i) the extraction of real rates and expected inflation from nominal yields and realized inflation or inflation forecasts, (ii) the empirical RS literature on interest rates and inflation, and (iii) the theoretical term structure literature and equilibrium affine models in finance.

F.1. Time-Series Models

An earlier literature uses neither term structure data, nor a pricing kernel to obtain estimates of real rates and expected inflation. Mishkin (1981) and Huizinga and Mishkin (1986) simply project ex post real rates on instrumental variables. This approach is sensitive to measurement error and omitted variable bias. Other authors, such as Hamilton (1985), Fama and Gibbons (1982), and Burmeister, Wall and Hamilton (1986), use low-order ARIMA models and identify expected inflation and real rates using a Kalman filter under the assumption of rational expectations. The time-series processes driving real rates and expected inflation, with rational expectations, remain critical ingredients in our approach, but we use inflation data and the entire term structure to obtain more efficient identification. In addition, our approach identifies the inflation risk premium, which this literature cannot do.

F.2. Empirical Regime-Switching Models

Many articles document RS behavior in interest rates (see, among many others, Hamilton (1988), Gray (1996), Sola and Driffill (1994), Bekaert, Hodrick and Marshall (2001), and Ang and Bekaert (2002)) without analyzing the real and nominal sources of the regimes. Evans and Wachtel (1993) and Evans and Lewis (1995) document the existence of inflation regimes, whereas Garcia and Perron (1996) focus on real interest rate regimes. Our model simultaneously identifies inflation and real factor sources behind the regime switches and analyzes how they contribute to nominal interest rate variation.

F.3. Term Structure Models

Relative to the extensive term structure literature, our model appears to be the first to identify real interest rates and the components of inflation compensation in a model accommodating regime switches, while still admitting closed-form solutions. Most of the articles using a pricing model to obtain estimates of real rates and expected inflation have so far ignored RS behavior. This includes papers by Pennacchi (1991), Boudoukh (1993), and Buraschi and Jiltsov (2005) for U.S. data and Barr and Campbell (1997) and Evans (1998) for U.K. data. This is curious, because the early literature implicitly demonstrated the importance of accounting for potential structural or regime changes. For example, the Huizinga and Mishkin (1986) projections are unstable over the

1979–1982 period, and the slope coefficients of regressions of future inflation onto term spreads in Mishkin (1990) are substantially different pre- and post-1979, which is also recently confirmed by Goto and Torous (2003).

The articles that have formulated term structure models accommodating regime switches mostly focus only on the nominal term structure. Articles by Hamilton (1988), Bekaert, Hodrick, and Marshall (2001), Bansal and Zhou (2002), and Bansal, Tauchen, and Zhou (2004) allow for RS in mean reversion parameters that we do not, but their derived bond pricing solutions, using discretization or linearization, are only approximate. None of these models features a time-varying price of risk factor like q_t in our model. Naik and Lee (1994) and Landén (2000) present models with closed-form bond prices, but these models feature constant prices of risk and only shift the constant terms in the conditional mean.

The RS term structure model by Dai, Singleton, and Yang (2006) incorporates regime-dependent mean reversions and state-dependent probabilities under the real measure, while still admitting closed-form bond prices. However, under the risk-neutral measure, both the mean reversion and the transition probabilities must be constants, exactly as in our formulation. Dai et al. allow for only two regimes, while we have a much richer RS specification. Another point of departure is that in their model, the evolution of the factors and the prices of risk depend on s_t rather than s_{t+1}. In contrast, our model specifies regime dependence using s_{t+1} as in Hamilton (1989), implying that the conditional variances of our factors embed a jump term reflecting the difference in conditional means across regimes. This conditional heteroskedasticity is absent in the Dai–Singleton–Yang parameterization. Our results show that the conditional means of inflation significantly differ across regimes, while the conditional variances do not, making the regime-dependent means an important source of inflation heteroskedasticity.

There are two related articles that use a term structure model with regime switches to investigate real and nominal yields. The first specification by Veronesi and Yared (1999) is quite restrictive as it only accommodates switches in the drifts. The second paper by Evans (2003) is most closely related to our article. He formulates a model with regime switches for U.K. real and nominal yields and inflation, but he does not accommodate time-varying prices of risk. Evans incorporates switches in mean-reversion parameters, but does not separate the sources of the regime switches into real factors and inflation.

II. Model Estimates

A. Data

We use 4-, 12- and 20-quarter maturity zero-coupon yield data from CRSP and the 1-quarter rate from the CRSP Fama risk-free rate file as our yield data. We compute inflation from the Consumer Price Index—All Urban Consumers (CPI-U, seasonally adjusted, 1982:Q4 = 100) from the Bureau of Labor Statistics. Our data span the sample from 1952:Q2 to 2004:Q4. Using monthly CPI

Table I

Nomenclature of Models

This table summarizes the models estimated. The affine models are single-regime models. In the two- and three-regime models, the real rate factor and inflation share the same regimes, so $s_t = s_t^f = s_t^\pi$, which take values from {1, 2} or {1, 2, 3}, respectively. In the four- and six-regime models, the regimes s_t reflect switches in both s_t^f and s_t^π. In the four-regime model, $s_t^f \in \{1, 2\}$, $s_t^\pi \in \{1, 2\}$, and the probability transition matrix can be one of two cases, independent (Case A) and the correlated case (Case C) outlined in Section I.B.4. In the six-regime model, $s_t^f \in \{1, 2\}$, $s_t^\pi \in \{1, 2, 3\}$, and s_t^f and s_t^π are independent. The three-factor models contain the factors $X_t = (q_t\ f_t\ \pi_t)'$ with q_t a time-varying price of risk factor, f_t is a latent RS term structure factor, and π_t is inflation. The dynamics of X_t are outlined in Section B. The models denoted with w subscripts also contain an additional factor representing expected inflation. These models are described in Appendix D.

		Regime-Switching Models			
	Affine	Two Regimes	Three Regimes	Four Regimes	Six Regimes
3-Factor Models	I	II	III	IV^A, IV^C	VI
4-Factor Models	I_w	II_w	–	IV_w^A, IV_w^C	–

figures creates a timing problem because prices are collected over the course of the month and monthly inflation data are seasonal. Therefore, similar to Campbell and Viceira (2001), we sample all data at the quarterly frequency. For the benchmark model, we specify the 1-quarter and 20-quarter yields to be measured without error to extract the unobserved factors (see Chen and Scott (1993)). The other yields are specified to be measured with error and provide overidentifying restrictions for the term structure model.[4]

B. Model Nomenclature

In Table I, we describe the different term structure models we estimate. The top row represents models with the three factors $(q_t\ f_t\ \pi_t)'$. In the bottom row, we list alternative models that add an unobserved factor representing expected inflation, which we denote by w_t, that generalize classic ARMA models of expected inflation. We describe these models in Appendix D.

To gauge the contribution of regime switches, we estimate single-regime counterparts to the benchmark and unobserved expected inflation models. The single-regime models I and I_w are simply affine models. Model I is the single regime counterpart of the benchmark RS model IV, described in Section I. Model I_w is similar to the model estimated by Campbell and Viceira (2001), except that Campbell and Viceira assume that the inflation risk premium is constant, whereas in all our models the inflation risk premium is stochastic. We specifically contrast real rates and inflation risk premia from Model I_w with the real rates and inflation risk premia implied by our benchmark model below.

[4] We estimate several of our models using alternative schemes where other yields are assumed to be measured without error and find that the results are very similar.

The remaining models in Table I are RS models. Models *II* and II_w contain two regimes where $s_t^f = s_t^\pi$. Two regime models are the main specifications used in the empirical and term structure literature (see, for example, Bansal and Zhou (2002)). Model *III* considers a similar model but the regime variable can take on three values. Model *IV* represents the benchmark model, which has four regimes, with the different cases describing the correlation of the s_t^f and the s_t^π regimes (Cases A and C as described in Section II.B). Model *VI* contains two regimes for s_t^f that are independent of the three regimes for s_t^π.

C. Specification Tests

We report two specification tests of the models, an unconditional moment test and an in-sample serial correlation test for first and second moments in scaled residuals. The former is particularly important because we want to decompose the variation of nominal yields into real and expected inflation components. A well-specified model should imply unconditional means, variances, and autocorrelograms of inflation and yields close to the sample moments. We outline these tests in Appendix E.

Table II reports the results of these specification tests. Panel A focuses on matching inflation dynamics, while Panel B focuses on matching the dynamics of yields. Of all the models, only Model IV^C passes the inflation residual tests and fits the mean, variance, and autocorrelogram of inflation (using autocorrelations of lags 1, 5, and 10). About half of the models fail to match the autocorrelogram of inflation. Inflation features a relatively low first-order autocorrelation coefficient with very slowly decaying higher-order autocorrelations. Generally, the presence of regimes and the additional expected inflation factor help in matching this pattern. However, most of the models with the w-factor fail to match the mean and variance of inflation. While Model *VI* passes all moment tests, both residual tests reject strongly at the 1% level, eliminating this model. The match with inflation dynamics is extremely important as the estimated inflation process not only identifies expected inflation but also plays a critical role in identifying the inflation risk premium. This makes Model IV^C the prime candidate for the best model.

Panel B reports goodness-of-fit tests for two sets of yield moments, namely, the mean and variance of the spread and the long rate (all models fit the mean of the short rate by construction in the estimation procedure), and the autocorrelogram of the spread. Only four models fit the moments of yields and spreads: *I*, *III*, IV^A, and IV^C. Unfortunately, apart from model IV^C, these other models fail to match the inflation moments in Panel A.

We also report the residual test for the short rate and spread equations in Panel B. With the exception of model *VI*, most models produce reasonably well-behaved residuals. While model IV^C nails the dynamics of inflation in Panel A and closely matches term structure moments, the model's residual tests for short rates and spreads are significant at the 5% level, but not at the 1% level. Thus, there is some serial correlation and heteroskedasticity that

Table II

Specification Tests

This table reports moment and residual tests of inflation (Panel A) and of yields (Panel B), which are outlined in Appendix E. In the columns titled "Moment Tests," we report the p-values of goodness-of-fit χ^2 tests for various moments implied by the different models. In Panel A, the first moment test matches the mean and variance of inflation, whereas in Panel B, the first moment test matches the mean and variance of the long rate and the spread jointly. The long rate refers to the 20-quarter nominal rate y_t^{20} and the spread refers to $y_t^{20} - y_t^1$, for y_t^1 the 3-month short rate. The second autocorrelogram moment test matches autocorrelations at lags 1, 5, and 10. The columns titled "Residual Tests" report p-values of scaled residual tests for the different models. The first entry reports the p-value of a test of E $(\epsilon_t \; \epsilon_{t-1}) = 0$ and the second row reports the p-value of a GMM-based test of E $[(\epsilon_t^2 - 1)(\epsilon_{t-1}^2 - 1)] = 0$, where ϵ_t is a scaled residual. P-values less than 0.05 (0.01) are denoted by * (**). Table I contains the nomenclature of the various models.

Panel A: Matching Inflation Dynamics

	Moment Tests		
Model	Mean/Variance	Auto-correlogram	Residual Tests
I	0.00**	0.02*	0.00**
			0.08
I_w	0.08	0.00**	0.02*
			0.09
II	0.00**	0.01*	0.10
			0.17
II_w	0.00**	0.16	0.03*
			0.31
III	0.02*	0.02*	0.67
			0.22
IV^A	0.15	0.04*	0.16
			0.12
IV^C	0.60	0.08	0.21
			0.10
IV_w^A	0.00**	0.27	0.26
			0.26
IV_w^C	0.00**	0.18	0.22
			0.27
VI	0.50	0.13	0.00**
			0.00**

(*continued*)

remains present in the residuals. Consequently, the unconditional moments of unobserved real rates and inflation risk premia produced by model IV^C will imply nominal rates and inflation behavior close to that in the data, but the conditional dynamics of real short rates and inflation risk premia may be slightly more persistent or heteroskedastic than our estimates suggest.

D. Model Estimates

We focus on the benchmark model IV^C, which is the model that best fits the inflation and term structure data.[5] We discuss the parameter estimates,

[5] Estimates of other models are available upon request.

Table II—*Continued*
Specification Tests

Panel B: Matching Yield Dynamics				
	Moment Tests		Residual Tests	
Model	Mean/Var Long Rate/Spread	Spread Autocorrelogram	Short Rate	Spread
I	0.78	0.14	0.19	0.14
			0.27	0.22
I_w	0.00**	0.26	0.47	0.34
			0.15	0.29
II	0.61	0.01**	0.05	0.65
			0.02*	0.15
II_w	0.00**	0.01*	0.52	0.48
			0.01**	0.34
III	0.12	0.09	0.05	0.05
			0.04*	0.05
IV^A	0.37	0.33	0.02*	0.96
			0.04*	0.08
IV^C	0.63	0.39	0.02*	0.34
			0.04*	0.03*
IV_w^A	0.00**	0.06	0.31	0.11
			0.08	0.35
IV_w^C	0.00**	0.24	0.33	0.07
			0.12	0.30
VI	0.04*	0.00**	0.01**	0.01*
			0.01**	0.00**

the implied factor dynamics, and the identification and interpretation of the regimes.

D.1. Parameter Estimates

Table III reports the parameter estimates. Inflation enters the real short rate equation (4) with a highly significant, negative coefficient of $\delta_\pi = -0.49$. In the companion form Φ of the VAR, the term structure latent factors q_t and f_t are both persistent, with correlations of 0.97 and 0.76, respectively. Their effects on the conditional mean of inflation and thus on expected inflation are positive with coefficients of 0.62 and 0.95, respectively. However, the coefficient on f_t is only borderline significant with a *t*-statistic of 1.85. Not surprisingly, lagged inflation also significantly enters the conditional mean of inflation, with a loading of 0.54. A test of money neutrality ($\delta_\pi = \Phi_{\pi,q} = \Phi_{\pi,f} = 0$) rejects with a *p*-value less than 0.001.

The conditional means and variances of the factors reveal that the first $s_t^f = 1$ regime is characterized by a low f_t mean and low standard deviation. Both the mean and standard deviations are significantly different across the two regimes at the 5% level. For the inflation process, the conditional mean of inflation is

Table III

Benchmark Model IV^C Parameter Estimates

The table reports estimates of the benchmark RS model IV^C with correlated s_t^f and s_t^π outlined in Section I. The stable probabilities of regime 1 to 4 are 0.725, 0.039, 0.197, and 0.038, with standard errors of 0.081, 0.029, 0.052, and 0.018, respectively. We reject the null of independent regimes (Case A) with a p-value of 0.033 using a likelihood ratio test.

Short Rate Equation $r_t = \delta_0 + \delta_1{}'X_t$				
			δ_1	
	δ_0	q	f	π
	0.008	1.000	1.000	-0.488
	(0.001)	–	–	(0.056)
Companion Form Φ				
		q	f	π
	q	0.975	0.000	0.000
		(0.014)	–	–
	f	0.000	0.762	0.000
		–	(0.012)	–
	π	0.618	0.954	0.538
		(0.164)	(0.516)	(0.064)

Conditional Means and Volatilities	Regime 1		Regime 2	P-value Test of Equality
$\mu_f(s_t^f) \times 100$	−0.010		0.034	0.037
	(0.005)		(0.016)	
$\mu_\pi(s_t^\pi) \times 100$	0.473		0.248	0.002
	(0.082)		(0.110)	
$\sigma_q \times 100$		0.094		–
		(0.011)		
$\sigma_f(s_t^f) \times 100$	0.078		0.175	0.000
	(0.019)		(0.047)	
$\sigma_\pi(s_t^\pi) \times 100$	0.498		0.573	0.249
	(0.028)		(0.063)	

(*continued*)

significantly different across the s_t^π regimes, with $s_t^\pi = 1$ being a relatively high inflation environment. However, there is no significant difference across regimes in the innovation variances. This does not mean that inflation is homoskedastic in this model. The regime-dependent means of f_t induce heteroskedastic inflation across the f_t factor regimes.

Table III also reports that the price of risk for the q_t factor is negative but imprecisely estimated. The prices of risk for the f_t factor are both significantly different from zero and significantly different across the two regimes. Moreover, they have a different sign in each regime, which may induce different term structure slopes across the regimes.

The transition probability matrix shows that the s_t^f regimes are persistent with probabilities $Pr(s^f{}_{t+1} = 1|s_t^f = 1) = 0.93$ and $Pr(s^f{}_{t+1} = 2|s_t^f = 2) = 0.77$.

Table III—*Continued*

Prices of Risk $\lambda(s_t^\pi) = (\gamma_1\, q_t\; \lambda_f(s_t^\pi)\; 0)'$			
	$\lambda_f(s_t^\pi)$		
γ_1	Regime 1	Regime 2	P-value Test of Equality
−17.1	−0.613	0.504	0.000
(15.7)	(0.097)	(0.151)	

Transition Probabilities Π				
	$s_{t+1} = 1$	$s_{t+1} = 2$	$s_{t+1} = 3$	$s_{t+1} = 4$
$s_t = 1$	0.930	0.000	0.065	0.005
	(0.025)	(0.008)	(0.020)	(0.002)
$s_t = 2$	0.125	0.804	0.019	0.052
	(0.030)	(0.029)	(0.007)	(0.016)
$s_t = 3$	0.228	0.000	0.716	0.056
	(0.047)	(0.002)	(0.045)	(0.024)
$s_t = 4$	0.031	0.197	0.205	0.567
	(0.010)	(0.041)	(0.039)	(0.064)
p^f	0.930	q^f	0.772	
	(0.021)		(0.047)	
p^{AA}	1.000	p^{AB}	0.135	
	(0.009)		(0.031)	
p^{AB}	0.865	p^{BB}	0.735	
	(0.031)		(0.055)	

Std Dev × 100 of Measurement Errors	
y_t^4	y_t^{12}
0.050	0.024
(0.003)	(0.001)

The probability $p^{AA} = Pr(s^\pi_{t+1} = 1 | s^f{}_{t+1} = 1,\, s^\pi_t = 1)$ is estimated to be one. Conditional on a period with a negative f_t and relatively high inflation (regime 1), we cannot transition into a period of lower expected inflation unless the f_t regime also shifts to the higher mean regime. Thus, the model assigns zero probability from transitioning from $s_t = 1 \equiv (s_t^f = 1, s_t^\pi = 1)$ to $s_{t+1} = 2 \equiv (s^f{}_{t+1} = 1,\, s^\pi_{t+1} = 2)$. Similarly, starting in regime 3, $s_t = 3 \equiv (s_t^f = 2,\, s_t^\pi = 1)$, we can transition into the low inflation regime ($s^\pi_{t+1} = 2$) only with a realization of $s^f{}_{t+1} = 2$, where f_t is high and volatile. We demonstrate below that this behavior has a plausible economic interpretation.

D.2. Factor Behavior

Table IV reports the relative contributions of the different factors driving the short rate, long yield, term spread, and inflation dynamics in the model. The price of risk factor q_t is relatively highly correlated with both inflation and the nominal short rate, but shows little correlation with the nominal spread.

Table IV

Factor Behavior

The table reports various unconditional moments of the three factors: the time-varying price of risk factor q_t, the RS factor f_t, and inflation π_t, from the benchmark model IV^C. The short rate refers to the 1-quarter nominal yield and the spread refers to the 20-quarter nominal term spread. The row labelled "Data π" refers to actual inflation data. The numbers between parentheses are standard errors reflecting parameter uncertainty from the estimation, computed using the delta method. The variance decomposition of the real rate is computed as $\text{cov}(r_t, z_t)/\text{var}(r_t)$, with z_t respectively q_t, f_t, and $\delta_\pi\ \pi_t$. The variance decomposition of expected inflation is computed as $\text{cov}(\text{E}_t[\pi_{t+1}], z_t)/\text{var}(\text{E}_t[\pi_{t+1}])$, with z_t respectively $\Phi_{\pi q}\, q_t$, $\Phi_{\pi f}\ f_t$, and $\Phi_{\pi\pi}\ \pi_t$. Panel B reports multivariate projection coefficients of inflation on the lagged short rate, spread, and inflation implied by the model and in the data. Standard errors in parentheses are computed using the delta method for the model-implied coefficients and are computed using GMM for the data coefficients.

Panel A: Moments of Factors

					Correlation with				
	St Dev	Auto	Contribution to Real Rate Variance	Contribution to Expected Inflation Variance	Inflation	Nominal Short Rate	Nominal Spread	Real Short Rate	Real Spread
q	1.70	0.98	0.51	0.28	0.61	0.90	−0.20	0.44	−0.09
	(0.55)	(0.01)	(0.35)	(0.08)	(0.11)	(0.05)	(0.07)	(0.21)	(0.02)
f	0.68	0.74	0.09	0.09	0.24	0.43	−0.99	0.19	−0.24
	(0.20)	(0.02)	(0.10)	(0.05)	(0.07)	(0.11)	(0.02)	(0.17)	(0.17)
π	3.50	0.76	0.40	0.62	1.00	0.69	−0.44	−0.34	0.59
	(0.42)	(0.05)	(0.36)	(0.08)	–	(0.08)	(0.06)	(0.29)	(0.12)
Data π	3.16	0.72				0.68	−0.37		

Panel B: Projection of Inflation on Lagged Instruments

	Inflation	Nominal Short Rate	Nominal Spread
Model	0.52	0.39	−0.08
	(0.06)	(0.07)	(0.17)
Data	0.49	0.29	−0.39
	(0.06)	(0.07)	(0.15)

In other words, q_t can be interpreted as a level factor. The RS term structure factor f_t is highly correlated with the nominal spread, in absolute value, so f_t is a slope factor. The factor f_t is also less variable and less persistent than q_t. Consequently, f_t does not play a large role in the dynamics of the real rate, only accounting for 9% of its variation. The most variable factor is inflation, which accounts for 51% of the variation of the real rate. Inflation is negatively correlated with the real short rate, at −34%, as a result of the negative $\delta_\pi = -\ 0.49$ coefficient, while q_t is positively correlated with the real short rate (44%). The model produces a 69% (−44%) correlation between inflation and the nominal short rate (nominal 5-year spread), which matches the data correlation of 68% (−37%) very closely.

Panel A also reports how the different factors contribute to the expected inflation dynamics. The latent factor components play an important role in the dynamics of expected inflation, with q_t and f_t accounting for 37% of the variance of expected inflation. Inflation itself accounts for 62% of the variance of inflation. Expected inflation also has a nonlinear RS component. We calculate the contribution of regimes to the variance of expected inflation by computing the variance of expected inflation assuming we never transition from regime 1, relative to the variance of expected inflation from the full model. Unconditionally, RS accounts for 12% of the variance of expected inflation. We also show later that regimes are critical for capturing sudden decreases in expected inflation occurring occasionally during the sample.

The implied processes for expected inflation and actual inflation are both very persistent. The first-order autocorrelation coefficient of one-quarter expected inflation is 0.89, which implies a monthly autocorrelation coefficient of 0.96 under the null of an AR(1). The autocorrelations decay slowly to 0.51 at 10 quarters. Fama and Schwert (1977) also note the strong persistence of expected inflation using time-series techniques to extract expected inflation estimates. For actual inflation, the first-order autocorrelation implied by the model is 0.76 and it is 0.35 at 10 quarters, matching the data almost perfectly at 0.72 and 0.35, respectively.[6] It is this very persistent nature of inflation that many of the other models cannot match. For example, in model I_w, similar to Campbell and Viceira (2001), the autocorrelations of actual inflation are 0.48 and 0.20 at 1 and 10 lags, respectively.

Because the factors are highly correlated with inflation, the nominal short rate, and the nominal spread, these three variables should capture a substantial proportion of the variance of expected inflation in our model. To verify this implication of our model with the data, we project inflation onto the short rate, spread, and past inflation both in the data and in the model. Panel B of Table IV reports these results. When the short rate increases by 1%, the model signals an increase in expected inflation of 39 basis points. A 1% increase in the spread predicts an eight basis point decrease in expected inflation. These patterns are consistent with what is observed in the data, but the response to an increase in the spread is somewhat stronger in the data. Past inflation has a coefficient of 0.52, matching the data coefficient of 0.49 almost exactly.

The model also matches other predictive regressions of future inflation. For example, Mishkin (1990) regresses the difference between the future n-period inflation rate and the one-period inflation rate onto the the n-quarter term spread. In the data, this coefficient takes on a value of 0.98 with a standard error of 0.36 for a horizon of 1 year. The model-implied coefficient is 0.97. Thus, we are confident that the model matches the dynamics of expected inflation well.

[6] The autocorrelations of inflation vary only modestly across regimes, with the first-order autocorrelation of inflation being highest in regime $s_t = 1$ at 0.77 and lowest in regime $s_t = 4$ at 0.74.

Table V

Real Rates, Inflation Compensation, and Nominal Rates across Regimes

We report means and standard deviations for real short rates, $\hat{r}_t$, the 20-quarter real term spread, $\hat{y}_t^{20} - \hat{r}_t$, 1-quarter ahead inflation compensation, $\pi^e_{t,1}$, and nominal short rates, r_t, implied by model IV^C across each of the four regimes. The regime $s_t = 1$ corresponds to $(s_t^f = 1, s_t^\pi = 1)$, $s_t = 2$ to $(s_t^f = 1, s_t^\pi = 2)$, $s_t = 3$ to $(s_t^f = 2, s_t^\pi = 1)$, and $s_t = 4$ to $(s_t^f = 2, s_t^\pi = 2)$. Standard errors reported in parentheses are computed using the delta method.

		Regime			
		$s_t = 1$	$s_t = 2$	$s_t = 3$	$s_t = 4$
Real Short Rate $\hat{r}_t$	Mean	1.14	1.98	1.34	1.97
		(0.39)	(0.53)	(0.35)	(0.45)
	Std Dev	1.40	1.55	1.55	1.68
		(0.22)	(0.29)	(0.25)	(0.29)
Real Term Spread $\hat{y}_t^{20} - \hat{r}_t$	Mean	0.15	−0.39	−0.03	−0.45
		(0.31)	(0.21)	(0.28)	(0.16)
	Std Dev	1.12	1.26	1.31	1.42
		(0.17)	(0.25)	(0.22)	(0.25)
Inflation Compensation $\pi^e_{t,1}$	Mean	3.92	2.46	4.43	3.20
		(0.38)	(0.79)	(0.39)	(0.67)
	Std Dev	2.75	2.95	3.01	3.13
		(0.50)	(0.51)	(0.48)	(0.49)
Nominal Short rate r_t	Mean	5.06	4.45	5.77	5.17
		(0.08)	(0.38)	(0.17)	(0.34)
	Std Dev	3.04	3.12	3.47	3.50
		(0.74)	(0.73)	(0.65)	(0.65)

D.3. Regime Interpretation

How do we interpret the behavior of the regime variable in economic terms? In Table V, we describe the behavior of real short rates, one-quarter ahead inflation compensation (which is virtually identical to one-period expected inflation except for Jensen's inequality terms), and nominal short rates across regimes. This information leads to the following regime characterization:

		Real Short Rates	Inflation	% Time
$s_t = 1$	$s_t^f = 1, s_t^\pi = 1$	Low and Stable	High and Stable	72%
$s_t = 2$	$s_t^f = 1, s_t^\pi = 2$	High and Stable	Low and Stable	4%
$s_t = 3$	$s_t^f = 2, s_t^\pi = 1$	Low and Volatile	High and Volatile	20%
$s_t = 4$	$s_t^f = 2, s_t^\pi = 2$	High and Volatile	Low and Volatile	4%

All the levels (low or high) and variability (stable or volatile) are relative statements, so caution must be taken in the interpretation. The last column lists the proportion of time spent in each regime in the sample based on the population probabilities.[7] The means of both real rates and inflation are driven mostly by the s_t^{π} regime, while their volatilities are driven by the s_t^f regime.

The first regime is a low real rate-high inflation regime, where both real rates and inflation are not very volatile. We spend most of our time in this regime. As we will see, it is better to characterize the relatively high inflation regime as a "normal regime" and the low inflation regime as a "disinflation regime." The volatilities of real short rates, inflation compensation, and nominal short rates are all lowest in regime 1. The regime with the second-largest stable probability is regime 3, which is also a low real rate regime. In this regime, the mean of inflation compensation is highest. Thus, in population we spend around 90% of the time in low real rate environments. Regimes 2 and 4 are characterized by relatively high and volatile real short rates. The inflation compensation in these regimes is relatively low. Table V shows that these regimes are also associated with downward-sloping term structures of real yields. Consequently, the transition probability estimates imply that passing through a downward-sloping real yield curve is necessary to reach the regime with relatively low inflation. Finally, regime 4 has the highest volatility of real rates, inflation compensation, and nominal rates.

D.4. Regimes over Time

In Figure 1, we plot the short rate, long rate, and inflation over the sample in the top panel and the smoothed regime probabilities in the bottom panel over the sample period. From 1952 to 1978, the estimation switches between $s_t = 1$ and $s_t = 3$. Recall that these regimes feature relatively low real rates and high inflation. In regime 3, inflation has its highest mean and is quite volatile, leading to high and volatile nominal rates. These regimes precede the recessions of 1960, 1970, and 1975.

Post-1978, the model switches between all four regimes. The period around 1979 to 1982 of monetary targeting is mostly associated with regime 4, characterized by the highest volatility of real rates and inflation and a downward sloping real yield curve. Before the economy transitions to regime $s_t = 2$ in 1982, with high real rates and low and more stable inflation, there are a few jumps into the higher inflation regime 3.

Post-1982, regimes 2 and 4, with lower expected inflation, occur regularly. These regimes are associated with rapid decreases in inflation and downward-sloping real yield curves. From a Taylor (1993) rule perspective, these regimes may reflect periods in which an activist monetary policy of raising real rates, especially through actions at the short-end of the yield curve, achieved disinflation. Several features of the occurrence of these regimes are consistent with

[7] If we identify the regimes through the sample by using the ex post smoothed regime probabilities, then we spend less time in regime $s_t = 1$ in sample than the population frequency. Unlike traditional two-regime estimations, like Gray (1996) and Bansal and Zhou (2002), this is not caused purely by switching out of $s_t = 1$ during the monetary targeting period of 1979 to 1982. In contrast, our model produces more recurring switches into regimes $s_t = 2$ and $s_t = 4$. Such switches also occur during the early 1990s and early 2000s, which we discuss below.

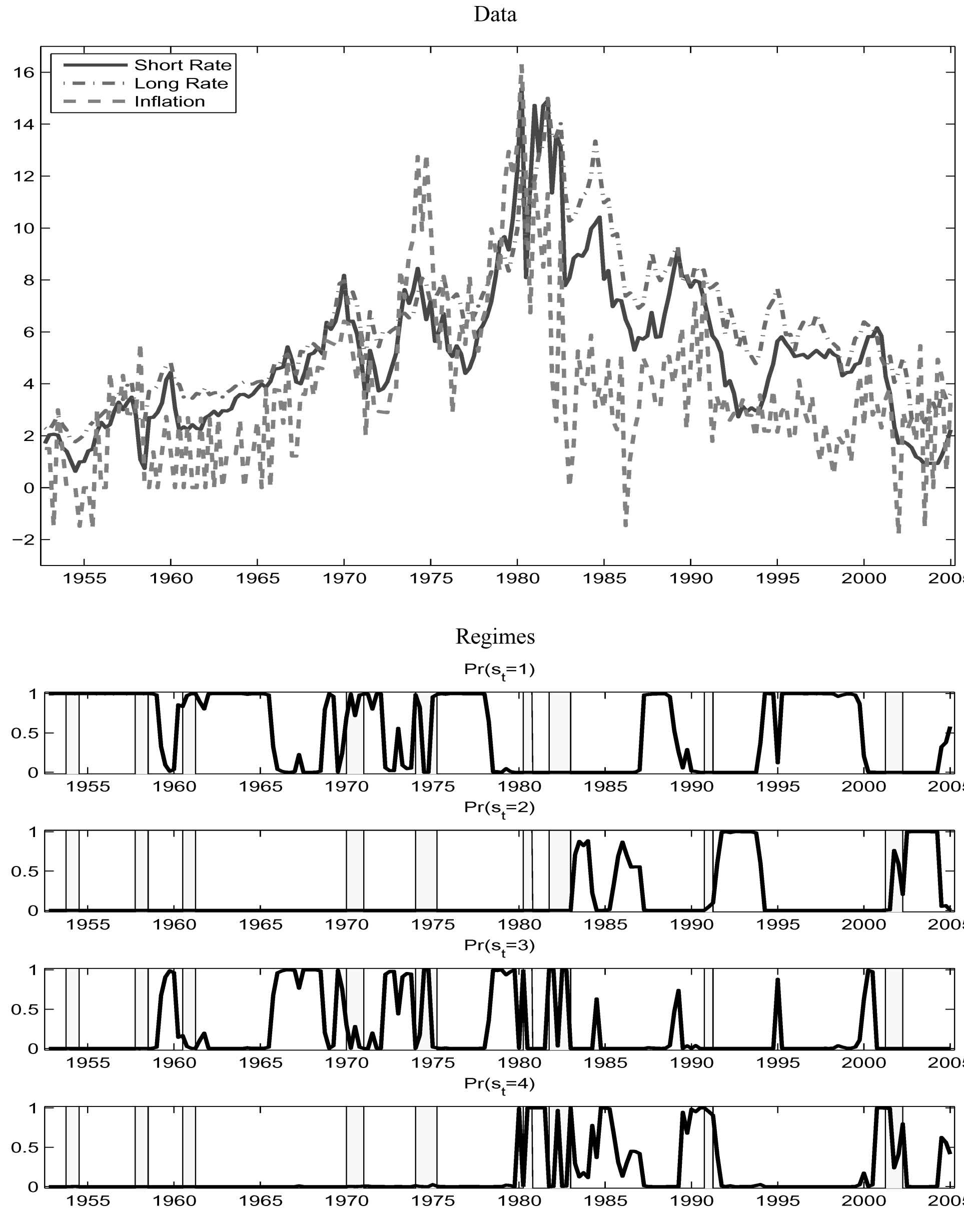

Figure 1. Smoothed regime probabilities, all regimes. The top graph plots the nominal short rate (1-quarter yield) and nominal long rate (20-quarter yield) together with quarter-on-quarter inflation. The top panel's y-axis units are annualized and are in percentages. In the bottom graph, we plot the smoothed probabilities of each of the four regimes, $Pr(s_t = i|I_T)$, conditioning on data over the entire sample, from the benchmark model IV^C. NBER recessions are indicated by shaded bars.

this interpretation. First, transitioning into regimes 2 and 4 requires high real rates. Second, these regimes only occur after the Volcker period, which is consistent with Nelson (2004) and Meltzer (2005), who argue that U.S. monetary authorities had sufficient credibility to change inflation behavior only after 1979. Third, it is also consistent with the econometric analysis of the Taylor rule in Bikbov (2005), Boivin (2006), and Cho and Moreno (2006), among others, who document a structural break from accommodating to activist monetary policies around 1980.

Towards the end of the 1980s we transition back to the normal regime 1, but just before the 1990 to 1991 recession the economy enters into regime 4, followed by regime 2, which lasts until 1994. During the late 1990s, the normal regime $s_t = 1$ prevails with normal, stable inflation and low real rates. During the early 2000s, quarter-on-quarter inflation was briefly negative, and the model transitions to the disinflation regimes $s_t = 2$ and $s_t = 4$ around the time of the 2001 recession. At the end of the sample, December 2004, the model seems to be transitioning back to the normal $s_t = 1$ regime.

In Figure 2, we sum the four s_t regimes into their s_t^f and s_t^π sources. In the top panel, we graph the real short and long 20-quarter real rates, together with one-period expected inflation and long-term inflation compensation for comparison. The real short rate exhibits considerable short-term variation, sometimes decreasing and increasing sharply. There are sharp decreases of real rates in the 1958 and 1975 recessions and after the 2001 recession. Real rates are highly volatile around the 1979–1982 period and increase sharply during the 1980 and 1983 recessions.[8] Consistent with the older literature like Mishkin (1981), real rates are generally low from the 1950s until 1980. The sharp increase in the early 1980s to above 7% was temporary, but it took until after 2001 before real rates reached the low levels common before 1980. Over 1961–1986, Garcia and Perron (1996) find three nonrecurring regimes for real rates: 1961–1973, 1973–1980, and 1980–1986. In Figure 2, these periods roughly correspond to low but stable real rates, very low to negative and volatile real rates, and high and volatile real rate periods. We generate this behavior with recurring s_t^f and s_t^π regimes. The Garcia–Perron model could not generate the gradual decrease in real rates observed since the 1980s. The long real rate shows less time variation, but the same secular effects that drive the variation of the short real rate are visible.

In the middle panel of Figure 2, we plot the smoothed regime probabilities for the regime $s_t^f = 1$, which is the low volatility f_t regime associated with relatively high nominal term spreads. The high variability $s_t^f = 2$ regime occurs just prior to the 1960 recession, during the OPEC oil shocks of the early 1970s, during the 1979–1982 period of monetary targeting, during the 1984 Volcker disinflation, in the 1991 recession, briefly in 1995, and in 2000.

In the bottom panel of Figure 2, the smoothed regime probabilities of s_t^π look very different from the regime probabilities of s_t^f, indicating the potential

[8] The 95% standard error bands computed using the delta method are very tight and well within 20 basis points, so we omit them for clarity.

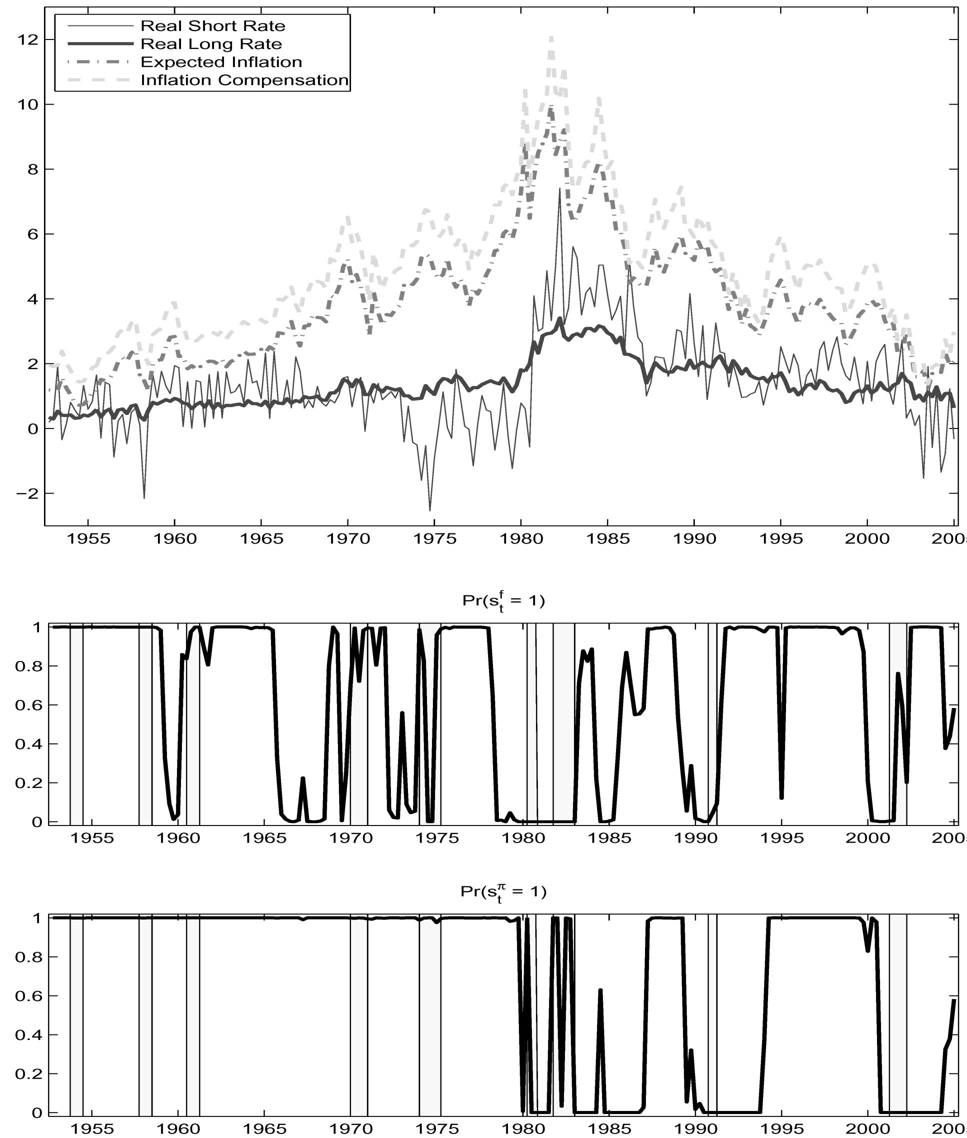

Figure 2. Smoothed regime probabilities. The top panel graphs the real short rate, $\hat{r}_t$, real long rate, $\hat{y}_t^{20}$, 1-quarter expected inflation, $\mathrm{E}_t(\pi_{t+1})$, and long-term inflation compensation, $\pi^e_{t,20}$, all implied from the benchmark model IV^C. The top panel's y-axis units are annualized and are in percentages. The middle and bottom panels plot smoothed regime probabilities using information from the whole sample. The middle panel shows the smoothed probabilities $Pr(s_t^f = 1|I_T)$ of the f factor regimes, s_t^f. The bottom panel graphs the smoothed probabilities $Pr(s_t^\pi = 1|I_T)$ of the inflation factor regime, s_t^π. NBER recessions are indicated by shaded bars.

importance of separating the real and inflation regime variables. We transition to $s_t^\pi = 2$, the disinflation regime, only after 1979, with the 1979–1982 period featuring some sudden and short-lived transitions to $s_t^\pi = 2$. The second inflation regime also occurs after 1985, during a sustained period in the early 1990s, and after 2000. In this last recession, there were significant risks of deflation. Clearly, the model accommodates rapid decreases in inflation by a transition to the second regime.[9]

Standard two-regime models of nominal interest rates (both empirical and term structure models) predominantly select the late 1970s and early 1980s as one regime change. These two-regime models identify the pre-1979 period and the period after the mid-1980s as a low mean, low volatility regime (see, for example, Gray (1996), Ang and Bekaert (2002), and Dai et al. (2006)). Our regimes for real factors and inflation have more frequent switches than two-regime models. In fact, the famous 1979–1982 episode is a period of both high real rates and high inflation in the late 1970s (regime 3), combined with high real rates and a transition to the second inflation regime caused by a dramatic decrease in inflation in the early 1980s (regime 4). Hence, our regime identification does not seem to be driven by a single period, but rather reflects a series of recurring regimes.

III. The Term Structure of Real Rates and Expected Inflation

We describe the behavior of real yields in Section III.A. Section III.B discusses the behavior of expected inflation and inflation risk premia. Combining real yields with expected inflation and inflation risk premia produces the nominal yield curve, which we discuss in Section III.C, before turning to variance decompositions in Section III.D.

A. The Behavior of Real Yields

A.1. The Real Term Structure

We examine the real term structure in Figure 3 and Table VI. Figure 3 graphs the regime-dependent real term structure. Every point on the curve for regime i represents the expected real zero-coupon bond yield conditional on regime i, $(\mathrm{E}[\hat{y}_t^n | s_t = i])$.[10] The unconditional real yield curve is graphed in the circles, which show a slightly humped real curve peaking around a 1-year maturity before converging to 1.3%. Panel A of Table VI reports that in the normal regime $(s_t = 1)$, the long-term rate curve assumes the same shape but is shifted slightly downwards, ranging from 1.14% at a 3-month horizon to 1.29% at a 5-year horizon.

[9] The inflation regime identifications of Evans and Wachtel (1993) and Evans and Lewis (1995) are not directly comparable as their models feature a random walk component in one regime (with no drift) and an AR(1) model in the other.

[10] These computations are detailed in Ang et al. (2007). It is also possible to compute the more extreme case $\mathrm{E}[\hat{y}_t^n | s_t = i, \forall t]$, that is, assuming that the process never leaves regime i. These curves have similar shapes to the ones shown in the figures but lie at different levels.

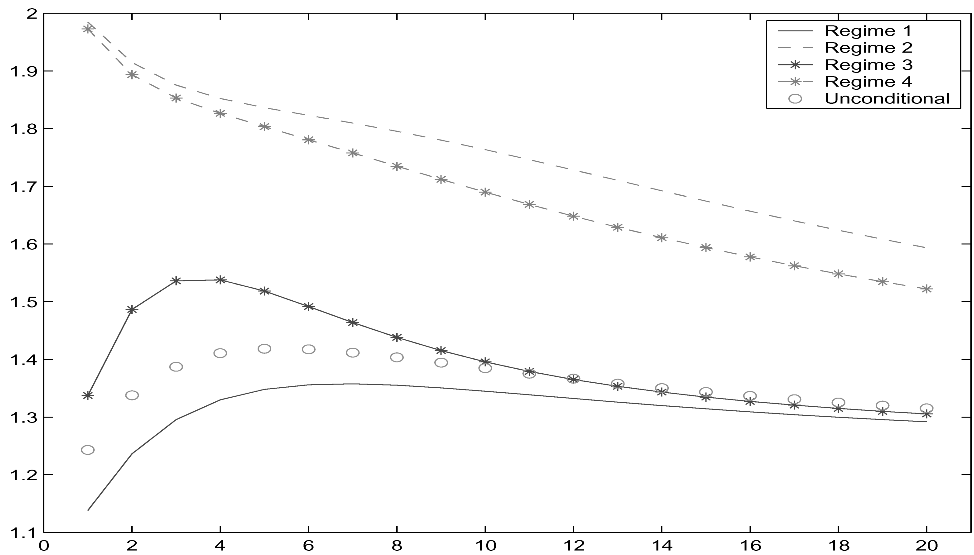

Figure 3. Real-term structure. We graph the real yield curve, conditional on each regime and the unconditional real yield curve implied from the benchmark model IV^C. The x-axis displays maturities in quarters of a year. The y-axis units are annualized and are in percentages.

In regimes 2 and 4, real rates start just below 2% at a 1-quarter maturity and decline to 1.59% for regime 2 and 1.52% for regime 4 at a 20-quarter maturity. Finally, regime 3, a low real rate-high inflation and volatile regime, has a humped, nonlinear, real term structure. This real yield curve peaks at 1.54% at the 1-year maturity before declining to the same level as the unconditional yield curve at 20 quarters. Thus, we uncover our first claim:

CLAIM 1: *Unconditionally, the term structure of real rates assumes a fairly flat shape around 1.3%, with a slight hump, peaking at a 1-year maturity. However, there are some regimes in which the real rate curve is downward sloping.*

Panel A of Table VI also reports that while the standard deviation of real short rates is lowest in regime 1 at 1.40%, the standard deviations of real long rates are approximately the same across regimes, at 0.55%. We compute unconditional moments of real yields in Panel B, which shows that the unconditional standard deviation of the real short rate (20-quarter real yield) is 1.46% (0.55%). These moments solidly reject the hypothesis that the real short rate is constant, but at long horizons real yields are much more stable and persistent. This is reflected in the autocorrelations of the real short rate and 20-quarter real rate, which are 60% and 94%, respectively. The mean of the 20-quarter real term spread is only 7 basis points. The standard error is only 28 basis points, so that the real term structure cannot account for the 1.00% nominal term spread in the data. Hence:

CLAIM 2: *Real rates are quite variable at short maturities but smooth and persistent at long maturities. There is no significant real term spread.*

Table VI

Characteristics of Real Rates

The table reports various moments of the real rate, implied from model IV^C. Panel A reports the conditional mean and standard deviation of real rates of various maturities in quarters across regimes. Panel B reports the unconditional mean, standard deviation, and autocorrelation of real yields. Panel C reports the correlation of real yields with actual and unexpected inflation implied from the model. We report the conditional correlation of real yields with actual inflation, $\text{corr}(\hat{y}^n_{t+1}, \pi_{t+1}|s_t)$, and the conditional correlation of real yields with expected inflation, $\text{corr}(\hat{y}^n_{t+1}, \text{E}_{t+1}(\pi_{t+1+n,n})|s_t)$. Standard errors reported in parentheses are computed using the delta method.

Panel A: Conditional Moments

Maturity Qtrs	Regime $s_t = 1$		Regime $s_t = 2$		Regime $s_t = 3$		Regime $s_t = 4$	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
1	1.14	1.40	1.98	1.55	1.34	1.55	1.97	1.68
	(0.39)	(0.22)	(0.53)	(0.29)	(0.35)	(0.25)	(0.45)	(0.29)
4	1.33	0.86	1.85	0.93	1.54	0.89	1.83	0.94
	(0.38)	(0.25)	(0.54)	(0.25)	(0.40)	(0.25)	(0.48)	(0.25)
20	1.29	0.55	1.59	0.56	1.31	0.55	1.52	0.56
	(0.39)	(0.32)	(0.42)	(0.32)	(0.44)	(0.32)	(0.41)	(0.49)

Panel B: Unconditional Moments

Maturity Qtrs	Mean	St Dev	Auto
1	1.24	1.46	0.60
	(0.38)	(0.23)	(0.08)
4	1.41	0.88	0.73
	(0.38)	(0.25)	(0.13)
20	1.32	0.55	0.94
	(0.40)	(0.32)	(0.05)
Spread 20-1	0.07	1.19	0.52
	(0.28)	(0.18)	(0.06)

(continued)

Table VI—*Continued*

Panel C: Correlations with Actual and Expected Inflation

Maturity	Regime $s_t = 1$		Regime $s_t = 2$		Regime $s_t = 3$		Regime $s_t = 4$		Unconditional	
Qtrs	Actual	Expected	Actual	Expected	Actual	Expected	Actual	Expected	Actual	Expected
1	−0.34	−0.02	−0.47	−0.12	−0.40	0.03	−0.49	−0.06	−0.34	−0.03
	(0.31)	(0.24)	(0.31)	(0.25)	(0.37)	(0.28)	(0.35)	(0.29)	(0.29)	(0.31)
4	−0.11	0.14	−0.26	0.02	−0.17	0.16	−0.29	0.06	−0.13	0.16
	(0.43)	(0.32)	(0.45)	(0.36)	(0.56)	(0.44)	(0.55)	(0.46)	(0.43)	(0.44)
20	0.41	0.46	0.30	0.38	0.46	0.54	0.34	0.45	0.37	0.57
	(0.26)	(0.20)	(0.33)	(0.26)	(0.36)	(0.29)	(0.41)	(0.35)	(0.29)	(0.28)

A.2. The Correlation of Real Rates and Inflation.

Panel C of Table VI reports conditional and unconditional correlations of real rates and inflation. At the 1-quarter horizon, the conditional correlation of real rates with actual inflation is negative in all regimes and hence also unconditionally. The negative estimate for δ_π mostly drives this result. The correlations with expected inflation are smaller in absolute value, but still mostly negative. However, the differences across regimes are not large in economic terms and the correlations are overall not significantly different from zero. Consequently, we do not find strong statistical evidence for a Mundell–Tobin effect:

CLAIM 3: *The real short rate is negatively correlated with both expected and unexpected inflation, but the statistical evidence for a Mundell–Tobin effect is weak.*

This negative correlation between real rates and inflation is consistent with earlier studies such as Huizinga and Mishkin (1986) and Fama and Gibbons (1982), but their analysis implicitly assumes a zero inflation risk premium so their instrumented real rates may partially embed inflation risk premiums. The small Mundell–Tobin effect we estimate is consistent with Pennachi (1991), who uses a two-factor affine model of real rates and expected inflation, but opposite in sign to Barr and Campbell (1997), who use U.K. interest rates and find that the unconditional correlation between real rates and inflation is small but positive. As each regime records a negative correlation between real rates and inflation, we do not find any evidence that the sign of the correlation has changed over time, unlike what Goto and Torous (2006) find using an empirical model that neither employs term structure information nor precludes arbitrage.

The correlations between real yields and actual or expected inflation turn robustly positive at long horizons. Some of these correlations are statistically significant, although again most are not precisely estimated. The positive signs at long horizons result from the positive feedback effect of the Φ coefficients dominating the negative effect of the δ_π coefficient in the short rate equation. This indicates that the Mundell–Tobin effect is only a short-horizon phenomenon. Over long horizons, real yields and inflation are positively correlated.

A.3. The Effect of Regimes on Real Rates

Introducing regimes allows a further nonlinear mapping between latent factors and nominal yields not available in a traditional affine model, so that the dynamics of real long yields are not just linear transformations of nominal yield factors. To compare the effect of incorporating regimes, we contrast our model-implied real yields with those implied by model I_w. Figure 4 plots real yields from models I_w and IV^C, and we characterize the differences between the real yields from each model in Table VII.

Panel A of Table VII reports the population moments of real yields from models I_w and IV^C. The mean real short rate in model I_w is 1.42%, very close to the 1.39% mean of the 1-quarter real yield for a similar model estimated by Campbell and Viceira (2001). This is slightly higher, but very similar to the

Table VII

Effect of Regimes on Real Rates

The table reports various characteristics of real yields from model I_w, an affine model similar to Campbell and Viceira (2001), and our model IV^C. In Panel A we report population means, standard deviations, and autocorrelations of real 1-quarter short rates and real 20-quarter long yields, together with their correlation. Standard errors reported in parentheses are computed using the delta method. In Panel B, we report statistics on the differences between the real yields implied by model I_w and model IV^C over the sample.

Panel A: Real Yield Characteristics

		Model I_w	Model IV^C
Real Short Rate $\hat{r}_t$	Mean	1.42	1.24
		(0.31)	(0.38)
	St Dev	1.59	1.46
		(0.29)	(0.23)
	Auto	0.72	0.60
		(0.09)	(0.08)
Real Long Rate $\hat{y}_t^{20}$	Mean	1.69	1.32
		(0.30)	(0.40)
	St Dev	1.04	0.55
		(0.34)	(0.32)
	Auto	0.96	0.94
		(0.02)	(0.05)
Correlation $\hat{r}_t$, $\hat{y}_t^{20}$		0.79	0.64
		(0.08)	(0.06)

Panel B: Comparisons of I_w and IV^C over the Sample

Real Short Rate $\hat{r}_t$ Differences	Std Dev	1.40
	Min	−2.61
	Max	6.01
Real Long Rate $\hat{y}_t^{20}$ Differences	Std Dev	0.54
	Min	−1.06
	Max	1.85

mean level of short rates from our model IV^C, at 1.24%. The standard deviations of real short rates are also similar across the two models, at 1.59% and 1.46%, for models I_w and IV^C, respectively. However, Model I_w's real short rates are somewhat more persistent, at 0.72, than the autocorrelation of short rates from model IV^C, at 0.60. There are bigger differences for population moments for real long yields between the models. The long end of the real yield curve for model I_w is, on average, 40 basis points higher than for model IV^C and twice as variable, with standard deviations of 1.04% and 0.55%, respectively. The correlation between short and long real rates is higher for model I_w, at 0.79, than for model IV^C, at 0.64. Thus, the addition of regimes has important consequences for inferring long real rates.

Figure 4 plots the real short and long yields over the sample from the two models. The top panel shows that the real short rates from models I_w and

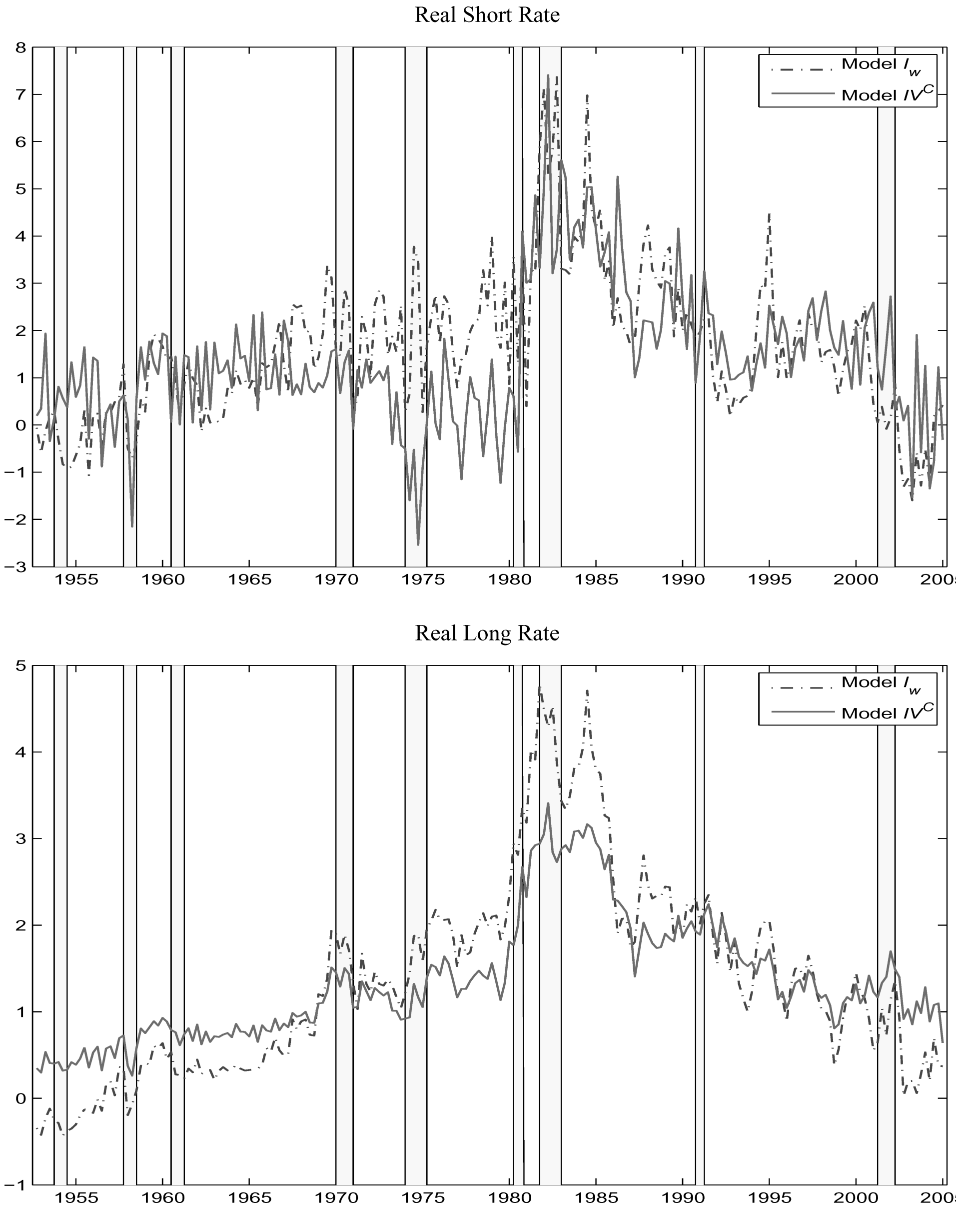

Figure 4. Comparing Model IV^C real yields with Model I_w. The figure compares the 1-quarter real short rate (5-year real long yield) of the benchmark model IV^C and model I_w in the top (bottom) panel over the sample period.

IV^C follow the same secular trends, but the correlation between the two model implied real rates is only 0.57. The main difference occurs during the late 1970s. Model IV^C documents that real short rates were fairly low during this period, consistent with the early estimates of Mishkin (1981) and Garcia and Perron (1996). In contrast, model I_w's real rates are much higher during this period. To quantify these differences, Panel B of Table VII reports summary statistics on the difference between $\hat{r}_t$ from model I_w and $\hat{r}_t$ from model IV^C. The largest difference of 6.01% occurs during the 1974 recession. In the bottom panel of Figure 4, we graph the real long yield from the two models. While the higher variability of the I_w-implied real long yield is apparent, the two models clearly share the same trends. In fact, the real long rates from the two models have a 0.95 correlation.

In a traditional affine model, there is a direct linear mapping between the latent factors and nominal yields, which may imply that real rates, which are linear combinations of the latent factors, are highly correlated with nominal yields. This is the case for model I_w. The bottom panel of Figure 4 shows that real long yields from model I_w start from below zero in 1952 and reach close to 5% in 1981, before declining to 30 basis points in 2005. These long real rates are highly correlated with long nominal rates, with a correlation coefficient of 0.98. Incorporating regimes in model IV^C reduces the correlation between real and nominal long rates to 90%. In contrast to model I_w, real long yields implied by model IV^C are more stable and have never been negative. This appears to be a more economically reasonable characterization of real long yields.

B. The Behavior of Inflation and Inflation Risk

B.1. The Term Structure of Expected Inflation

Table VIII reports some characteristics of inflation compensation, $\pi^e_{t,n}$, expected inflation, $E_t(\pi_{t+n,n})$, and the inflation risk premium, $\varphi_{t,n}$. We focus first on the inflation compensation estimates. The most striking feature in Table VIII is that the term structure of inflation compensation slopes upwards in all regimes. Regime $s_t = 1$ is the normal regime, and in this regime the inflation compensation spread is $\pi^e_{t,20} - \pi^e_{t,1} = 1.17\%$, very close to the unconditional inflation compensation spread of 1.14%. In regimes $s_t = 2$ and $s_t = 4$, inflation compensation starts at a lower level because these are the regimes with downward-sloping real yield curves and a disinflationary environment. However, the inflation compensation spreads are roughly comparable to the unconditional compensation spread, at 1.34% and 1.16% for regimes $s_t = 2$ and $s_t = 4$, respectively. We report the term structure of expected inflation in the second panel of Table VIII. Expected inflation always approaches the unconditional mean of inflation as the horizon increases in all regimes, because inflation is a stationary process.

B.2. The Inflation Risk Premium

Since the term structure of inflation compensation is upward sloping but expected inflation converges to long-run unconditional expected inflation, the

Table VIII
Inflation Compensation, Expected Inflation, and Inflation Risk Premiums

The table reports means of inflation compensation, the difference between nominal and real yields, expected inflation, and the inflation risk premium all implied from the benchmark model IV^C. Standard errors reported in parentheses are computed using the delta method.

Qtrs	$s_t = 1$	$s_t = 2$	$s_t = 3$	$s_t = 4$	Unconditional
Inflation Compensation $\pi^e_{t,n}$					
1	3.92	2.46	4.43	3.20	3.94
	(0.38)	(0.78)	(0.39)	(0.67)	(0.38)
4	4.20	2.49	4.95	3.34	4.25
	(0.34)	(0.70)	(0.39)	(0.59)	(0.35)
20	5.09	3.80	5.45	4.36	5.08
	(0.41)	(0.45)	(0.43)	(0.42)	(0.38)
Expected Inflation $E_t(\pi_{t+n,n})$					
1	3.93	2.47	4.44	3.21	3.94
	(0.38)	(0.79)	(0.39)	(0.67)	(0.38)
4	3.89	2.63	4.48	3.47	3.94
	(0.38)	(0.73)	(0.41)	(0.65)	(0.38)
20	3.91	3.39	4.20	3.82	3.94
	(0.38)	(0.49)	(0.39)	(0.46)	(0.38)
Inflation Risk Premium $\varphi_{t,n}$					
4	0.31	−0.14	0.47	−0.13	0.31
	(0.09)	(0.06)	(0.15)	(0.09)	(0.10)
20	1.18	0.42	1.25	0.55	1.14
	(0.36)	(0.23)	(0.42)	(0.31)	(0.36)

increasing term structure of inflation compensation is due to an inflation risk premium:

CLAIM 4: *The model matches an unconditional upward-sloping nominal yield curve by generating an inflation risk premium that is increasing in maturity.*

The third panel of Table VIII reports statistics on the inflation risk premium $\varphi_{t,n}$. In the normal regime $s_t = 1$ and unconditionally, the 5-year inflation risk premium is around 1.15%, which is almost the same magnitude as the 5-year term spread generated by the model of 1.21%. The inflation risk premium is higher in regime $s_t = 3$ with higher and more variable inflation than in regime $s_t = 1$. In the high real rate regimes $s_t = 2$ and $s_t = 4$, the inflation risk premium is less than 55 basis points. In regime $s_t = 4$, the inflation risk premium is not statistically different from zero. In Campbell and Viceira's (2001) one-regime setting, $\varphi_{t,40}$ is approximately 0.42%, accounting for about half of their model-implied 40-quarter nominal term spread of 0.88%.[11] We obtain inflation risk premiums of this low magnitude only in high real rate regimes, and in normal

[11] Campbell and Viceira (2001) report that the difference in expected holding-period returns on 10-year nominal bonds over nominal 3-month T-bills in excess of the expected holding-period returns on 10-year real bonds over the real 3-month short rate is approximately 1.1% and define

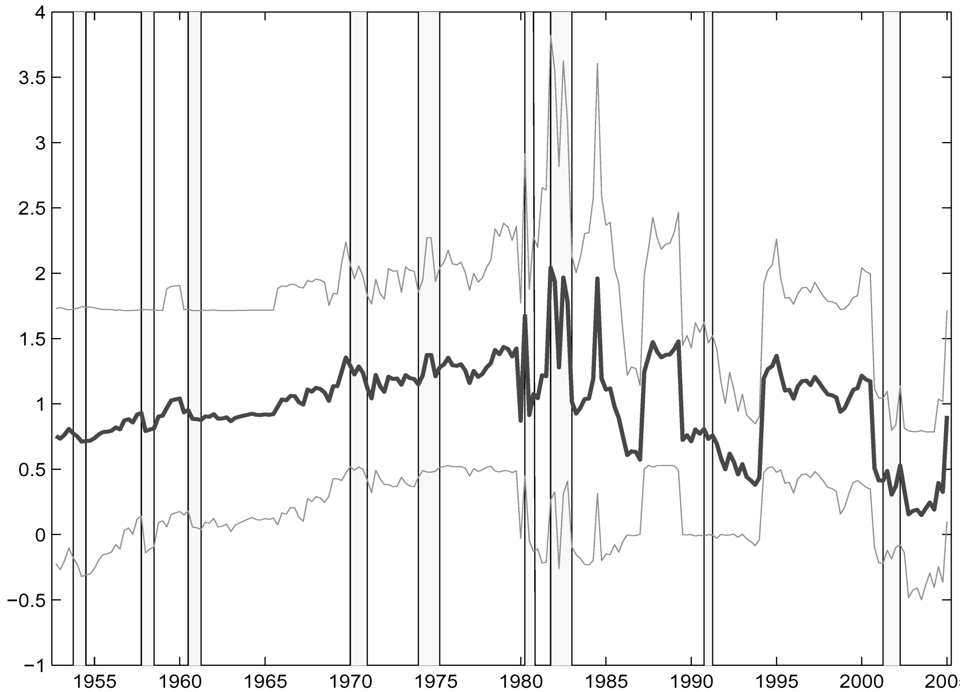

Figure 5. Inflation risk premiums. The figure graphs the time-series of the 20-quarter inflation risk premium, $\varphi_{t,20}$, with two standard error bounds, implied from the benchmark model IV^C. NBER recessions are indicated by shaded bars.

times assign almost all of the positive nominal yield spread to inflation risk premiums.

The time variation of the inflation risk premium is correlated with the time variation of the price of risk factor, q_t, but the correlation of the inflation risk premium with q_t is small, at 9.5% for a 20-quarter maturity. To calculate the proportion of the variance of $\varphi_{t,20}$ due to regime changes, we compare the unconditional variance of $\varphi_{t,20}$ varying across all four regimes with the variance of $\varphi_{t,20}$ if the model never switched from $s_t = 1$. We find that a significant fraction, namely 40%, of the variation of $\varphi_{t,20}$ is due to regime changes.

Figure 5 graphs the 20-quarter inflation risk premium over time and shows that the inflation risk premium decreased in every recession. During the 1981 to 1983 recession, the inflation premium is very volatile, increasing and decreasing by over 75 basis points. The general trend is that the premium rose very gradually from the 1950s until the late 1970s before entering a very volatile period during the monetary targeting period from 1979 to the early 1980s. It is then that the premium reached a peak of 2.04%. While the trend since then has been downward, there have been large swings in the premium. From a

this to be the inflation risk premium. In our model, the corresponding number for this quantity at a 20-quarter maturity is $\mathrm{E}[\ln(P^{19}_{t+1}/P^{20}_t) - y^1_t] - \mathrm{E}[\ln(\hat{P}^{19}_{t+1}/\hat{P}^{20}_t) - \hat{r}_t] = 1.46\%$.

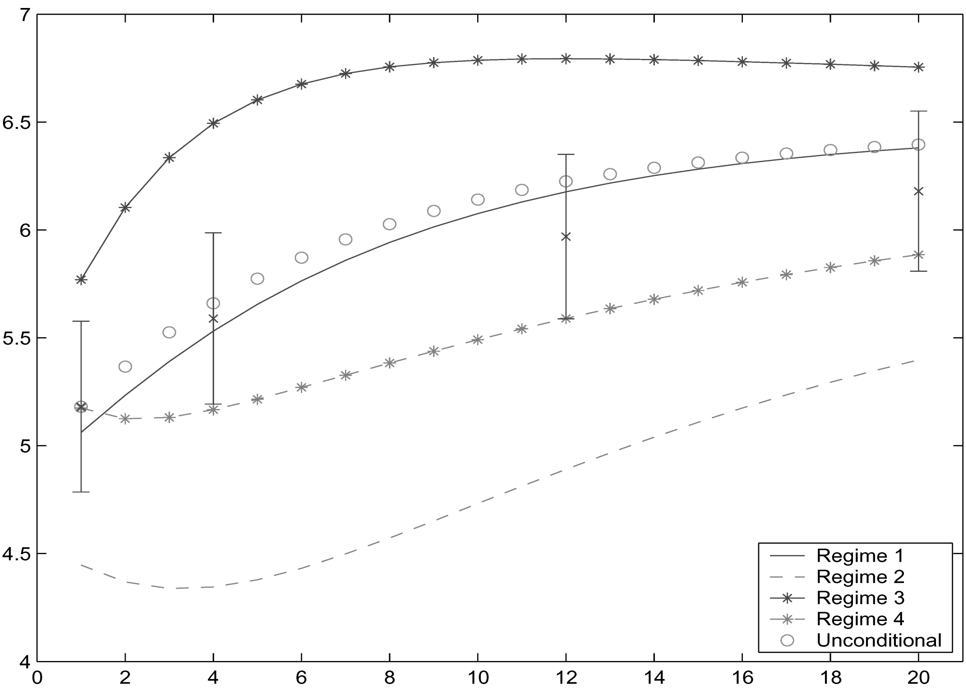

Figure 6. Nominal term structure The figure graphs the nominal yield curve, conditional on each regime and the unconditional nominal yield curve from the benchmark model IV^C. The x-axis displays maturities in quarters of a year. The y-axis units are annualized and are in percentages. Average yields from data are represented by "x," with 95% confidence intervals represented by vertical bars.

temporary low of 50 basis points in the mid-1980s it shot above 1%, coinciding with the halting of the large dollar appreciation of the early 1980s. The inflation premium dropped back to around 50 basis points in the late eighties and reached a low of 0.38% in 1993. The sharp drops in the inflation risk premium coincide with transitions to regimes with high real short rates. During 1994, the premium shot back up to 1.37% at the same time the Federal Reserve started to raise interest rates. During the late 1990s bull market inflation risk premiums were fairly stable and declined to 0.15% after the 2001 recession when there were fears of deflation. At the end of the sample in December 2004, the inflation risk premium started to increase again edging close to 1%.

C. Nominal Term Structure

Figure 6 graphs the average nominal yield curve. The unconditional yield curve is upward sloping, with the slope flattening out for longer maturities. The benchmark model produces a nominal term spread of $y_t^{20} - y_t^1 = 1.21\%$, well inside a one-standard error bound of the 1.00% term spread in data. Strikingly, in no regime does the benchmark model generate a conditional downward-sloping

Table IX

Conditional Moments across NBER Business Cycles

The table reports various sample moments of real rates, nominal rates, and inflation compensation from the benchmark model IV^C, conditional on expansions and recessions as defined by the NBER. Standard errors reported in parentheses are computed using the delta method on sample moments.

	Maturity Qtrs	Mean		Std Dev	
		Expansion	Recession	Expansion	Recession
Real Rates $\hat{y}_t^n$	1	1.45	1.23	1.30	2.06
		(0.20)	(0.20)	(0.04)	(0.08)
	20	1.33	1.43	0.65	0.87
		(0.38)	(0.38)	(0.18)	(0.25)
Nominal Rates y_t^n	1	5.03	5.95	2.59	4.07
		(0.09)	(0.14)	(0.27)	(0.41)
	20	6.05	6.85	2.46	3.71
		(0.20)	(0.22)	(0.26)	(0.38)
Inflation Compensation $\pi_{t,n}^e$	1	3.57	4.73	2.23	3.62
		(0.19)	(0.17)	(0.18)	(0.28)
	20	4.72	5.42	1.89	2.93
		(0.37)	(0.39)	(0.38)	(0.57)

nominal yield curve. In regimes $s_t = 2$ and $s_t = 4$, the real rate term structure is downward-sloping, but the upward-sloping term structure of inflation risk premiums completely counteracts this effect. Thus, regimes are important for the shape of the real, not nominal yield curve.

The first regime (low real rate-normal inflation regime) displays a nominal yield curve that almost matches the unconditional term structure. In the second regime, the yield curve is shifted downwards but is more steep because rates are lower than in the first regime due to lower expected inflation and inflation risk. In the third regime, the term structure is steeply upward sloping at the short end but then becomes flat and slightly downward sloping for maturities extending beyond 10 quarters. Nominal interest rates are the highest in this regime because in this regime, expected inflation is high and the level of real rates is about the same as in regime 1. In regime 4, the real interest rate curve is downward sloping, starting at a high level. Inflation compensation, however, is low in this regime (resulting in nominal yields of an average level), and is upward sloping, making the nominal yield curve upward sloping on average. Yet, in both regimes 2 and 4, a slight J-curve effect is visible at short maturities with nominal rates decreasing slightly before starting to increase.

Interest rates are often associated with the business cycle. The business cycle dates reported by the NBER are regarded as benchmark dates by both academics and practitioners. According to the conventional wisdom, interest rates are procyclical and spreads countercyclical (see, for example, Fama (1990)). Table IX shows that this is incorrect when measuring business cycles using NBER recessions and expansions. Interest rates are overall larger during

Table X
Unconditional Variance Decomposition of Nominal Yields

The table reports unconditional variance decompositions of nominal yields, y_t^n, into real rate, expected inflation, and inflation risk premium components, denoted by $\hat{y}_t^n$, $\mathrm{E}_t(\pi_{t,n})$, and $\varphi_{t,n}$, respectively, implied from model IV^C. This is done using the equation:

$$1 = \frac{\mathrm{var}(y_t^n, y_t^n)}{\mathrm{var}(y_t^n)} = \frac{\mathrm{cov}(\hat{y}_t^n, y_t^n) + \mathrm{cov}(\mathrm{E}_t(\pi_{t+n,n}), y_t^n) + \mathrm{cov}(\varphi_{t,n}, y_t^n)}{\mathrm{var}(y_t^n)}.$$

Standard errors reported in parentheses are computed using the delta method on population moments.

Maturity Qtrs	Real Rates	Expected Inflation	Inflation Risk
1	0.20	0.80	0.00
	(0.09)	(0.09)	(0.00)
20	0.20	0.71	0.10
	(0.09)	(0.09)	(0.08)

NBER recessions. However, when we focus on real rates, the conventional story obtains:

CLAIM 5: *Nominal interest rates do not behave procyclically across NBER business cycles but our model-implied real rates do.*

This can only be the case if expected inflation is countercyclical. Table IX shows that this is indeed the case, with inflation compensation averaging 4.73% in recessions but only 3.57% in expansions. Veronesi and Yared (1999) also find that real rates are procyclical in an RS model. In contrast, the real rates implied by model I_w are actually countercyclical, averaging 1.58% (1.80%) across NBER expansions (recessions). Thus, the presence of the regimes helps to induce the procyclical behavior of real rates. Finally, Table IX also illustrates that recessions are characterized by more volatility in real rates, nominal rates, and inflation.

D. Variance Decompositions

Table X reports the population variance decomposition of the nominal yield into real rates and inflation compensation. The variance decompositions, conditioning on the regime, are very similar across regimes and so are not reported. The results show that:

CLAIM 6: *The decompositions of nominal yields into real yields and inflation components at various horizons indicate that variation in inflation compensation (expected inflation and inflation risk premia) explains about 80% of the variation in nominal rates at both short and long maturities.*

This is at odds with the conventional wisdom that expected inflation primarily affects long-term bonds (see, among others, Fama (1975) and Mishkin

Table XI

Unconditional Variance Decomposition of Nominal Yield Spreads

The table reports unconditional variance decompositions of nominal yield spreads, $y_t^n - y_t^1$, into real rate, expected inflation, and inflation risk premium components, denoted by $\hat{y}_t^n - \hat{r}_t, \mathrm{E}_t(\pi_{t+n,n}) - \mathrm{E}_t(\pi_{t+1})$, and $\varphi_{t,n}$, respectively, implied from model IV^C. This is done using the equation:

$$1 = \frac{\mathrm{var}(y_t^n - y_t^1, y_t^n - y_t^1)}{\mathrm{var}(y_t^n - y_t^1)} = \frac{\mathrm{cov}(\hat{y}_t^n - \hat{r}_t, y_t^n - y_t^1) + \mathrm{cov}(\mathrm{E}_t(\pi_{t+n,n}) - \mathrm{E}_t(\pi_{t+1}), y_t^n - y_t^1) + \mathrm{cov}(\varphi_{t,n}, y_t^n - y_t^1)}{\mathrm{var}(y_t^n - y_t^1)}.$$

Standard errors reported in parentheses are computed using the delta method on population moments.

Panel A: Unconditional

Maturity Qtrs	Real Rates	Expected Inflation	Inflation Risk
4	0.44	0.56	−0.01
	(0.15)	(0.15)	(0.00)
20	0.19	0.85	−0.05
	(0.18)	(0.18)	(0.02)

Panel B: Conditional on Regime

Maturity Qtrs	Real Rates	Expected Inflation	Inflation Risk	Real Rates	Expected Inflation	Inflation Risk
	Regime $s_t = 1$			Regime $s_t = 2$		
4	0.14	0.87	−0.01	0.08	0.93	−0.01
	(0.19)	(0.19)	(0.00)	(0.22)	(0.22)	(0.00)
20	0.04	1.03	−0.08	−0.02	1.07	−0.05
	(0.20)	(0.20)	(0.03)	(0.22)	(0.22)	(0.03)
	Regime $s_t = 3$			Regime $s_t = 4$		
4	0.69	0.32	−0.00	0.64	0.36	−0.00
	(0.12)	(0.12)	(0.00)	(0.13)	(0.13)	(0.00)
20	0.31	0.71	−0.02	0.29	0.73	−0.02
	(0.16)	(0.16)	(0.01)	(0.17)	(0.17)	(0.01)

(1981)). The single-regime model I_w attributes even less of the variance of long-term yields to inflation components: At a 20-quarter maturity, variation in real yields accounts for 37% of movements in nominal rates compared to 28% at a 1-quarter maturity. This may be caused by the poor match of inflation dynamics using an affine model calibrated to inflation data. Pennachi's (1991) affine model identifies expected inflation from survey data and finds that expected inflation and inflation risk show little variation across horizons. Table X also reports that the inflation risk premium accounts for 10% of the variance of a 20-quarter maturity nominal yield.

In Table XI, we decompose the variation of nominal term spreads into real rate, expected inflation, and inflation risk premium components. Unconditionally, inflation components account for 55% of the 4-quarter term spread and 80% of the 20-quarter term spread variance. For term spreads, inflation shocks only dominate at the long end of the yield curve. In the regimes with relatively stable real rates (regimes 1 and 2), inflation components account for over 100%

of the variance of long-term spreads. In regimes 3 and 4, real rates are more volatile, and expected inflation accounts for approximately 35% of the variation in the 4-quarter term spread, increasing to over 70% for the 20-quarter term spread. Hence, the conventional wisdom that inflation is more important for the long end of the yield curve holds, not for the level of yields, but for term spreads:

CLAIM 7: *Inflation compensation is the main determinant of nominal interest rate spreads at long horizons*.

The intuition behind this result is that the long and short ends of nominal yields have large exposure to common factors, including the factors driving inflation and inflation risk. It is only after controlling for an average effect, or by computing a term spread, that we can observe relative differences at different parts of the yield curve. Thus, only after computing the term spread do we isolate the factors that differentially affect long yields controlling for the short rate exposure. The finding that inflation components are the main driver of term spreads is not dependent on having regimes in the term structure model. Mishkin (1990, 1992) finds consistent evidence with simple regressions using inflation changes and term spreads, as do Ang, Dong, and Piazzesi (2006) in a single-regime affine model. In model I_w, the attribution of the unconditional variance of the 20-quarter term spread to inflation is also close to 100%.

IV. Conclusion

In this article, we develop a term structure model that embeds regime switches in both real and nominal factors, and incorporates time-varying prices of risk. The model that provides the best fit with the data has correlated regimes coming from separate real factor and inflation sources.

We find that the real rate curve is fairly flat but slightly humped, with an average real rate of around 1.3%. The real short rate has an unconditional variability of 1.46% and has an autocorrelation of 60%. In some regimes, the real rate curve is downward sloping. In these regimes, expected inflation is low. The term structure of inflation compensation, the difference between nominal and real yields, is upward sloping. This is due to an upward-sloping inflation risk premium, which is unconditionally 1.14% on average. We find that expected inflation and inflation risk account for 80% of the variation in nominal yields at both short and long maturities. However, nominal term spreads are primarily driven by changes in expected inflation, particularly during normal times.

It is interesting to note that our results are qualitatively consistent with Roll's (2004) analysis on TIPS data, over the very short sample period since TIPS began trading. Consistent with our results, Roll also finds that the nominal yield curve is more steeply sloped than the real curve, which is also mostly flat over our overlapping sample periods. Roll also shows direct evidence of an inflation premium that increases with maturity.

Our work here is only the beginning of a research agenda. In future work, we could use our model to link the often-discussed deviations from the Expectations Hypothesis (see, for example, Campbell and Shiller (1991)) to deviations from the Fisher Hypothesis (Mishkin (1992)). Although we have made one step in the direction of identifying the economic sources of regime switches in interest rates, more could be done. In particular, a more explicit examination of the role of business cycle variation and changes in monetary policy as sources of the regime switches is an interesting topic for further research.

Appendix A. Real Bond Prices

Let N_1 be the number of unobserved state variables in the model ($N_1 = 3$ for the stochastic inflation model, $N_1 = 2$ otherwise) and $N = N_1 + 1$ be the total number of factors, including inflation. The following proposition describes how our model implies closed-form real bond prices.

PROPOSITION A: *Let $X_t = (q_t\ f_t\ \pi_t)'$ or $X_t = (q_t\ f_t\ w_t\ \pi_t)'$ follow (2), with the real short rate (4) and real pricing kernel (5) with prices of risk (6). The regimes s_t follow a Markov chain with transition probability matrix $\Pi = \{p_{ij}\}$. Then the real zero-coupon bond price for period n conditional on regime i, $\widehat{P}_t^n(s_t = i)$, is given by*

$$\widehat{P}_t^n(i) = \exp(\widehat{A}_n(i) + \widehat{B}_n X_t). \tag{A1}$$

The scalar $\widehat{A}_n(i)$ is dependent on regime $s_t = i$ and $\widehat{B}_n$ is a $1 \times N$ vector that is partitioned as $\widehat{B}_n = [\widehat{B}_{nq}\ \widehat{B}_{nx}]$, where $\widehat{B}_{nq}$ corresponds to the q variable and $\widehat{B}_{nx}$ corresponds to the other variables in X_t. The coefficients $\widehat{A}_n(i)$ and $\widehat{B}_n$ are given by

$$\begin{aligned}\widehat{A}_{n+1}(i) &= -\left(\delta_0 + \widehat{B}'_{nq}\sigma_q\gamma_0\right) + \log\sum_j p_{ij}\exp\Bigg(\widehat{A}_n(j) + \widehat{B}_n\mu(j) \\ &\qquad -\widehat{B}_{nx}\Sigma_x(j)\lambda(j) + \frac{1}{2}\widehat{B}_n\Sigma(j)\Sigma(j)'\widehat{B}'_n\Bigg) \\ \widehat{B}_{n+1} &= -\delta'_1 + \widehat{B}_n\Phi - \widehat{B}_{nq}\sigma_q\gamma_1 e'_1,\end{aligned} \tag{A2}$$

where e_i denotes a vector of zeros with a "1" in the ith place and $\Sigma_x(i)$ refers to the lower $N_1 \times N_1$ matrix of $\Sigma(i)$ corresponding to the non-q_t variables in X_t. The starting values for $\widehat{A}_n(i)$ and $\widehat{B}_n$ are

$$\begin{aligned}\widehat{A}_1(i) &= -\delta_0 \\ \widehat{B}_1 &= -\delta'_1.\end{aligned} \tag{A3}$$

Proof: We first derive the initial values in (A3):

$$\begin{aligned} P_t^1(i) &= \textstyle\sum_j p_{ij} \mathrm{E}_t \left[\widehat{M}_{t+1} | S_{t+1} = j \right] \\ &= \sum_j p_{ij} \exp\left(-r_t - \frac{1}{2} \lambda_t(j)' \lambda_t(j) - \lambda_t(j)' \varepsilon_{t+1} \right) \\ &= \exp\left(-\delta_0 - \delta_1' X_t \right). \end{aligned} \tag{A4}$$

Hence,

$$\widehat{P}_t^1(i) = \exp(\widehat{A}_1(i) + \widehat{B}_1 X_t),$$

where $A_1(i)$ and B_1 take the form in (A3).

We prove the recursion (A2) by induction. We assume that (A1) holds for maturity n and examine $\widehat{P}_t^{n+1}(i)$:

$$\begin{aligned} \widehat{P}_t^{n+1}(i) &= \sum_j p_{ij} \mathrm{E}_t \exp\left[-r_t - \frac{1}{2} \lambda_t(j)' \lambda_t(j) - \lambda_t(j)' \varepsilon_{t+1} + \widehat{A}_n(j) + \widehat{B}_n X_{t+1} \right], \\ &= \sum_j p_{ij} \mathrm{E}_t \exp\left[-\delta_0 - \delta_1' X_t - \frac{1}{2} \lambda_t(j)' \lambda_t(j) - \lambda_t(j)' \varepsilon_{t+1} + \widehat{A}_n(j) \right. \\ &\quad \left. + \widehat{B}_n \left(\mu(j) + \Phi X_t + \Sigma(j) \varepsilon_{t+1} \right) \right]. \end{aligned} \tag{A5}$$

Evaluating the expectation, we have

$$\begin{aligned} \widehat{P}_t^{n+1}(i) &= \sum_j p_{ij} \exp\left[-\delta_0 - \delta_1' X_t - \frac{1}{2} \lambda_t(j)' \lambda_t(j) + \widehat{A}_n(j) + \widehat{B}_n \mu(j) \right. \\ &\quad \left. + \widehat{B}_n \Phi X_t + \frac{1}{2} \left(\widehat{B}_n \Sigma(j) - \lambda_t(j)' \right) \left(\widehat{B}_n \Sigma(j) - \lambda_t(j)' \right)' \right] \\ &= \exp\left[-\delta_0 + \left(\widehat{B}_n \Phi - \delta_1' \right) X_t \right] \\ &\quad \times \sum_j p_{ij} \exp\left[\widehat{A}_n(j) + \widehat{B}_n \mu(j) - \widehat{B}_n \Sigma(j) \lambda_t(j) + \frac{1}{2} \widehat{B}_n \Sigma(j) \Sigma(j) \widehat{B}_n' \right]. \end{aligned} \tag{A6}$$

But, we can write

$$\begin{aligned} \widehat{B}_n \Sigma(j) \lambda_t(j) &= [\widehat{B}_{nq} \ \widehat{B}_{nx}] \begin{bmatrix} \sigma_q \left(\gamma_0 + \gamma_1 e_1' X_t \right) \\ \Sigma_x(j) \lambda(j) \end{bmatrix} \\ &= \widehat{B}_{nq} \sigma_q \left(\gamma_0 + \gamma_1 e_1' X_t \right) + \widehat{B}_{nx} \Sigma_x(j) \lambda(j). \end{aligned} \tag{A7}$$

Expanding and collecting terms, we can then write

$$\widehat{P}_t^n(i) = \exp(\widehat{A}_n(i) + \widehat{B}_n X_t),$$

where $\widehat{A}_n(i)$ and $\widehat{B}_n$ take the form of (A2). Q.E.D.

Appendix B. Nominal Bond Prices

Following the notation of Appendix A, let N_1 be the number of unobserved state variables in the model ($N_1 = 3$ for the stochastic inflation model, $N_1 = 2$ otherwise) and $N = N_1 + 1$ be the total number of factors including inflation. The following proposition describes how our model implies closed-form nominal bond prices.

PROPOSITION B: *Let $X_t = (q_t\ f_t\ \pi_t)'$ or $X_t = (q_t\ f_t\ w_t\ \pi_t)'$ follow (2), with the real short rate (4) and real pricing kernel (5) with prices of risk (6). The regimes s_t follow a Markov chain with transition probability matrix $\Pi = \{p_{ij}\}$. Then the nominal zero-coupon bond price for period n conditional on regime i, P_t^n $(s_t = i)$, is given by:*

$$P_t^n(i) = \exp(A_n(i) + B_n X_t), \tag{B1}$$

where the scalar $A_n(i)$ is dependent on regime $s_t = i$ and B_n is an $N \times 1$ vector:

$$\begin{aligned} A_{n+1}(i) &= -\left(\delta_0 + B'_{nq}\sigma_q\gamma_0\right) + \log\sum_j p_{ij}\exp\Big(A_n(j) + \left(B_n - e'_N\right)\mu(j) \\ &\quad - \left(B_{nx} - e'_{N_1}\right)\Sigma_x(j)\lambda(j) + \frac{1}{2}\left(B_n - e'_N\right)\Sigma(j)\Sigma(j)\left(B_n - e'_N\right)'\Big) \\ B_{n+1} &= -\delta'_1 + \left(B_n - e'_N\right)\Phi - B_{nq}\sigma_q\gamma_1 e'_1, \end{aligned} \tag{B2}$$

where e_i denotes a vector of zeros with a "1" in the ith place, $A(i)$ is a scalar dependent on regime $s_t = i$, B_n is a row vector, which is partitioned as $B_n = [B_{nq}\ B_{nx}]$, where B_{nq} corresponds to the q variable, and $\Sigma_x(i)$ refers to the lower $N_1 \times N_1$ matrix of $\Sigma(i)$ corresponding to the non-q_t variables in X_t. The starting values for $A_n(i)$ and B_n are

$$\begin{aligned} A_1(i) &= -\delta_0 + \log\sum_j p_{ij}\exp\left(-e'_N\mu(j) + \frac{1}{2}e'_N\Sigma(j)\Sigma(j)'e_N + e'_{N_1}\Sigma_x(j)\lambda(j)\right) \\ B_1 &= -\left(\delta'_1 + e'_N\Phi\right). \end{aligned} \tag{B3}$$

Proof: We first derive the initial values (B3) by directly evaluating

$$\begin{aligned} P_t^1(i) &= \sum_j p_{ij}E_t\left[\widehat{M}_{t+1}|S_{t+1} = j\right] \\ &= \sum_j p_{ij}\exp\Big(-r_t - \frac{1}{2}\lambda_t(j)'\lambda_t(j) - \lambda_t(j)'\varepsilon_{t+1} - e'_N\left(\mu(j)\right. \\ &\quad \left. + \Phi X_t + \Sigma(j)\varepsilon_{t+1}\right)\Big) \\ &= \exp\left(-\delta_0 - \delta'_1 X_t - e'_N\Phi X_t\right) \\ &\quad \times \sum_j p_{ij}\exp\left(-e'_N\mu(j) - e'_N\Sigma(j)\varepsilon_{t+1} - \frac{1}{2}\lambda_t(j)'\lambda_t(j) - \lambda_t(j)'\varepsilon_{t+1}\right) \\ &= \exp\left(-\delta_0 - \delta'_1 X_t - e'_N\Phi X_t\right) \\ &\quad \times \sum_j p_{ij}\exp\left(-e'_N\mu(j) + \frac{1}{2}e'_N\Sigma(j)\Sigma(j)'e_N + e'_N\Sigma(j)\lambda_t(j)\right). \end{aligned} \tag{B4}$$

Note that $e'_N \Sigma(j)\lambda_t(j) = e'_{N_1}\Sigma_x(j)\lambda(j)$. Hence

$$P_t^1(i) = \exp\left(A_1(i) + B_1 X_t\right),$$

where $A_1(i)$ and B_1 are given by (B3).

To prove the general recursion we use proof by induction:

$$\begin{aligned}
P_t^{n+1}(i) &= \sum_j p_{ij} E_t\Big[\exp\Big(-r_t - \frac{1}{2}\lambda_t(j)'\lambda_t(j) - \lambda_t(j)'\varepsilon_{t+1} - e'_N X_{t+1}\Big) \\
&\qquad \exp\left(A_n(j) + B_n X_{t+1}\right)\Big] \\
&= \sum_j p_{ij} E_t\Big[\exp\Big(-\delta_0 - \delta_1' X_t - \frac{1}{2}\lambda_t(j)'\lambda_t(j) - \lambda_t(j)'\varepsilon_{t+1} + A_n(j) \\
&\qquad + \left(B_n - e'_N\right)\left(\mu(j) + \Phi X_t + \Sigma(j)\varepsilon_{t+1}\right)\Big)\Big] \\
&= \sum_j p_{ij} \exp\Big(-\delta_0 - \delta_1' X_t - \frac{1}{2}\lambda_t(j)'\lambda_t(j) + A_n(j) + \left(B_n - e'_N\right)\mu(j) \\
&\qquad + \left(B_n - e'_N\right)\Phi X_t + \frac{1}{2}\left(\left(B_n - e'_N\right)\Sigma(j) - \lambda_t(j)'\right) \\
&\qquad \times \left(\left(B_n - e'_N\right)\Sigma(j) - \lambda_t(j)'\right)'\Big) \\
&= \exp\left(-\delta_0 + \left(\left(B_n - e'_N\right)\Phi - \delta_1'\right)X_t\right)\sum_j p_{ij}\exp\Big(A_n(j) + \left(B_n - e'_N\right)\mu(j) \\
&\qquad - \left(B_n - e'_N\right)\Sigma(j)\lambda_t(j) + \frac{1}{2}\left(B_n - e'_N\right)\Sigma(j)\Sigma(j)\left(B_n - e'_N\right)'\Big).
\end{aligned} \tag{B5}$$

Now note that

$$\begin{aligned}
\left(B_n - e'_N\right)\Sigma(j)\lambda_t(j) &= \left(B_n - e'_N\right)\begin{bmatrix}\sigma_q\left(\gamma_0 + \gamma_1 e_1' X_t\right) \\ \Sigma_x(j)\lambda(j)\end{bmatrix} \\
&= \begin{bmatrix} B_{nq} \\ B_{nx} - e'_{N_1}\end{bmatrix}\begin{bmatrix}\sigma_q\left(\gamma_0 + \gamma_1 e_1' X_t\right) \\ \Sigma_x(j)\lambda(j)\end{bmatrix} \\
&= B_{nq}\sigma_q\left(\gamma_0 + \gamma_1 e_1' X_t\right) + \left(B_{nx} - e'_{N_1}\right)\Sigma_x(j)\lambda(j),
\end{aligned} \tag{B6}$$

where $B_n = [B_{nq} \;\; B_{nx}]$.

Hence, collecting terms and substituting (B6) into (B5), we have:

$$P_t^{n+1}(i) = \exp\left[A_{n+1}(i) + B_{n+1}X_t\right],$$

where $A_n(i)$ and B_n are given by (B2). Q.E.D.

Appendix C. Likelihood Function and Identification

A. Likelihood Function

We specify the set of nominal yields without measurement error as $Y_{1t}(N_1 \times 1)$ and the remaining yields as $Y_{2t}(N_2 \times 1)$. There are as many yields measured without error as there are latent factors in X_t. The complete set of yields are denoted as $Y_t = (Y'_{1t}\, Y'_{2t})'$ with dimension $M \times 1$, where $M = N_1 + N_2$. Note that the total number of factors in X_t is $N = N_1 + 1$, since the last factor, inflation, is observable.

Given the expression for nominal yields in (11), the yields observed without error and inflation, $Z_t = (Y'_{1t}\, \pi_t)'$, take the form

$$Z_t = \mathcal{A}_1(s_t) + \mathcal{B}_1 X_t, \tag{C1}$$

$$\mathcal{A}_1(s_t) = \begin{bmatrix} \mathcal{A}_n(s_t) \\ 0 \end{bmatrix}, \qquad \mathcal{B}_1 = \begin{bmatrix} \mathcal{B}_n \\ e'_N \end{bmatrix}, \tag{C2}$$

where $\mathcal{A}_n(s_t)$ is the $N_1 \times 1$ vector stacking the $-\ A_n(s_t)/n$ terms for the N_1 yields observed without error, and $\mathcal{B}_n$ is a $N_1 \times N$ matrix that stacks the $-$ B_n/n vectors for the two yields observed without error. Then we can invert for the unobservable factors:

$$X_t = \mathcal{B}^{-1}(Z_t - \mathcal{A}_1(s_t)). \tag{C3}$$

Substituting this into (C1) and using the dynamics of X_t in (2), we can write

$$Z_t = c(s_t, s_{t-1}) + \Psi Z_{t-1} + \Omega(s_t)\epsilon_t, \tag{C4}$$

where

$$\begin{aligned} c(s_t, s_{t-1}) &= \mathcal{A}_1(s_t) + \mathcal{B}_1 \mu(s_t) - \mathcal{B}_1 \Phi \mathcal{B}_1^{-1} \mathcal{A}_1(s_{t-1}) \\ \Psi &= \mathcal{B}_1 \Phi \mathcal{B}_1^{-1} \\ \Omega(s_t) &= \mathcal{B}_1 \Sigma(s_t). \end{aligned}$$

Note that our model implies an RS-VAR for the observable variables with complex cross-equation restrictions.

The yields Y_{2t} observed with error have the form

$$Y_{2t} = \mathcal{A}_2(s_t) + \mathcal{B}_2 X_t + u_t, \tag{C5}$$

where $\mathcal{A}_2$ and $\mathcal{B}_2(s_t)$ follow from Proposition B and u is the measurement error, $u_t \sim N(0, V)$, where V is a diagonal matrix. We can solve for u_t in equation (C5) using the inverted factor process (C3). We assume that u_t is uncorrelated with the errors ε_t in (2).

Following Hamilton (1994), we redefine the states s_t^* to count all combinations of s_t and s_{t-1}, with the corresponding redefined transition probabilities $p_{ij}^* =$

$p(s^*_{t+1} = i \mid s^*_t = j)$. We rewrite (C4) and (C5) as:

$$\begin{aligned} Z_t &= c(s^*_t) + \Psi Z_{t-1} + \Omega(s^*_t)\epsilon_t, \\ Y_{2t} &= \mathcal{A}_2(s^*_t) + \mathcal{B}_2 X_t + u_t. \end{aligned} \tag{C6}$$

Now the standard Hamilton (1989, 1994) and Gray (1996) algorithms can be used to estimate the likelihood function. Since (C6) gives us the conditional distribution $f(\pi_t, Y^1_t \mid s^*_t = i, I_{t-1})$, we can write the likelihood as:

$$\begin{aligned} \mathcal{L} &= \prod_t \sum_{s^*_t} f(\pi_t, Y_{1t}, Y_{2t} \mid s^*_t, I_{t-1}) Pr(s^*_t \mid I_{t-1}) \\ &= \prod_t \sum_{s^*_t} f(Z_t \mid s^*_t, I_{t-1}) f(Y_{2t} \mid \pi_t, Y_{1t}, s^*_t, I_{t-1}) Pr(s^*_t \mid I_{t-1}), \end{aligned} \tag{C7}$$

where

$$\begin{aligned} f(Z_t \mid s^*_t, I_{t-1}) &= (2\pi)^{-(N_1+1)/2} |\Omega(s^*_t)\Omega(s^*_t)'|^{-1/2} \\ &\quad \exp\left(-\frac{1}{2}(Z_t - c(s^*_t) - \Psi Z_{t-1})'[\Omega(s^*_t)\Omega(s^*_t)\prime]^{-1}(Y_{2t} - c(s^*_t) - \Psi Z_{t-1})\right) \end{aligned}$$

is the probability density function of Z_t conditional on s^*_t and

$$\begin{aligned} & f(Y_{2t} \mid \pi_t, Y_{1t}, s^*_t, I_{t-1}) \\ &\quad = (2\pi)^{-N_2/2} |V|^{-1/2} \exp\left(-\frac{1}{2}(Y_{2t} - \mathcal{A}_2(s^*_t) - \mathcal{B}_2 X_t)' V^{-1} (Y_{2t} - \mathcal{A}_2(s^*_t) - \mathcal{B}_2 X_t)\right) \end{aligned}$$

is the probability density function of the measurement errors conditional on s^*_t.

The ex ante probability $Pr(s^*_t = i \mid I_{t-1})$ is given by

$$Pr(s^*_t = i \mid I_{t-1}) = \sum_j p^*_{ji} Pr(s^*_{t-1} = j \mid I_{t-1}), \tag{C8}$$

which is updated using

$$\begin{aligned} Pr(s^*_t = j \mid I_t) &= \frac{f(Z_t, s^*_t = j \mid I_{t-1})}{f(Z_t \mid I_{t-1})} \\ &= \frac{f(Z_t \mid s^*_t = j, I_{t-1}) Pr(s^*_t = j \mid I_{t-1})}{\sum_k f(Z_t \mid s^*_t = k, I_{t-1}) Pr(s^*_t = k \mid I_{t-1})}. \end{aligned}$$

An alternative way to derive the likelihood function is to substitute (C3) into (C5). We then obtain an RS-VAR with complex cross-equation restrictions for all variables in the system $(Z_t{}' \, Y_{2t}{}')'$. Note that unlike a standard affine model, the likelihood is not simply the likelihood of the yields measured without error multiplied by the likelihood of the measurement errors. Instead, the regime variables must be integrated out of the likelihood function.

B. Identification

There are two identification problems. First, there are the usual identification conditions that must be imposed to estimate a model with latent variables, which have been derived for affine models by Dai and Singleton (2000). In a single-regime Gaussian model, Dai and Singleton show that identification can be accomplished by setting the conditional covariance to be a diagonal matrix and letting the correlations enter through the feedback matrix (Φ), which is parameterized to be lower triangular, which we do here.

The RS model complicates identification relative to an affine model. The parameterization in equations (2) to (7) already imposes some of the Dai and Singleton (2000) conditions, but some further restrictions are necessary. Since q_t and f_t are latent variables, they can be arbitrarily scaled. We set $\delta_1 = (\delta_q\, \delta_f\, \delta_\pi)' = (1\,1\,\delta_\pi)'$ in (4). Setting δ_q and δ_f to be constants allows σ_q and $\sigma_f(s_{t+1})$ to be estimated. Because q_t is an unobserved variable, estimating μ_q in (3) is equivalent to allowing γ_0 in (6) or δ_0 in (4) to be nonzero. Hence, q_t must have zero mean for identification. Therefore, we set $\mu_q = 0$, since q_t does not switch regimes. Similarly, because we estimate $\lambda_f(s_{t+1})$, we constrain f_t to have zero mean.

The resulting model is theoretically identified from the data, but it is well known that some parameters that are identified in theory can be very hard to estimate in small samples. This is especially true for price of risk parameters. Because we are using four nominal yields, we should be able to identify all three prices of risk. However, Dai and Singleton (2000) note that it is typically difficult to identify more than one constant price of risk. Hence, we set $\gamma_0 = 0$ in (6) and instead estimate the RS price of risk $\lambda_f(s_{t+1})$.

We also set $\Phi_{fq} = 0$ in equation (3). With this restriction, there are, in addition to inflation factors, two separate and easily identifiable sources of variation in interest rates: An RS factor and a time-varying price of risk factor. Identifying their relative contribution to interest rate dynamics becomes easy with this restriction and it is not immediately clear how a nonzero coefficient would help enrich the model.

As q_t and f_t are zero mean, the mean level of the real short rate in (4) is determined by the mean level of inflation multiplied by δ_π and the constant term δ_0. We set δ_0 to match the mean of the nominal short rate in the data, similar to Ang et al. (2006) and Dai et al. (2006).

Finally, we set the one-period price of inflation risk equal to zero, $\lambda_\pi(s_{t+1}) = 0$. Theoretically, this parameter is uniquely identified, but in practice the average level of real rates and the premium is largely indeterminate without further restrictions. It turns out that the first-order effect of λ_π on real rates and the inflation risk premium is similar and of opposite sign. Because of this, the parameter is not only hard to pin down, but also essentially prevents the identification of the average level of real rates and the average level of the inflation risk premium. Models with a positive one-period inflation risk premium will imply lower real rates and higher inflation premiums than the results we report.

Appendix D. A Regime-Switching Model with Stochastic Expected Inflation

In a final extension, motivated by the ARMA-model literature (see Fama and Gibbons (1982), Hamilton (1985)), we allow inflation to be composed of a stochastic expected inflation term plus a random shock:

$$\pi_{t+1} = w_t + \sigma_\pi \varepsilon^{\pi}_{t+1}, \qquad \text{Appendix D.}$$

where $w_t = \mathrm{E}_t\,[\pi_{t+1}]$ is the one-period-ahead expectation of future inflation. This can be accomplished in our framework by expanding the state variables to $X_t = (q_t\ f_t\ w_t\ \pi_t)'$, which follow the dynamics of equation (2), except now:

$$\mu(s_t) = \begin{bmatrix} \mu_q \\ \mu_f(s_t) \\ \mu_w(s_t) \\ 0 \end{bmatrix}, \quad \Phi = \begin{bmatrix} \Phi_{qq} & 0 & 0 & 0 \\ \Phi_{fq} & \Phi_{ff} & 0 & 0 \\ \Phi_{wq} & \Phi_{wf} & \Phi_{ww} & \Phi_{w\pi} \\ 0 & 0 & 1 & 0 \end{bmatrix}, \tag{D1}$$

and $\Sigma(s_t)$ is a diagonal matrix with $(\sigma_q\ \sigma_f(s_t)\sigma_w(s_t)\sigma_\pi(s_t))'$ on the diagonal. Note that both the variance of inflation and the process of expected inflation are regime-dependent. Moreover, past inflation affects current expected inflation through $\Phi_{w\pi}$.

The real short rate and the regime transition probabilities are the same as in the benchmark model. The real pricing kernel also takes the same form as (5) with one difference: The regime-dependent part of the prices of risk in equation (6) is now given by

$$\lambda(i) = (\lambda_f(i)\ \lambda_w(i)\ \lambda_\pi(i))',$$

but we set $\lambda_w(i) = 0$ for identification.

Appendix E. Specification Tests

A. Moment Tests

To enable comparison across several nonnested models of how the moments implied from various models compare to the data, we introduce the point statistic:

$$H = (h - \bar{h})' \Sigma_h^{-1} (h - \bar{h}), \tag{E1}$$

where $\bar{h}$ are sample estimates of unconditional moments, h are the unconditional moments from the estimated model, and Σ_h is the covariance matrix of the sample estimates of the unconditional moments, estimated by GMM with four Newey and West (1987) lags. In this comparison, the moments implied by various models are compared to the data, with the data sampling error Σ_h held constant across the models. The moments we consider are the first and second moments of term spreads and long yields, the first and second moments of inflation, the autocorrelogram of term spreads, and the autocorrelogram of inflation.

Equation (E1) ignores the sampling error of the moments of the model, implied by the uncertainty in the parameter estimates, making our moment test informal. However, this allows the same weighting matrix, computed from the data, to be used across different models. If parameter uncertainty is also taken into account, we might fail to reject, not because the model accurately pins down the moments, but because of the large uncertainty in estimating the model parameters.

B. Residual Tests

We report two tests on in-sample scaled residuals ϵ_t of yields and inflation. The scaled residuals ϵ_t are not the same as the shocks ε_t in (2). For a variable x_t, the scaled residual is given by $\epsilon_t = (x_t - \mathrm{E}_{t-1}(x_t))/\sqrt{\mathrm{var}_{t-1}(x_t)}$, where x_t are yields or inflation. The conditional moments are computed using our RS model and involve ex ante probabilities $p(s_t = i | I_{t-1})$. Following Bekaert and Harvey (1997), we use a GMM test for serial correlation in scaled residuals ϵ_t:

$$E[\epsilon_t \, \epsilon_{t-1}] = 0. \tag{E2}$$

We also test for serial correlation in the second moments of the scaled residuals:

$$E\left[(\epsilon_t^2 - 1)(\epsilon_{t-1}^2 - 1)\right] = 0. \tag{E3}$$

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Breaking the Break-even Inflation Rate[1]

The break-even inflation rate (BEIR) or implied inflation rate, is usually defined as the difference between nominal and real interest rates of securities with similar characteristics. Although it is commonly related to expected inflation – according to Fisher's hypothesis (1930) – BEIR is composed by other factors.

Among these factors, we have the uncertainty related to: (i) risk premium associated with inflation future path, which is equivalent to the additional remuneration that agents require to compensate for the risk of the realized inflation differ from the expected inflation; and (ii) liquidity premium, defined as the reward due to the difficulty to change a position in illiquidity securities (in the case at hand, real bonds). In addition to these risk premia, a third factor entails the difference between nominal and real interest rates, (iii) the convexity bias[2], which represents the difference between the implied inflation and inflation expectation in a risk neutral world.

Therefore, the difference between nominal and real interest rates can be decomposed from market price data – though its components are not observable – so that the implied inflation is given by:

Implied Inflation = Nominal rate - Real Rate = Inflation Expectation + Inflation Risk Premium - Liquidity Premium + Convexity.

Given the importance of the issue to understanding the evolution of expectations and price dynamics, this box uses a pricing model based on consumption that allows the decomposition of the difference between nominal and real interest rates on expectations and premia. Nominal rates are obtained from the National Treasury Bills

1/ This box is based on Vicente and Graminho (2014).

2/ The relation between bonds prices and rates is given by a convex function – the exponential relationship that connects bond prices with rates. Therefore, when taking the expected values of this function, we need to make a correction, due to the Jensen's inequality which may be stated as: let f be a convex function and X a random variable. Then $E[f(X)]>f(E[X])$, where E[.] represents the expected value.

(LTN) and National Treasury Notes, Series F (NTN-F). Real rates are taken from the National Treasury Notes, Series B (NTN-B), which are securities indexed to the Broad National Consumer Price Index (IPCA). The sample covers the period between January 2006 and September 2013, and the rates are for the horizons of 1, 2, 3 and 4 years, interpolated via parametric model of Svensson (1994).

Figure 1 – Break-even inflation rate

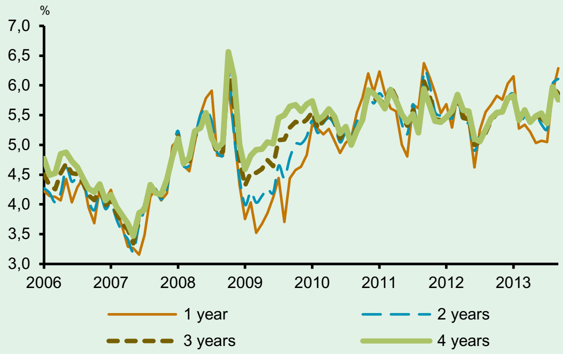


Figure 2 – Inflation expectations

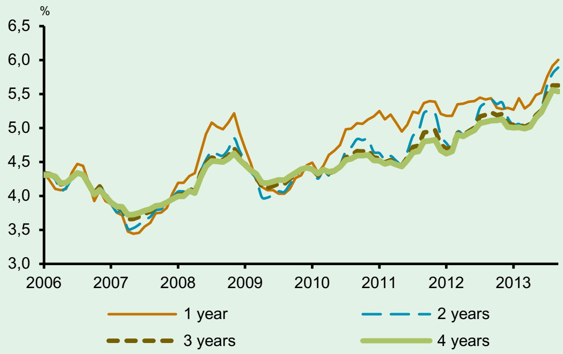


Figure 1 shows the daily evolution of the difference between nominal and real rates for horizons of 1, 2, 3 and 4 years between January 2006 and September 2013. During this period, the difference between the nominal and real interest rates orbited around an average of 5% p.a., with a minimum of 3% p.a. in July 2007 and maximum of more than 6% p.a. in the second half of 2008.

Inflation expectations shown in Figure 2 are obtained by the construction of the term structure via flat forward interpolation. The monthly inflation expectations are extracted from the Focus survey conducted by the Banco Central do Brasil's Investor Relations and Special Studies Department (Gerin). For horizons of 2, 3 and 4 years the expectations are calculated assuming constant inflation in months not informed.

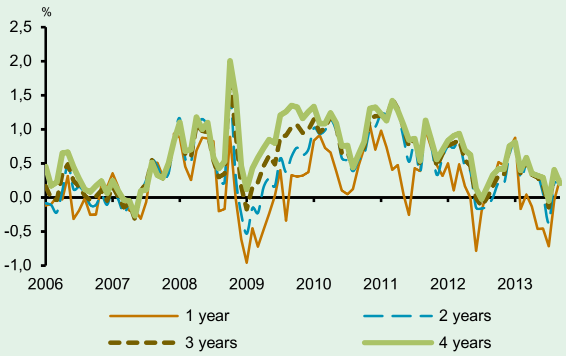
The convexity bias, derived from the relationship between prices and bonds under certain hypothesis, is calculated as the variance of inflation[3], using an autoregressive process of order 1 (AR (1)) to model the monthly percentage change in the IPCA. As a result, we obtained values close to one basis point (b.p.) for the horizons 1-4 years, similar to the results found by Ang, Bekaert and Wei (2008) for the US market. Thus, the convexity bias presents little relevance when compared to the average bid-ask spread[4] of the NTN-F and LTN, which is close to 3 b.p., and NTN-B, which is about 10 b.p.

The liquidity premium is computed following Pflueger and Viceira (2013), who estimate a model of the difference between nominal and real interest rates on measures of bond liquidity, controlling for the Focus inflation expectation. We used three liquidity measures: the first is based on the average turnover of bonds and

3/ For this result, there must be no arbitrage and the real stochastic discount factor and the price index are conditionally lognormal variables. Without the assumption of log normality, this relationship is valid until the second order approximation. For details, see Vicente and Graminho (2014).

4/ Estimates of average spreads were obtained based on data provided by ANBIMA. ANBIMA collects every day at 11 AM buying and selling offers consists on the difference between the turnover of real and nominal bonds, as a proportion of the negotiated bonds; the second captures differences between the buying and selling spreads of nominal and real bonds; and the third follows Hu, Pang and Wang (2013), who define illiquidity as the root mean squared error of bonds prices relative to an interpolated yield curve via the Svensson (1994) model. Evidences indicate that the liquidity difference between the assets is ignored by investors, that is, liquidity premium is not statistically different from zero[5].

Figure 3 – Inflation risk premium



The inflation risk premium (Figure 3) is obtained by simple difference, once the other implicit inflation components are estimated.

The inflation risk premium is positive in most of the sample, that is, nominal bonds positively covary with the economy. Therefore, investors require an additional premium in order to invest in nominal securities. For short horizons, the risk premium is negative in few months, being associated with times of increased volatility in financial markets, as in late 2008 and early 2009.

In order to capture the relative importance of components of the difference between nominal and real interest rates, we estimated a model of BEIR (minus the constant convexity) as a function of Focus inflation expectation; liquidity metrics mentioned above; the covariance of future inflation and changes in consumption; and the volatility of Ibovespa (proxy for uncertainty in the economy). Confirming the previous result, liquidity metrics do not show significant results and the variables that influence the inflation risk premium are significant only for the horizons of 3 and 4 years. The linear coefficient is not significant. On the other hand, the coefficient of inflation expectation is not statistically different from one in all regressions, which is an evidence that agents consider inflation forecasts close to Focus expectation when making their investment decisions.

Therefore, although the Fisher hypothesis is incomplete, by observing the difference between nominal and real

5/ Although apparently counterintuitive, this result may be explained by the prefereces of investor in the fixed income market. As Carvalho and Morais (2009) point, NTN-Bs are bonds which are strongly demanded by long term investor and who in general hold these bonds to maturity, which makes the uncertainty regarding lack of liquidity irrelevant.

interest rates is possible to extract information about the future price level, which is relevant input for the formulation and implementation of monetary policy.

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A TIPS Scorecard: Are They Accomplishing Their Objectives?

Michelle L. Barnes, Zvi Bodie, Robert K. Triest, and J. Christina Wang

Treasury Inflation-Protected Securities were developed to provide (1) consumers with assets that permit hedging against real interest rate risk, (2) nominal contract holders a means of hedging against inflation risk, and (3) everyone with an indicator of the term structure of expected inflation. This article evaluates progress toward these objectives.

When the U.S. Treasury introduced TIPS (Treasury Inflation-Protected Securities) in 1997, they were designed to achieve three major policy objectives. The first objective was to provide consumers with a class of assets that allows them to hedge against real interest rate risk. This objective required a term structure of default-free bonds denominated in consumption units. The second objective was to provide holders of nominal contracts with a way to hedge against inflation risk. This objective required a term structure of default-free forward contracts pegged to the U.S. Consumer Price Index (CPI). The third objective was to provide everyone with a reliable indicator of the term structure of expected inflation. In our study, we examined the extent to which these objectives have been achieved and sought to identify ways whereby they can be better achieved in the future, including the use of various inflation indices (e.g., those more closely matched with particular geographic regions or demographics) and extending the maturity of TIPS.

The viability of the TIPS market hinges on whether these securities provide an effective hedge for most investors against unexpected changes in the real rate of interest arising from unexpected fluctuations in inflation. Such indexed bonds are designed to deliver, to the extent possible, a certain pretax real return to maturity. In the United States, these bonds are indexed to the CPI for all urban consumers (CPI-U). We focused on two important factors that may limit the ability of this class of securities to offer investors a complete hedge against unexpected changes in the real rate: (1) the possibility that the CPI may not be an appropriate index for all investors and (2) the potential for technical revisions to the measurement of the CPI, such as those recommended by the Boskin Commission (Boskin, Dulberger, Gordon, Griliches, and Jorgenson 1996) just before the initial auctioning of TIPS in January 1997. Both factors could engender inflation basis risk.[1] We did not address another widely known limiting factor—namely, that the CPI is not continuously measured and published, with the result that the indexation of these securities' nominal cash flows occurs with some lag.

During the summer of 2008, a spate of articles in the popular press decried the construction of the CPI with claims that the existing methodology underestimates true inflation. In an article in *Harper's Magazine*, Kevin Phillips went so far as to assert that the measure of inflation is subject to political influence and has been biased downward over time via methodological changes during presidential regimes.[2] Because these concerns speak to fundamental uncertainties regarding the ability of TIPS to offer an effective hedge against unexpected changes in the real rate, a few of these articles concluded, unsurprisingly, that TIPS are not good hedges against inflation as broadly experienced by investors.[3] Another criticism of TIPS is the observation that breakeven inflation rates—as implied by simultaneous consideration of the TIPS and nominal Treasury markets—often diverge substantially from survey measures of inflation expectations. Such mounting criticisms and concerns could jeopardize the viability of the TIPS market.

Michelle L. Barnes is a senior economist and policy advisor, Robert K. Triest is a vice president and economist, and J. Christina Wang is a senior economist at the Federal Reserve Bank of Boston. Zvi Bodie is the Norman and Adele Barron Professor of Management at Boston University.

Note: The views expressed in this article are solely those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Boston or the Federal Reserve System.

We evaluated these criticisms and, to the extent that they have any validity, assessed their implications for the efficacy of TIPS as a hedge against unexpected changes in the real rate of interest. In particular, we evaluated the criticisms concerning the accuracy of the CPI as a basis for measuring changes in the rate of inflation. In addition, given that heterogeneity exists across households, we tried to determine who benefits the most and the least from hedging with TIPS and whether long-term TIPS investors are better off than short-term investors. Moreover, we explored whether indexing TIPS to other inflation measures offers significant gains.[4] We also examined the divergence between inflation expectations as implied by breakeven inflation rates and survey measures of consumers' inflation expectations.

The Market for TIPS—How They Work, Who Uses Them, and How They Are Used

Indexed bonds, in general, and TIPS, in particular, are designed to provide a certain pretax real return. With TIPS, this objective is achieved by adjusting the principal for inflation—that is, multiplying the principal by an index ratio for accrued CPI inflation from the date of first issuance of the security.[5] For a particular date, this quantity is essentially the ratio of the three-month lagged CPI value at that date divided by the CPI value at the time of the first issuance of the security. The semiannual interest payment on TIPS is then calculated as this adjusted principal amount multiplied by half the fixed rate of interest determined at auction.[6] With respect to repayment of the principal, the Treasury also guarantees that the redemption of the principal will not be below the amount of principal originally invested, and so the principal is protected from declines in the CPI since the issuance date.[7] TIPS and nominal Treasuries are treated alike for tax purposes in that the compensation for inflation is taxed as interest income in both cases. Hence, the *ex ante* nominal tax burden is certain for nominal Treasuries but uncertain for TIPS, whose pretax nominal return is uncertain. The *ex ante* real tax burden, however, is uncertain for both TIPS and nominal Treasuries, although probably less uncertain for TIPS.[8]

Unfortunately, to our knowledge, no demographic information about the end consumers of TIPS is available because no such information is available from the secondary market and the Treasury's information regarding competitive auction winners is aggregated. But a number of studies are suggestive with respect to who TIPS holders are likely to be (see, e.g., Hammond 1999; Anderson 1999; Kinney 1999; Shelton 2000). These researchers have contended, for example, that TIPS are better suited to buy-and-hold investors than to frequent traders. They have recommended TIPS for investors who have retirement income not indexed to inflation. They have further reasoned that such investors as pension funds—or indeed any investor—that may need to match assets against liabilities in real terms are natural holders of TIPS.

The available aggregate data are somewhat supportive of such studies' claims regarding the demographics of likely TIPS owners. Various Treasury publications show that the distribution of competitive auction awards for TIPS, compared with that of their nominal counterparts, has a smaller share of awards allocated to primary dealers and a much higher share allocated to "investment funds" and "other."[9] **Table 1** gives the most recently available Department of the Treasury distribution of competitive awards for 10-year TIPS and 10-year nominal notes.[10] The table shows that for auctions between 2003:Q3 and 2004:Q2, the share of competitive awards to primary dealers was 54 percent for TIPS and 64 percent for the nominal equivalents. The share of TIPS competitive auction awards granted to "investment funds" was 31 percent, compared with just 10 percent for nominal Treasuries.[11]

In addition to providing a certain pretax inflation-adjusted return, TIPS are also useful for constructing financial market–based measures of "inflation compensation," or what is more commonly referred to as "breakeven inflation rates." Although there are a number of practical approaches for backing out the implied breakeven

Table 1. Distribution of Competitive Auction Awards for 10-Year Treasury Notes

	10-Year TIPS	10-Year Nominal Notes
Primary dealers	54%	64%
Investment funds	31	10
Foreign and international	7	22
Financial institutions	1	1
Other	8	3

Note: Data on 10-year TIPS are from July 2003, October 2003, January 2004, and April 2004; data on 10-year nominal notes are from November 2003, December 2003, February 2004, and March 2004.

Source: Bitsberger (2004). Similar charts are available in various issues of the Treasury's *Quarterly Refunding Charts & Data* series.

inflation rates by simultaneously considering nominal Treasuries and TIPS, one can think of the implied breakeven inflation rate as the nominal Treasury yield less the equivalent TIPS yield.[12] **Figure 1** abstracts from differential liquidity, tax, and convexity conditions in these two markets and shows simply how the nominal Treasury yield can be broken down into a TIPS part—the expected real rate plus a real rate risk premium—and the inflation compensation part, consisting of both expected inflation and the inflation risk premium. This diagram demonstrates that, because inflation compensation also includes an inflation risk premium, these measures of inflation compensation or breakeven inflation rates are not pure measures of "inflation expectations," despite the fact that some commentators use these terms interchangeably.

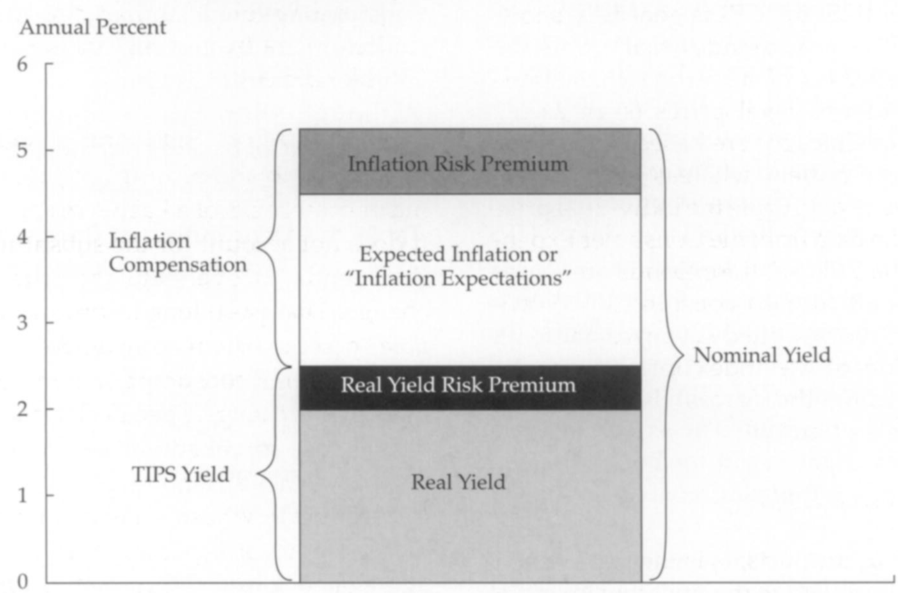
Differential liquidity premiums in nominal Treasury securities and TIPS, differences in their relative convexity, and differential *ex ante* uncertainty regarding tax payments are also, like the inflation risk premium, embedded in the breakeven inflation rate. So, also for these reasons, the breakeven inflation rate is not a pure measure of "inflation expectations."[13] Thus, even if we had a clean survey measure of consumers' inflation expectations, we could not expect the breakeven rate to be even close to perfectly correlated with such a measure. Of course, such a comparison is further complicated by the fact that the participants whose expectations are reflected in these measures may be different in the survey sample and in the financial market sample. In addition, it is not always clear what the expectations are measuring; for example, it probably is not the CPI-U NSA (nonseasonally adjusted) for every participant in the survey sample. For these various reasons, we also cannot expect the breakeven inflation rate—without adjustments for these different risk premiums—to be a good forecast of future inflation.

The CPI, Alternative Inflation Measures, and Hedging

The CPI—particularly the application of various index number methods for its construction—came under renewed and sometimes harsh criticism in 2008, especially during the months when oil prices spiked. We examined the CPI methodologies that are most subject to popular criticism: treatment of substitution bias, quality adjustments, and owners' equivalent rent.

We focused on the methodological choices of the Bureau of Labor Statistics (BLS) concerning these three aspects of price index construction and

Figure 1. Decomposition of the Nominal Yield into Inflation Compensation and the TIPS Yield



Note: This simplified depiction abstracts from differential liquidity premiums, convexity issues, and the relative uncertainty of future tax burdens.

the implications of these choices for hedging real returns against inflation risk—specifically for investors who hold TIPS to maturity and consume the coupon payment every period. That is, we ignored the random capital gain (loss) if TIPS are sold prior to maturity.[14] We found that, whatever bias may be in the CPI as an inflation measure, the optimal strategy for hedging against unexpected inflation fluctuations is unaltered, so long as the bias is time invariant. Rather, investors care about the time variations in the bias, which constitutes a basis risk for investors who want to hedge the real rate of return.[15] To the extent that this bias is correlated with the risk factors priced in the market, investors would demand a risk premium for bearing that risk; some would prefer to hedge that risk, given its prevailing market price. Either way, if this bias is perceived to be present and priced in the Treasury markets, then it is likely embedded in the inflation risk premium implied by the simultaneous consideration of nominal and real Treasury yields.[16]

We then considered the likely "basis risk" in using the CPI to hedge inflation risk. The further away a household's expenditure weights are from the average, the greater the basis risk because the CPI measures the price change of the average consumption bundle. Again, this risk would be priced and captured in the inflation risk premium. We then explored some alternative aggregate price indices.

An Index Methodology and Popular Criticisms of the CPI

Compiled by the BLS, the CPI is generally shorthand for the CPI-U, a price index that covers the out-of-pocket expenses of all urban consumers. The detailed item-area level prices (such as the price of apples in Chicago) are based on surveys conducted at retail outlets, whereas the expenditure weights used to aggregate the individual price series are based on data from the Consumer Expenditure Survey. The CPI uses the expenditure shares averaged across all (urban) consumers. By construction, the CPI is a modified Laspeyres index. A simplified version of the index formula can be illustrated by using the (gross) inflation rate between periods $t-1$ and t:[17]

$$\Pi_{t-1,t} = \sum_{i=1}^{N} p_t^i q_{t_0}^i \Big/ \sum_{i=1}^{N} p_{t-1}^i q_{t_0}^i . \qquad (1)$$

N is the number of products, t_0 is the base period for period t, and p^i and q^i are the price and quantity (serving as aggregation weight) for product i, respectively. Currently, the base year is updated every three years. The formula makes clear that, as with any Laspeyres index, the constituent individual price changes in the CPI are weighted by their share in the consumption bundle in the base period.

In 1997, the BLS embraced the Boskin Commission's recommendation that the CPI be constructed as a cost of living index. As such, it is intended to gauge how much the average consumer's income would need to change between two periods in order to keep pace with the overall cost of goods and services to enable the consumer to maintain the same standard of living in terms of satisfaction level (utility). So, the key here is that the consumer would be left no better or worse off, not that the consumer would necessarily be able to purchase the *same basket* of goods and services.

The methods adopted by the BLS to make the CPI a more accurate index for the cost of living have come under popular criticism from a number of perspectives. Three criticisms, each corresponding to a methodological choice, are potentially most relevant for hedging purposes. The first criticism concerns the way the CPI deals with likely upward biases in deflators arising from the substitution effect. The second argues against the use of hedonic models to adjust for product quality changes or even the whole concept of quality adjustment. The third touches on the subindex for the cost of housing. In the popular press, these adjustments are cited as contributing to understating CPI inflation, but the experts in price index methodology still contend that measured CPI inflation has an upward bias, even after these adjustments are made. We examined, in turn, the three primary criticisms leveled against the methodological choices made by the BLS in the construction of CPI-like indices.[18]

Substitution Bias and Chain Weighting. According to index number theory, one of the major drawbacks of a Laspeyres price index is that it does not account for the substitution effect and thus tends to overstate the true rate of price change. That is, so long as products are substitutable to some extent, consumers most likely will buy a different consumption bundle when the relative prices change. Specifically, consumers generally choose to substitute away from goods and services whose relative prices have risen and toward those whose relative prices have fallen. This tendency is especially relevant at highly disaggregated levels of product categories, such as breakfast cereals and carbonated soft drinks, where the cross-product elasticity of substitution is high. Thus, consumers can achieve the same level of utility without needing income to rise by the same percentage as the (weighted) price increase on the old consumption basket.

Index number theory suggests that the substitution bias is best mitigated by a "superlative" index, such as the chain-weighted personal consumption expenditures (PCE) deflator.[19] A key feature of superlative price indices is that the aggregation weights are updated in a timely manner to reflect changes in expenditure shares in the average consumption basket. The CPI has improved along this dimension: It now updates the base year with a lag of only 3 years, instead of an average of 11 years prior to 2002 (U.S. BLS 1999). Nevertheless, studies put the magnitude of the remaining "upper-level" positive bias arising from the Laspeyres formula at 0.1–0.4 percentage point per year.[20]

In addition, starting in January 1999, the BLS adopted the geometric mean formula for index categories that make up about 61 percent of total spending in the CPI,[21] which amounts to assuming unitary (instead of zero) elasticity of substitution across those products. This change is estimated to have reduced the upward bias of measured CPI inflation by about 0.2 percentage point.[22]

Quality Adjustments, New Products, and Hedonic Models. The other major complaint against the methodology of official price indices concerns quality adjustment—imputing and removing the portion of the change in a good's price that results from quality variations. That is, only price increases that are not the result of advances in a good's quality—broadly defined to encompass a wide array of attributes (from simple tangible ones, such as the weight of a bottle of water, to less visible ones, such as the clock speed of a CPU chip)—count as true price movements. The logic of this adjustment is straightforward: At the fundamental level, consumers derive utility from the desirable characteristics of each good or service, and changes in the number and level of such characteristics should thus alter the utility that consumers derive from the good.

The specific class of approaches to quality adjustment that has encountered the most vocal criticism is the class encompassing so-called hedonic models. These models are essentially a multivariate regression technique that isolates the value of a marginal change in a particular product characteristic. For our purposes, we focused on the quantitative impact of quality adjustments—in particular, those done with hedonic models.[23] The total CPI expenditure weight of products subject to hedonic adjustment is about 32 percent, of which 31 percentage points are accounted for by shelter and apparel (an adjustment in place for more than two decades) and the remainder by consumer durables (an adjustment introduced in 1998), such as personal computers, microwave ovens, and televisions. Ironically, criticisms of this adjustment notwithstanding, hedonic quality adjustment of housing units owing to aging *adds* about 0.2–0.3 percentage point per year to the inflation of shelter price.[24] Hedonic adjustments applied to consumer durables have had minimal impact on inflation—*increasing* the rate by 0.005 percentage point per year.[25]

Owners' Equivalent Rent, Shelter Cost, and House Prices. Criticism has also been directed at the way the CPI accounts for the price change of housing services, especially the component called the owners' equivalent rent (OER) for primary residences. Disapproval was especially widespread during the height of house-price appreciation in 2003–2005, as the OER decelerated—in fact, growing at its slowest pace since the mid-1980s.

This significant divergence in recent boom years between OER inflation and house-price appreciation, however, is unusual by historical standards. Between 1982 and 2002 (the OER series extends back only to 1982), the OER and the Federal Housing Finance Agency (FHFA) House Price Index were reasonably correlated in terms of growth rate ($\rho = 0.29$).[26] After 2003, the correlation between the two inflation rates fell to –0.18. So, both the OER component of the CPI and a hypothetical security indexed to the OER appear to be poor hedges for house prices, primarily during periods of house-price bubbles.

At a fundamental level, the discrepancy, or even extended divergence, in growth rates between house prices and the OER lies in the fact that the former concerns the investment aspect of housing whereas the latter concerns the consumption aspect. Unlike most other products in the CPI basket, real estate is also the primary vehicle for wealth accumulation for most households. Thus, the price of a house is analogous to the price of a stock; both are equal to the present discounted value of the income stream generated by a long-lived asset. In contrast, the OER is an application of the rental equivalence approach to capturing the opportunity cost of the *current-period services* generated by the (physical) housing capital and consumed by households.[27] As such, it follows the same principle as shelter cost for renters. This conceptual distinction between house prices and the OER suggests the desirability of providing separate financial instruments to enable households to hedge the risk of house-price fluctuations.

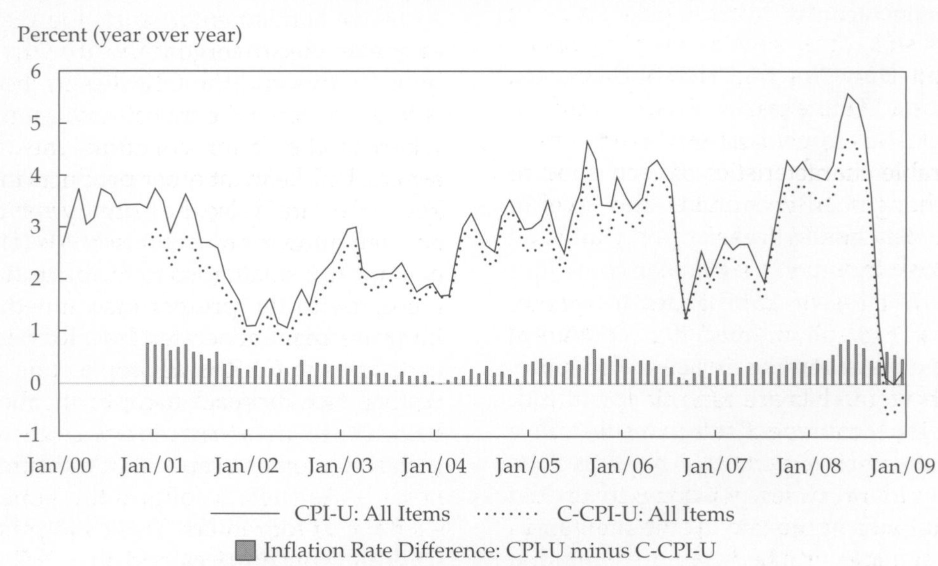
Systematic Risk of the CPI Bias and Implications for Hedging

Quite a few studies have estimated the impact of the methodological changes in the CPI following the Boskin Commission's report, as well as the remaining substitution bias—positive, on average—in the CPI. All these estimates, however, concern the average magnitude of bias over particular sample periods, in large part because of data limitations—any estimate of the bias in a particular month or quarter is surrounded by a high degree of uncertainty. For this reason, we urge the reader to interpret with caution the numerical estimates of likely time variations in the CPI biases that we present here. For TIPS investors who wish to obtain a certain real rate of return—that is, to hedge the risk of unexpected fluctuations in the true inflation rate—the presence of biases in the CPI does not pose a problem per se. If the CPI always overstates true inflation by x percent, then investors should just reduce the amount invested in TIPS by x percent, and vice versa. Only when the bias in the CPI is *time varying* does it constitute a basis risk. The more variable the cumulative bias in the CPI over a holding period, the more imperfect TIPS are as a hedge against true inflation.[28] Moreover, if this basis risk covaries with priced risk factors, investors will demand a return premium on TIPS.[29]

To gauge the substitution bias that may still be present in the CPI, our preferred proxy is the gap between the regular CPI and the chained CPI-U (C-CPI-U). The latter is constructed by using the same underlying micro-level price data as in the regular CPI and by also using chain weighting (at the upper level) to further reduce substitution bias.[30] The BLS started publishing the C-CPI-U in 2002, with data going back to December 1999. **Figure 2** shows that, as would be expected, the inflation rate as measured by the chained CPI-U tends to be lower than the rate as measured by the CPI; that is, the substitution bias is, on average, positive—0.38 percentage point per year, to be precise.[31] Our preferred proxy of the residual substitution bias is basically uncorrelated with the overall stock market, according to either the simple market model or the augmented model that includes the two Fama–French (1993) factors.[32] In short, little suggests that the bias in the CPI arising from each of the three arguably most prominent aspects of methodological choice, or the three combined, is correlated with the typical aggregate risk factors.

In summary, to the extent that these three biases dominate fluctuations in the biases in the CPI components, biases that may still be present in the CPI should matter little to investors who use TIPS to hedge return risk arising from the true inflation process. Again, we emphasize that investors care about *fluctuations* in CPI bias, not the bias per se, because the fluctuations introduce basis risk and prevent investors from perfectly hedging the true inflation risk.

Figure 2. Difference in Inflation Rates: Chained CPI-U vs. CPI-U



Source: Bureau of Labor Statistics.

Best Price Indices for Inflation Protection

We next examined the CPI with respect to heterogeneous consumption bundles and basis risk and also looked at the costs and benefits of price indices for subpopulations to ascertain whether there are better aggregate price indices for inflation hedging.

The CPI, Heterogeneous Consumption Bundles, and the Basis Risk. The CPI is an index number designed to measure the "average" price level experienced by the relevant population. That is, the weights used for aggregating price changes in the thousands of items covered by the CPI-U are the expenditure shares averaged across all urban consumers.[33] So, by design, the CPI does not correspond to the exact price changes experienced by any individual consumer, unless she consumes exactly the average basket of goods and services in every period.[34]

The existence of such deviations does not by itself render TIPS an imperfect instrument for hedging against inflation risk. Just as in the case of biases in the CPI, if the inflation rate on an individual's consumption bundle is constantly x percent higher (lower) than the CPI inflation, then the consumer should simply invest x percent more (less) in TIPS. Such a case, however, is unlikely to be realistic. Instead, the idiosyncratic inflation rate experienced by an individual consumer almost surely deviates from the average (i.e., the CPI) inflation rate in a time-varying manner. If this deviation is correlated with the relevant risk factor for that consumer, then, again, a basis risk arises when she uses TIPS to hedge against inflation risk.

Costs and Benefits of Price Indices for Subpopulations. The type of basis risk arising from heterogeneous consumption bundles is a form of market incompleteness. If there were no transaction costs (broadly defined), the government would ideally issue a separate bond, indexed to the price of a consumer's particular consumption bundle, so that he would be perfectly hedged. With the basis risk eliminated, the consumer would no longer demand the associated risk premium and thus would be willing to accept, all else being equal, a lower *real* rate of return on the tailor-made, inflation-protected bond. Therefore, the government could offer a lower average real yield on these bonds in the aggregate. At the same time, it would be paying the same amount of inflation compensation because the average of individual inflation rates equals the inflation rate of the average consumption basket.

In reality, however, making markets incurs nontrivial transaction costs, which encompass operational costs, search costs, and informational costs (owing to adverse selection). So, to the extent that investors in indexed bonds value market liquidity, issuing a large number of bonds indexed to individual-specific deflators may not be optimal. The optimal number of price indices to use should be determined according to the usual principle of equating the marginal benefit (equal to the consumer welfare gain from introducing a new bond indexed to an additional price deflator) to the marginal cost (equal to the welfare loss arising from the fall in market liquidity).

On the one hand, the literature on TIPS market liquidity suggests that—at least regarding the issuance volume to date—the marginal liquidity cost of introducing additional inflation-protected bonds may be somewhat modest, as evidenced mostly by the prevalence of two-sided quotes.[35] On the other hand, caution must be exercised in extrapolating the estimates of liquidity cost based on the additional issuance of bonds indexed to the same price deflator to a case where the new bonds would be indexed to different deflators. For instance, liquidity cost could be highly convex and rise significantly faster in the latter case as the market becomes segmented. In addition, compositional changes in the investor base could alter the liquidity cost function.

A related question is whether to expand the universe of issuers of inflation-protected real bonds. In particular, should state and local governments issue bonds indexed to the cost of living specific to their region? This outcome might raise social welfare, on net, by completing markets if the heterogeneity in inflation is driven more by components that differ along the geographic dimension (e.g., housing costs and, more generally, commodities that are difficult to trade, such as services) than by nongeographic factors. But such state and local bonds clearly suffer from diminished liquidity, as previously discussed. Experience in the existing market for municipal bonds can provide some guidance on the degree of liquidity demanded by typical investors in such instruments. Another factor to consider, as recent history has demonstrated, is that municipalities have credit risk that can be quite varied and is certainly greater than that of the Treasury.

Are There Better Aggregate Price Indices for Inflation Hedging? Are any of the other aggregate price indices better than the CPI for inflation protection? Indexing bond returns to any of these deflators is likely more feasible than introducing detailed price indices for subsections of the population. Because we focused on protection against inflation for consumers, we considered the other members of the CPI family (i.e., CPI-W, CPI-E, and chained CPI) and the PCE deflator.[36]

The CPI-W is the price index for urban wage earners and clerical workers, a subset of the urban population. Social Security benefits are indexed to the CPI-W. It differs from the CPI-U only in the expenditure weights used to aggregate the item-level price indices. The weights differ most as follows: The CPI-W population spends more on transportation, more on tenant rent, and less on OER. But even the biggest weight difference is less than 3 percentage points. So, it is not surprising that the time series of the CPI-U and the CPI-W have nearly the same sample mean inflation rate: The former, on average, has risen faster by less than 0.1 percentage point since 1983. Their growth rates are also highly correlated (**Table 2**).[37] More importantly, regressions (see the first four rows of **Table 3**) show that the difference in the inflation rates of the two indices does not covary significantly with any of the three commonly used aggregate risk factors.[38] This finding means that for those consumers who (for whatever reason) want to hedge the inflation risk as specifically measured by the CPI-W, indexing to the CPI-U does not expose them to systematic risk.

The CPI-E, the CPI for the elderly, is an experimental price index for Americans 62 years of age or older. The BLS first reported its CPI-E calculations to the U.S. Congress in 1988; in 1994, it extended the series back to 1982. Over the common sample period (1982–2007), the CPI-E rose at a slightly faster pace than the other CPIs, averaging 0.3 percentage point more per year. Stewart (2008) explained that this pace was mainly a result of the faster-than-average inflation of medical care and shelter costs, both of which account for a greater share of the CPI-E. But the CPI-U and the CPI-E are also highly correlated (Table 2).

If we suppose that the CPI-E should, in principle, be a more accurate index for retirees than the other CPIs, then for hedging purposes, retirees should note that the difference in the two inflation rates is not significantly correlated with any of the three aggregate risk factors. This is the case for both the full sample (beginning in January 1983) and the more recent subsample (beginning in January 1990), as shown in the last four rows of Table 3. This finding suggests that indexing TIPS to the CPI-U exposes retirees to little systematic risk. These calculations are, of course, rather uncertain, subject to possibly substantial measurement errors in the CPI-E.[39] Nonetheless, to the extent that the measurement errors are uncorrelated with the market risk factors, the coefficient estimates should be unbiased.

The chained CPI for all urban consumers (C-CPI-U) is the newest addition; it uses chain weighting, the chief methodological recommendation of the Boskin Commission. As explained previously, the chain-weighting methodology better mitigates substitution bias by also including in the index calculation the current-period expenditure shares, which reflect consumers' (optimal) purchase decisions in response to price changes. The C-CPI-U series starts in December 1999. As we have shown, the C-CPI-U inflation rate is, on average, lower than the CPI inflation rate (Figure 2) by about

Table 2. Comparison of Aggregate Price Indices: Average Inflation Rate and Correlation, 1983–2009

	CPI-U	CPI-W	CPI-E	C-CPI-U	PCE Deflator	GDP Deflator
	Dec. 1983–Feb. 2009	Dec. 1983–Feb. 2009	Dec. 1983–Feb. 2009	Dec. 2000–Feb. 2009	Dec. 1983–Feb. 2009	1983:Q1–2008:Q4
Avg. inflation rate (%)[a]	3.12	3.02	3.33	2.41	2.70	2.61
Correlation						
CPI-U	1.0000					
CPI-W	0.9788	1.0000				
CPI-E	0.9860	0.9550	1.0000			
C-CPI-U	0.9856	0.9861	0.9794	1.0000		
PCE deflator	0.8939	0.8513	0.9408	0.9619	1.0000	
GDP deflator	0.7410	0.8507	0.9382	0.9629	0.8863	1.0000

Note: All correlation coefficients with the C-CPI-U are computed over the sample period December 2000–February 2009.

[a]The inflation rate is computed as the rate of increase over the previous 12 months.

Table 3. Factor Loadings of the Alternative Aggregate Price Indices to the CPI-U, 1983–2009

	Market Return	Fama–French SMB	Fama–French HML
CPI-W (1983:Q1–2009:Q4)	–0.0019	—	—
	(0.0011)		
	–0.0021	0.0016	0.0002
	(0.0012)	(0.0016)	(0.0017)
CPI-W (1986:Q1–2009:Q4)	–0.0007	—	—
	(0.0009)		
	–0.0010	0.0005	–0.0007
	(0.0010)	(0.0014)	(0.0015)
CPI-E (1983:Q1–2009:Q4)	0.0009	—	—
	(0.0009)		
	0.0015	–0.0018	0.0013
	(0.0010)	(0.0014)	(0.0015)
CPI-E (1991:Q1–2009:Q4)	0.0007	—	—
	(0.0011)		
	0.0015	–0.0025	0.0012
	(0.0011)	(0.0015)	(0.0016)

Notes: The dependent variable in each regression is the inflation rate difference between the CPI-U and the respective alternative price index. Standard errors are reported in parentheses. All the regressions include a full set of month dummies. "SMB" represents the historical returns of a portfolio consisting of small (market capitalization) minus big companies, or the excess return of small-cap over large-cap stocks. "HML" represents the historical returns of a portfolio consisting of high (book-to-price ratio) minus low companies, or the excess return of value over growth stocks. See Fama and French (1993) for a more detailed description.

0.4 percentage point over the common sample period, although the difference between this inflation rate and the inflation rate implied by the CPI-U is uncorrelated with the three aggregate risk factors.

The PCE deflator is the price index constructed by the Bureau of Economic Analysis (BEA) to deflate the expenditures of the personal consumption sector as defined in the context of the U.S. national income and product accounts (NIPAs); this sector includes households and nonprofit organizations that serve households. The PCE deflator differs from the CPI along five dimensions: index formula, aggregation weights, scope, seasonal adjustments, and some item-level price indices. **Exhibit 1** outlines these differences. The exact contribution of each dimension to the difference between the inflation rates of the CPI and the PCE deflator varies from one sample period to another. For the most recent years (2002:Q1–2007:Q2), analysis shows that almost half the difference in these two indices' average inflation rates can be attributed to the different index number formulas and that the different relative weights more than account for the rest. (For details, see McCully, Moyer, and Stewart 2007.)[40]

One can argue that the PCE deflator is superior to the CPI as a cost of living index. Above all, the PCE deflator's index number formula—chain weighting with the geometric mean of expenditure shares in adjacent periods—minimizes substitution bias and mitigates the bias arising from new products. It is also based on more objective data of expenditure weights—actual spending versus survey responses.[41] For inflation hedging purposes, however, the scope of the PCE deflator may be broader than necessary for some services.[42]

In sum, owing to their use of chain weighting, both the C-CPI-U and the PCE deflator are relatively more accurate than the regular CPIs in capturing time variations in the cost of living, which is what matters for inflation protection. Before we recommend issuing real bonds indexed to either index, however, we must balance the potential benefits against a common practical difficulty suffered by both indices: Current expenditure data become available with a lag, and so the price index figures published in real time must be revised over time as more complete data are gathered. This need contrasts with the regular CPI data, which are never revised. Moreover, the average lag for the final release far exceeds six months, which is the typical interest payment frequency for indexed bonds. In fact, the difficulty of dealing with data revisions and delays is one of the traditional arguments for indexing TIPS to the CPI-U NSA and not to other indices that are based on the national accounts (e.g.,

Exhibit 1. Comparison between the CPI-U and the PCE Deflator

	CPI-U	PCE Deflator
Index formula	Laspeyres (fixed weights)	Fisher ideal (chain weighting)
Agency responsible	BLS	BEA
Price data	Outlet surveys	BLS price data (CPI and U.S. Producer Price Index), input-cost indices, and others
Expenditure weights	Consumer Expenditure Survey	NIPA actual expenditure data
Scope	Out-of-pocket expenses only	All expenses related to the household sector[a]
Others[b]	Seasonal adjustments of 73 selected CPI components	Seasonal adjustments of item-level price indices; different price data for a few specific CPI-comparable items[c]

[a]Includes both household out-of-pocket expenses and expenses paid on behalf of households; the latter consist mainly of medical costs paid by employers and government (via various programs, such as Medicare and Medicaid).
[b]Other differences also include different revision schedules followed by the BLS for the CPI and by the BEA for the PCE deflator.
[c]Specifically, the BEA uses an implicit deflator for passenger air transportation based on revenue and total miles traveled; the BEA also treats increases in gasoline prices owing to mandated pollution control as quality improvement, whereas the BLS treats such cases as price increases.

the PCE deflator and the GDP deflator)—although, in principle, one could always just index the security to the preliminary, real-time release figures and ignore the revisions when calculating the coupon.

In summary, our analysis indicates that differences across the available aggregate price indices related to consumption seem minor in terms of the impact on inflation risk hedging. So, to the extent that there is non-negligible liquidity loss stemming from "fragmenting" the market for inflation-protected bonds, *not* introducing additional price indices for bond return indexation may be the more sensible approach.

TIPS as a Short- or Long-Run Hedge against Inflation Risk

The primary appeal of TIPS is their ability to allow investors to hedge against unexpected changes in the inflation rate. We documented the extent to which investors have historically experienced *ex post* real returns that deviated substantially from expected returns. For investors who bought newly issued long-term Treasury notes during the 1970s and 1980s and held the notes to maturity, these deviations were large and variable. During the 1970s, sharp increases in price inflation caught many investors by surprise and at times produced *ex post* negative real rates of return on long-term Treasury securities. The speed of the Volcker disinflation of the 1980s, along with the subsequent revelation of the Fed's ability and commitment to keep the inflation rate low and stable, seemed to surprise many and resulted in *ex post* Treasury real returns that were very high by historical standards. Buying a TIPS note at issue and holding the note to maturity locks in a real rate of return with certainty and so eliminates this risk.

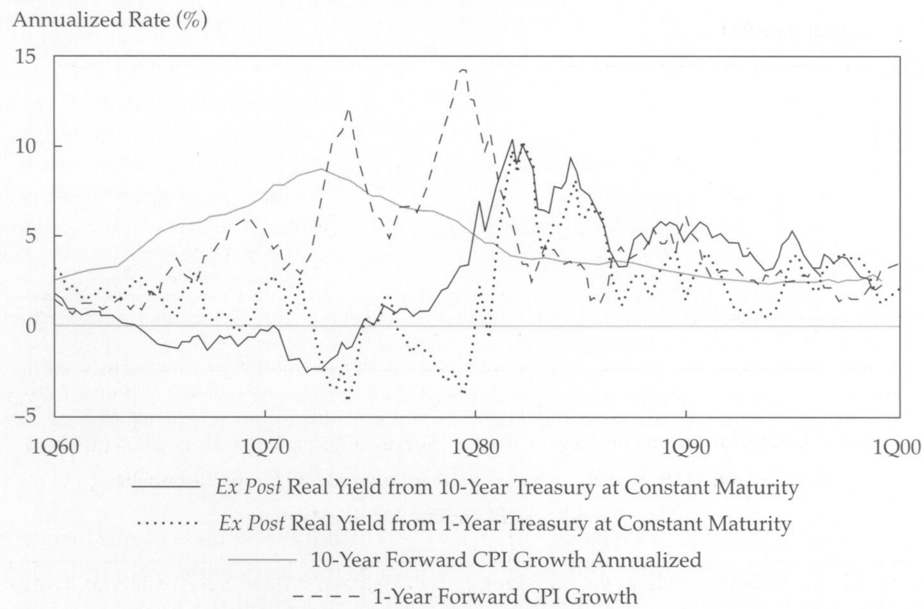
Unlike TIPS that are held to maturity, TIPS sold prior to maturity expose their holders to the risk of substantial capital gains or losses arising from changes in real interest rates. We found that a strategy of holding a TIPS note for a relatively short period before maturity is an ineffective means of hedging against changes in inflation over that period. Over relatively short horizons, the volatility in bond prices arising from fluctuations in real interest rates overwhelms the relatively small deviations between actual and expected inflation.

Actual Inflation and *Ex Post* Treasury Yields

The difference between expected (*ex ante*) real yields on long-term Treasuries at the time of issue and their *ex post* realized real returns provides one measure of the potential value of TIPS as a real return hedge. To calculate this difference, one needs a measure of expected inflation to use in calculating *ex ante* expected yields. **Figure 3** illustrates the *ex post* real annualized yields on 10-year Treasury notes and 1-year Treasury bills that were purchased at issue and held to maturity. The dates on the horizontal axis refer to the issue dates. The annualized rates of change in the CPI-U over 1- and 10-year horizons, which are also shown in the figure, were used to convert the nominal Treasury coupon yields to real yields.

The most striking finding that emerges from the figure is that the era of high 10-year forward inflation rates coincides with very low, and often negative, *ex post* real yields on Treasury notes. This finding raises the question, To what extent were the low real yields anticipated at the time of issue, and

Figure 3. *Ex Post* Real Yields vs. CPI Growth



Sources: Haver Analytics; Federal Reserve Board; Bureau of Labor Statistics.

to what extent were they caused by deviations between expected and actual inflation over the 10-year holding periods? If TIPS, or other inflation-indexed bonds, had been issued during this time, investors could have avoided the risk of inflation deviating from its expected path. Because such bonds were unavailable, however, investors were exposed to inflation risk.

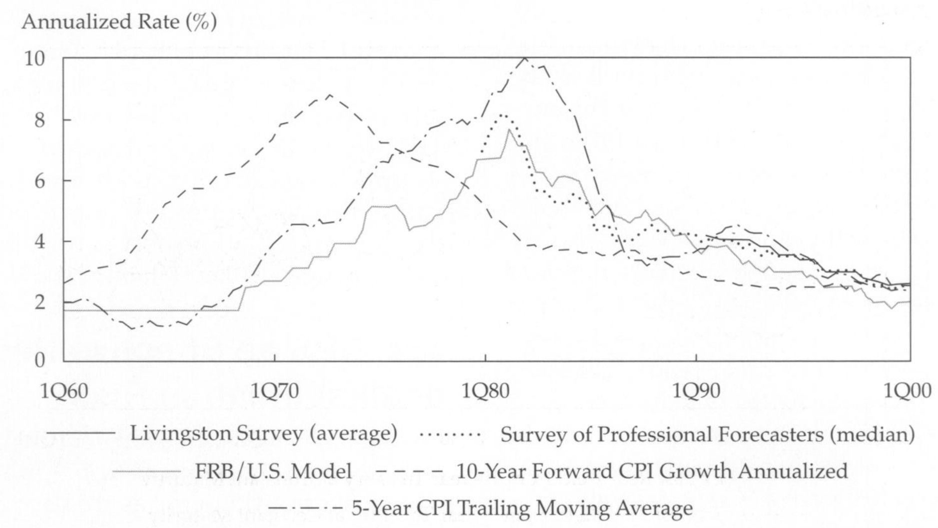
Expected and Actual Inflation over Long Horizons

Most of the evidence points toward the low *ex post* real yields as having resulted from higher-than-expected inflation. Survey data on forecasts of average inflation over the next 10 years are available only for 1979 and thereafter. Therefore, we supplemented the survey-based data on expected inflation with a constructed 10-year-ahead expected inflation variable used in the Fed's FRB/U.S. model.[43] The FRB/U.S. expected inflation variable is based on predictions from a regression of survey estimates of expected inflation on its lagged value, the long-term expected federal funds rate, four lags of the quarterly value of core inflation, the federal funds rate, and the gap between actual and potential output. As shown in **Figure 4**, this variable tracks the survey measures of expected inflation very well during the 1980s and 1990s.[44] The constructed variable takes on sensible values. Inflation was relatively low and stable during the early 1960s, and the FRB/U.S. 10-year-ahead expected inflation variable tracks past CPI inflation (shown as the 5-year trailing moving average of annualized CPI inflation rates) very closely during that period. By the late 1960s, inflation started to increase, and the FRB/U.S. 10-year expected inflation variable began a gradual ascent from slightly below 2 percent in the mid-1960s to nearly 8 percent in the early 1980s.

All the expected inflation measures are largely backward looking, move with recent actual rates of inflation, and often deviate substantially from the actual inflation rates that would be experienced over the subsequent 10 years. Even if professional forecasters had foreseen the oil shocks and policy responses, they likely would have underestimated the extent of the resulting increase in inflation. Starting in the mid-1960s, the actual 10-year forward CPI growth rates were much larger than 10-year forward expected inflation because of the unforeseen shocks—and most likely also because of errors in forecasting the response of inflation to the shocks. **Figure 5** shows the difference between the FRB/U.S. 10-year expected inflation variable and the actual 10-year forward average CPI inflation rate.

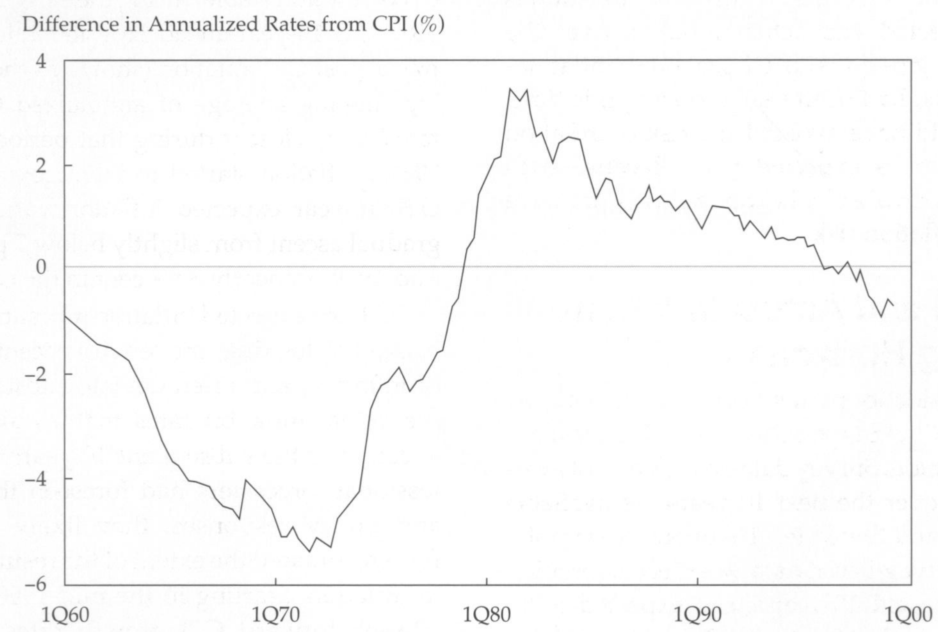
The difference between various 10-year forward inflation rates and the FRB/U.S. expected inflation variable is generally much larger, and less

Figure 4. 10-Year Forecast vs. Actual CPI Growth



Sources: Haver Analytics; Federal Reserve Bank of Philadelphia; Federal Reserve Board; Bureau of Labor Statistics.

Figure 5. FRB/U.S. Model Inflation Expectations Tracking Error



Sources: Haver Analytics; Bureau of Labor Statistics; Federal Reserve Board.

predictable, than the differences among the average inflation rates based on different price indices. This fact argues strongly in support of the value of TIPS as a real return hedge. A price index–linked bond provides a means of hedging against swings in inflation caused by supply shocks or changes in policy. So long as the price indices largely move together in response to shocks, that a price index–linked bond is available matters more than which specific price index is picked for the link.

Short and Long Holding Period Returns

The large divergence between expected and actual inflation over 10-year horizons suggests that the low realized real rates of return on 10-year Treasury notes purchased in the 1960s and early 1970s and held to maturity were a result of unexpected increases in inflation. **Figure 6** shows both the *ex post* and the *ex ante* real yields on 10-year Treasury notes; the CPI-U was used to convert nominal yields to *ex post* real yields, and the FRB/U.S. 10-year expected inflation variable was used to convert nominal yields to *ex ante* real yields. Although the *ex post* real yield fluctuates widely—swinging from negative values for Treasury notes issued in the early 1970s to more than 10 percent for notes issued in the early 1980s—the *ex ante* real yield stays within a much narrower range. The *ex ante* real yield is elevated during the periods of uncertain fiscal and monetary policy during the late 1960s and early 1980s but is otherwise contained within a fairly tight band.

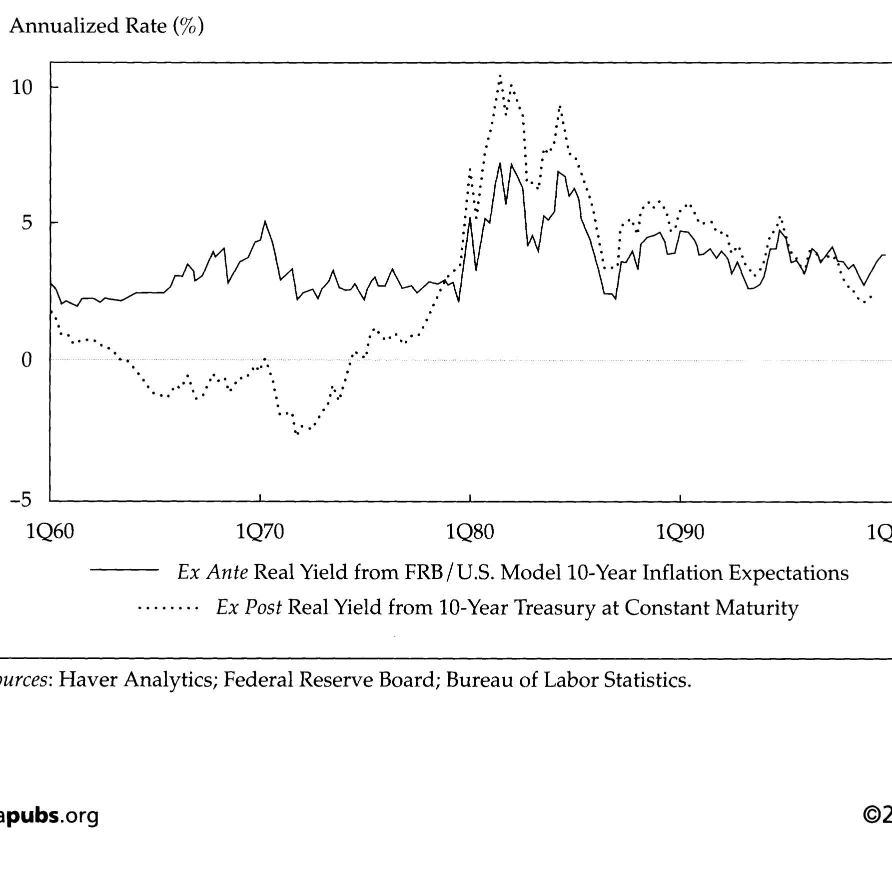
This finding suggests that had TIPS been available, they would have been a very useful means of hedging against inflation risk from the 1960s through the 1980s. Although Treasury notes essentially had no default risk, they exposed investors to considerable inflation risk. TIPS allow investors to equate the *ex post* return with the *ex ante* return and thus avoid inflation risk if the note is held to maturity.

If a TIPS note is not held to maturity, the investor is no longer guaranteed a fixed real rate of return. Fluctuations in the yield on newly issued TIPS result in changes in the prices of existing securities, which can expose investors to capital gains or losses. In practice, this exposure implies that holding TIPS for short periods is a very ineffective hedge against inflation risk.[45]

Are TIPS an Effective Hedge against Inflation Risk?

Buying a newly issued TIPS and then holding it to maturity is an effective way to lock in a risk-free real rate of return. Although, as we have documented, there are important differences across price indices, the changes in the inflation rate based on the CPI-U are highly correlated with inflation rates based on other price indices over long periods. So, TIPS provide effective protection against unanticipated changes in the average inflation rate over fairly long horizons. If TIPS had been available during the 1970s and 1980s, they would have been a very effective means of locking in a real rate of return. In contrast, long-term nominal Treasury issues produced unexpectedly erratic rates of return.

Figure 6. *Ex Ante* Real Yields vs. *Ex Post* Real Yields



Sources: Haver Analytics; Federal Reserve Board; Bureau of Labor Statistics.

One caveat is that TIPS can provide protection against only a fraction of inflation for taxable investors. The inflation compensation of TIPS is taxable on individual federal returns, which is essentially no different from the tax treatment of nominal bonds because the inflation premium component of nominal interest payments is also taxed. TIPS are not tax disadvantaged relative to nominal bonds, but investors are protected against only $(1 - t)$ of inflation, where t is the investor's federal marginal income tax rate. Of course, the investor receives full inflation protection if TIPS are held in a tax-preferred account, such as a 401(k).

Holding TIPS for a relatively short period is not an effective means of hedging against short-term fluctuations in inflation. Whether the CPI-U is the most appropriate price index is more important in the short run than in the long run because inflation rates based on different price indices will generally diverge in less predictable ways in the short run than in the long run. Moreover, investors looking to hedge against short-term inflation fluctuations may be trying to ensure that they can make a particular purchase in the future, such as intermediate inputs for a business or for a college education for their children; thus, changes in the relative prices of these purchases may be of particular concern to such investors.

The most appropriate and useful role for TIPS may be in life-cycle saving by individuals and their agents. As the proportion of retirees who have defined benefit pensions continues to decrease, the need for individuals to manage lump-sum accounts to provide a steady stream of real income during their retirement becomes more difficult. A "ladder" of TIPS with maturities linked to the dates when money will be needed for expenses is a safe investment well suited to retirees and those approaching retirement. TIPS also have the potential to be the backbone asset underlying inflation-indexed life annuities. Such annuities are currently very rare, partly because of the financial literacy problems that plague the general immediate annuity market but also because of the difficulty that insurance companies face in hedging against long-term inflation risk. Individuals may spend 30 or more years in retirement, and thus, extending the maximum duration of TIPS would likely help improve the functioning of the indexed life annuity market.

Conclusion

Through a variety of means, we showed that the efficacy of TIPS in hedging against inflation risk is, for the most part, independent of the inflation measure used. In particular, many measures of inflation move together, and thus, differences among these measures are swamped by the difference between any of these measures and any survey-based measure of expected inflation. The difference between expected real yields (as measured by the nominal Treasury return less the expected inflation rate) and realized real returns (as measured by the nominal Treasury return less the actual inflation rate) provides one measure of the value of TIPS as a hedge against inflation fluctuations. We also showed that TIPS indexed to the CPI are at least as good as TIPS indexed to other measures of inflation because the correlation between the implied inflation basis risk and common risk factors is neither economically nor statistically meaningful. Inflation basis risk arising from mismeasurement of the CPI is also uncorrelated with common risk factors, which suggests that the concern on the part of the popular press that such mismeasurement leaves TIPS investors poorly hedged against inflation risk is unfounded. We emphasized that buy-and-hold investors are hedged best and that investors who buy and hold long-maturity TIPS are better hedged than investors who hold short-term TIPS maturities. The same shocks that generate unexpected changes in inflation will alter the coupon yield on new TIPS issues, so the short holding period strategy becomes an ineffective hedge against short-term inflation fluctuations. We also explained that TIPS-implied breakeven inflation rates are not the same as inflation expectations and thus are not necessarily good measures of inflation expectations. Therefore, they are also unlikely to be good forecasts of future inflation.

Finally, we drew some implications for the design of the TIPS market and for related issues regarding financial institutions. We conclude that, as is, the TIPS market provides a good hedge against inflation risk and that from a cost/benefit perspective, little is to be gained from indexing to other inflation measures, be they broader, such as the GDP deflator, or narrower, such as regional inflation measures or the CPI-E. A "ladder" of TIPS, with maturities linked to when money is needed for expenses, would help investors in or near retirement hedge against their nominal expenses over time. TIPS have the potential to be the backbone asset underlying inflation-indexed annuities, but the maximum duration of TIPS would need to be extended in order to facilitate such annuities. With respect to housing as an investment rather than a consumption good, there is room for alternative hedging instruments, which are currently available in the form of futures contracts on S&P/Case-Shiller Metro Area Home Price Indices and forward contracts on the Residential Property Index 25-MSA Composite.

We thank Jeff Fuhrer for helpful discussions and Adrienne Hathaway, Brendan Mackoff, and Aaron Pancost for excellent research assistance.

This article qualifies for 1 CE credit.

Notes

1. The U.S. Treasury declared that such changes would be deemed "technical" (as opposed to "fundamental") and would thus not call for a replacement series as recommended by the U.S. Bureau of Labor Statistics (BLS); nevertheless, it draws attention to another source of pretax real return uncertainty. See Title 31, Part 356, Appendix B in the *Federal Register*, "Sale and Issue of Marketable Book-Entry Treasury Bills, Notes, and Bonds" (Department of the Treasury Circular, Public Debt Series No. 1–93, 6 January 1997) and Anderson (1999). In September 2000, the BLS announced a miscalculation of the CPI, which prompted the Treasury to reopen the 2029 indexed bond "to preclude any computational issues regarding the Reference CPI that would be associated with the issuance of a new security." See U.S. Department of the Treasury (2000); see also Deacon, Derry, and Mirfendereski (2004, p. 150).
2. Kevin P. Phillips, "Numbers Racket: Why the Economy Is Worse Than We Know," *Harper's Magazine* (May 2008):43–47.
3. See, for example, Gross (2008) and Hernandez (2008).
4. This article does not add to the literature on the cost/benefit analysis of the TIPS program from the perspective of the Treasury. For that analysis, see, among others, papers by Sack and Elsasser (2004), Roush (2008), and Roush, Dudley, and Steinberg Ezer (2008).
5. The reference price level index is the CPI-U NSA (nonseasonally adjusted). See Kan (1999).
6. Note that corporate inflation-protected securities (CIPS) are not a good substitute for TIPS even if one ignores the difference in credit risk because CIPS adjust the semiannual coupon for inflation by adding the semiannual inflation rate to it rather than by adjusting the principal. The result is a variable-rate bond that does not produce a series of certain real cash flows in the future.
7. For more detailed technical information, see Title 31, Part 356, Appendix B in the *Federal Register*, "Sale and Issue of Marketable Book-Entry Treasury Bills, Notes, and Bonds" (Department of the Treasury Circular, Public Debt Series No. 1–93, 6 January 1997) or the accessible and more succinct exposition by Deacon, Derry, and Mirfendereski (2004).
8. For a more thorough discussion of this point, see Kopcke and Kimball (1999).
9. Primary dealers are broker/dealers that trade in U.S. government securities with the Federal Reserve Bank of New York; see www.newyorkfed.org/markets/pridealers_current.html for a list. "Investment funds" includes investment managers, mutual funds, and hedge funds; "other" includes individuals, nonfinancial companies, and financial companies other than dealers, depository institutions, and insurance companies.
10. A series of figures can be found at www.treas.gov/offices/domestic-finance/debt-management/qrc, although the data in Table 1 are from Bitsberger (2004).
11. Previous data provided by the Department of the Treasury yield similar implications.
12. Investors who participate in both nominal Treasury and TIPS markets ensure that arbitrage opportunities across these two markets are traded away. Thus, we can assume that the expected real rate and the real rate risk premium in the two markets are the same, and we can use this information to back out the expected breakeven inflation rate from these two markets. In the absence of differential liquidity or convexity premiums, the breakeven inflation rate is the rate of inflation compensation (expected inflation plus the inflation risk premium) that is consistent with no arbitrage between the markets.
13. There are also duration differences between nominal Treasuries and TIPS because TIPS are relatively more backloaded than their nominal counterparts as a result of the inflation uplift in the principal over time.
14. As previously shown, TIPS are risk free (in terms of real rate of return) only if held until maturity. Because the real rate is stochastic, TIPS are still subject to random capital gains (losses) if sold prematurely.
15. It is worth pointing out that few studies of CPI bias have made this point explicitly. Most such studies are concerned with the average *level* of the biases. See Lebow and Rudd (2003) and Gordon (2006) for in-depth discussions of the likely biases in the CPI and estimates of the average level.
16. Note that, to the extent that the marginal investor in the TIPS market does not buy and hold, the systematic risk in the random capital gain (loss) from trading TIPS prior to maturity should also be priced. It is probably also embedded in the implied inflation risk premium. We ignored this issue.
17. For the exact formula—in particular, the change since 1999, when the BLS introduced geometric means within some item-area strata (e.g., oranges versus apples in Chicago)—see the CPI manual ("The Consumer Price Index," chap. 17 of the *BLS Handbook of Methods*).
18. Greenlees and McClelland (2008) of the BLS published a timely article intended to address the criticisms and complaints most prevalent in the popular press about what they termed the "myths" regarding the CPI. In addition to the three criticisms we examined, they also considered core versus headline CPI.
19. See Diewert (1998) for a summary in the context of the CPI, including comparisons with a true superlative index.
20. See Lebow and Rudd (2003) and Gordon (2006).
21. More specifically, the geometric mean calculation is performed only across merchandise within each item-area stratum. It is applied in order to mitigate the within-stratum substitution bias (the so-called lower-level bias). In contrast, the CPI's Laspeyres formula across the item-area strata amounts to assuming no substitutions across strata.
22. Greenlees (2006) confirmed this initial estimate of the likely reduction in bias.
23. See Greenlees and McClelland (2008) for a more detailed discussion of the general concept of quality adjustment and the specific properties of hedonic models.
24. See Poole, Ptacek, and Verbrugge (2005) for more details. Brown and Stockburger (2006) estimated that the hedonic method has also slightly increased the inflation rate for apparel.
25. See Johnson, Reed, and Stewart (2006).
26. If we include the previous house-price boom in 1976–1979 by extending the sample to 1976 (when the FHFA House Price Index began) and approximate the OER by using the rental cost of the primary residence, then the correlation rises to 0.52 (between 1976 and 2002). The primary rent series is a reasonable proxy for the OER because the correlation between their inflation rates runs steadily at 0.79 during the overlapping years (since 1982).
27. In theory, the user cost of (housing) capital should give the same measure of per-period price of housing services as the rental equivalence approach behind the calculation of OER. The user cost (also called the rental price) of capital depends not only on the price of the capital good (i.e., the house price) but also on the depreciation rate and the financial cost of capital, which, in turn, depends on the mortgage interest

rate and on property and income tax rates. In reality, however, the OER and the user cost are found to diverge for extended periods (Verbrugge 2008), mainly as a result of substantial transaction costs in the real estate market.

28. One implication is that if the CPI bias is independently and identically distributed, then the longer the holding period, the less the bias matters for hedging purposes because time averaging smooths out the variations.
29. Note that this basis risk does not arise for (institutional) investors that use TIPS to maturity-match their real liabilities that are indexed to the official, not the true, underlying inflation, such as pension funds with liabilities indexed to the CPI-U. This fact suggests that the premium priced in the TIPS market may be smaller than that implied by the covariance between the remaining CPI bias and the market factors if some participants are those institutional investors that seek to hedge the inflation risk as officially measured.
30. Part of the gap is bias arising from the slow incorporation of new products into the regular CPI, which uses expenditure weights updated every three years, whereas the chained CPI-U also uses current-period expenditure shares, which incorporate new goods more quickly.
31. Because the C-CPI-U is only available nonseasonally adjusted (NSA), to be consistent, we computed the difference in inflation by using the NSA version of the CPI-U. Note that TIPS are in fact indexed to the CPI-U NSA series. To minimize the influence of seasonality, the inflation rates are computed as the 12-month growth rate.
32. The correlation of this proxy for the substitution bias with the excess return on the market, for example, is 0.0013, with a standard error of 0.0016. We also examined the risk characteristics of alternative proxies for the substitution bias, as well as proxies for biases resulting from inadequate quality adjustment and the use of OER. We found that none of these measurement issues induce a bias that is correlated with the common risk factors. Unreported results are available from the authors upon request.
33. Specifically, the expenditure shares are calculated on the basis of data from the Consumer Expenditure Survey, which is conducted by the U.S. Census Bureau on behalf of the BLS.
34. Note that this feature is independent of the CPI's substitution bias, which would cause the CPI to mismeasure the true price change even if a representative consumer existed.
35. See, for example, Fleming and Krishnan (2009) and Goldreich, Hanke, and Nath (2005).
36. We based our analysis on NSA data for all these series because only NSA data are available for the chained CPI. This constraint, however, should have minimal effect on our results because we used the 12-month growth rate. Judging by the series for which both seasonally adjusted and NSA data are available, seasonal adjustment seems to make little difference. We also examined the comparison with the GDP deflator. Those results are qualitatively similar to the results reported here and are available from the authors upon request.
37. We included in the table only results over the sample period that overlap with the CPI-E. In terms of average inflation rate, the difference between the CPI-U and the CPI-W is, in fact, much smaller over the full sample (only 0.03 percentage point), and the correlation is higher (0.998). The smaller difference may be because the availability of data in the early years precludes a finer distinction between the two indices. For inflation hedging in the future, the behavior of these price indices in recent decades is presumably more relevant.
38. Starting the sample in January 1983 allowed us to match with the sample for the CPI-E. Starting the subsample in January 1986 removed the early years, when the inflation difference was unusually large; as expected, doing so lowered the loading on the market return, although the coefficient is insignificant in both cases.
39. As emphasized in the CPI manual ("The Consumer Price Index," chap. 17 of the *BLS Handbook of Methods*), the CPI-E is merely a reweighting of item-level indices underlying the regular CPI that uses expenditure weights from households headed by a person 62 years of age or older, without recalculating the detailed indices to represent the retail outlets and consumption items of older consumers.
40. Fixler and Jaditz (2002) examined an earlier period (1992:Q1–1997:Q2) and found that both the formula effect and the individual item-level price effect led to a faster increase (0.2 percentage point per year, on average) in the CPI than in the PCE deflator, mostly offset by weight and scope effects.
41. Perhaps for these reasons, the shares of salient expenditure items (e.g., housing costs) are much higher in the CPI (where housing has had a weight of around 42 percent in recent decades) than in the PCE deflator (where housing's weight hovers between 14 percent and 16 percent).
42. In particular, the PCE deflator also covers spending by employers and the government (mostly related to medical care) on behalf of households. Consumers need to hedge the inflation risk for these items only to the extent that such expenses substitute for explicit compensation or may be "privatized" in the future or both.
43. See Brayton and Tinsley (1996) for an exposition of the FRB/U.S. model.
44. The measures of expected inflation shown in Figure 4 are based on surveys of economists who were asked to state their forecast of the average growth rate of the CPI over the next 10 years. One of the lines splices together (1) data for 1979 through the first half of 1991 from the consensus forecast of the annualized increase in the CPI from professional forecasters surveyed by the Blue Chip Economic Indicators program with (2) data for the fourth quarter of 1991 on from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (Croushore 1993). Another line in Figure 4 shows, for 1990 on, the mean responses of participants in the Federal Reserve Bank of Philadelphia's Livingston Survey (Croushore 1997). All the survey data were obtained from the Federal Reserve Bank of Philadelphia's website (www.phil.frb.org/index.cfm).
45. In unreported results, we found that the real return from holding a TIPS note for a single year is nearly as variable as the return from holding a nominal Treasury security for a single year. The same shocks that produce unexpected changes in inflation are also likely to affect the coupon yield on new TIPS issues, making the short holding period strategy an ineffective means of hedging against short-term inflation fluctuations.

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JOHN Y. CAMPBELL
Harvard University

ROBERT J. SHILLER
Yale University

LUIS M. VICEIRA
Harvard University

Understanding Inflation-Indexed Bond Markets

ABSTRACT This paper explores the history of inflation-indexed bond markets in the United States and the United Kingdom. It documents a massive decline in long-term real interest rates from the 1990s until 2008, followed by a sudden spike during the financial crisis of 2008. Breakeven inflation rates, calculated from inflation-indexed and nominal government bond yields, were stable from 2003 until the fall of 2008, when they showed dramatic declines. The paper asks to what extent short-term real interest rates, bond risks, and liquidity explain the trends before 2008 and the unusual developments that followed. Low yields and high short-term volatility of returns do not invalidate the basic case for inflation-indexed bonds, which is that they provide a safe asset for long-term investors. Governments should expect inflation-indexed bonds to be a relatively cheap form of debt financing in the future, even though they have offered high returns over the past decade.

In recent years government-issued inflation-indexed bonds have become available in a number of countries and have provided a fundamentally new instrument for use in retirement saving. Because expected inflation varies over time, conventional, nonindexed (nominal) Treasury bonds are not safe in real terms; and because short-term real interest rates vary over time, Treasury bills are not safe assets for long-term investors. Inflation-indexed bonds fill this gap by offering a truly riskless long-term investment (Campbell and Shiller 1997; Campbell and Viceira 2001, 2002; Brennan and Xia 2002; Campbell, Chan, and Viceira 2003; Wachter 2003).

The U.K. government first issued inflation-indexed bonds in the early 1980s, and the U.S. government followed suit by introducing Treasury inflation-protected securities (TIPS) in 1997. Inflation-indexed government bonds are also available in many other countries, including Canada, France, and Japan. These bonds are now widely accepted financial instruments. However, their history creates some new puzzles that deserve investigation.

First, given that the real interest rate is determined in the long run by the marginal product of capital, one might expect inflation-indexed bond yields to be extremely stable over time. But whereas 10-year annual yields on U.K. inflation-indexed bonds averaged about 3.5 percent during the 1990s (Barr and Campbell 1997), and those on U.S. TIPS exceeded 4 percent around the turn of the millennium, by the mid-2000s yields on both countries' bonds averaged below 2 percent, bottoming out at around 1 percent in early 2008 before spiking to near 3 percent in late 2008. The massive decline in long-term real interest rates from the 1990s to the 2000s is one puzzle, and the instability in 2008 is another.

Second, in recent years inflation-indexed bond prices have tended to move opposite to stock prices, so that these bonds have a negative "beta" with the stock market and can be used to hedge equity risk. This has been even more true of prices on nominal government bonds, although these bonds behaved very differently in the 1970s and 1980s (Campbell, Sunderam, and Viceira 2009). The reason for the negative beta on inflation-indexed bonds is not well understood.

Third, given integrated world capital markets, one might expect that inflation-indexed bond yields would be similar around the world. But this is not always the case. During the first half of 2000, the yield gap between U.S. and U.K. inflation-indexed bonds was over 2 percentage points, although yields have since converged. In January 2008, 10-year yields were similar in the United States and the United Kingdom, but elsewhere yields ranged from 1.1 percent in Japan to almost 2.0 percent in France (according to Bloomberg data). Yield differentials were even larger at long maturities, with U.K. yields well below 1 percent and French yields well above 2 percent.

To understand these phenomena, it is useful to distinguish three major influences on inflation-indexed bond yields: current and expected future short-term real interest rates; differences in expected returns on long-term and short-term inflation-indexed bonds caused by risk premiums (which can be negative if these bonds are valuable hedges); and differences in expected returns on long-term and short-term bonds caused by liquidity premiums or technical factors that segment the bond markets. The expectations hypothesis of the term structure, applied to real interest rates, states that only the first influence is time-varying whereas the other two are constant. However, there is considerable evidence against this hypothesis for nominal Treasury bonds, so it is important to allow for the possibility that risk and liquidity premiums are time-varying.

The path of real interest rates is undoubtedly a major influence on inflation-indexed bond yields. Indeed, before TIPS were issued, Campbell and Shiller (1997) argued that one could anticipate how their yields would behave by applying the expectations hypothesis of the term structure to real interest rates. A first goal of this paper is to compare the history of inflation-indexed bond yields with the implications of the expectations hypothesis, and to explain how shocks to short-term real interest rates are transmitted along the real yield curve.

Risk premiums on inflation-indexed bonds can be analyzed by applying theoretical models of risk and return. Two leading paradigms deliver useful insights. The consumption-based paradigm implies that risk premiums on inflation-indexed bonds over short-term debt are negative if returns on these bonds covary negatively with consumption, which will be the case if consumption growth rates are persistent (Backus and Zin 1994; Campbell 1986; Gollier 2007; Piazzesi and Schneider 2007; Wachter 2006). The capital asset pricing model (CAPM) implies that risk premiums on inflation-indexed bonds will be negative if their prices covary negatively with stock prices. The second paradigm has the advantage that it is easy to track the covariance of inflation-indexed bonds and stocks using high-frequency data on their prices, in the manner of Viceira and Mitsui (2007) and Campbell, Adi Sunderam, and Viceira (2009).

Finally, it is important to take seriously the effects of institutional factors on inflation-indexed bond yields. Plausibly, the high TIPS yields in the first few years after their introduction were due to the slow development of TIPS mutual funds and other indirect investment vehicles. Currently, long-term inflation-indexed yields in the United Kingdom may be depressed by strong demand from U.K. pension funds. The volatility of TIPS yields in the fall of 2008 appears to have resulted in part from the unwinding of large institutional positions after the failure of the investment bank Lehman Brothers in September. These institutional influences on yields can alternatively be described as liquidity, market segmentation, or demand and supply effects (Greenwood and Vayanos 2008).

This paper is organized as follows. Section I presents a graphical history of the inflation-indexed bond markets in the United States and the United Kingdom, discussing bond supplies, the levels of yields, and the volatility and covariances with stocks of high-frequency movements in yields. Section II asks what portion of the TIPS yield history can be explained by movements in short-term real interest rates, together with the expectations hypothesis of the term structure. This section revisits the vector autoregression (VAR) analysis of Campbell and Shiller (1997). Section III discusses the risk characteristics of TIPS and estimates a model of TIPS pricing with time-varying systematic risk, a variant of the model in Campbell, Sunderam, and Viceira (2009), to see how much of the yield history can be explained by changes in risk. Section IV discusses the unusual market conditions that prevailed in the fall of 2008 and the channels through which they might have influenced inflation-indexed bond yields. Section V draws implications for investors and policymakers. An appendix available online presents technical details of our bond pricing model and of data construction.[1]

I. The History of Inflation-Indexed Bond Markets

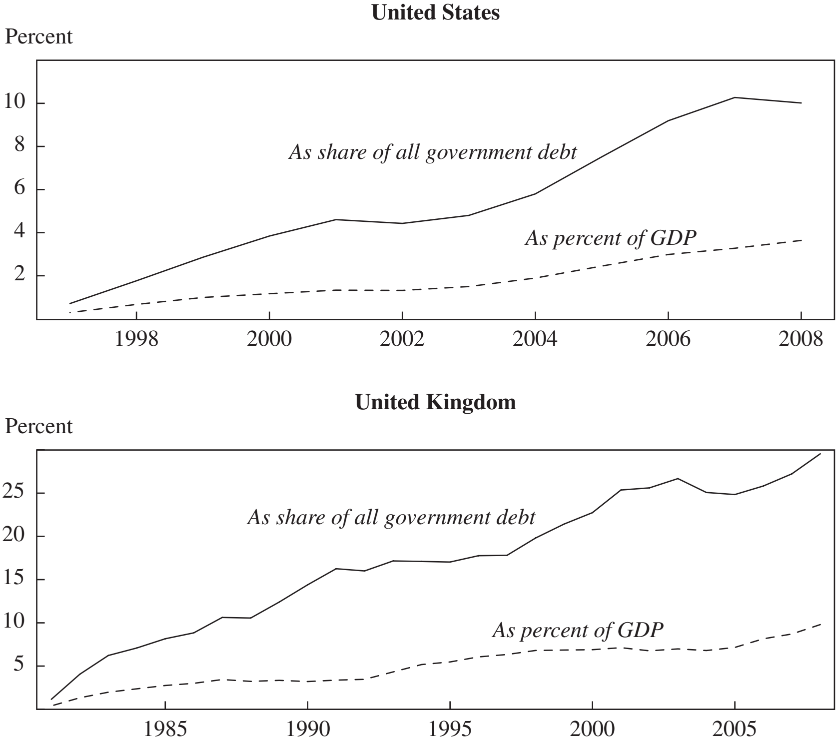
The top panel of figure 1 shows the growth of the outstanding supply of TIPS during the past 10 years. From modest beginnings in 1997, TIPS grew to around 10 percent of the marketable debt of the U.S. Treasury, and more than 3.5 percent of U.S. GDP, in 2008. This growth has been fairly smooth, with a minor slowdown in 2001–02. The bottom panel shows a comparable history for U.K. inflation-indexed gilts (government bonds). From equally modest beginnings in 1982, the stock of these bonds has grown rapidly and accounted for almost 30 percent of the British public debt in 2008, equivalent to about 10 percent of GDP. Growth in the inflation-indexed share of the public debt slowed in 1990–97 and reversed in 2004–05 but otherwise proceeded at a rapid rate.

The top panel of figure 2 plots yields on 10-year nominal and inflation-indexed U.S. Treasury bonds from January 1998, a year after their introduction, through March 2009.[2] The figure shows a considerable decline in both nominal and real long-term interest rates since TIPS yields peaked early in 2000. Through 2007 the decline was roughly parallel, as inflation-indexed bond yields fell from slightly over 4 percent to slightly over

1. The online appendix can be found at kuznets.fas.harvard.edu/~campbell/papers.html.

2. We calculate the yield for the longest-maturity inflation-indexed bond outstanding at each point in time whose original maturity at issue was 10 years. This is the on-the-run TIPS issue. We obtain constant-maturity 10-year yields for nominal Treasury bonds from the Center for Research in Security Prices (CRSP) database. Details of data construction are reported in the online appendix.

Figure 1. Stocks of Inflation-Indexed Government Bonds Outstanding

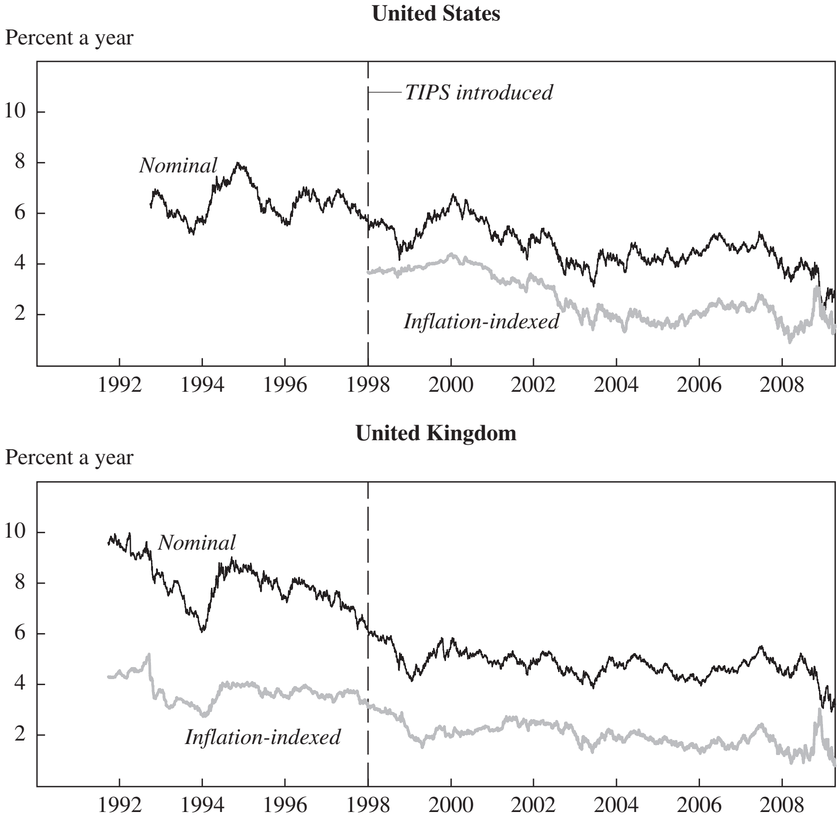


Sources: *Treasury Bulletin,* various issues, table FD-2; Heriot-Watt/Faculty and Institute of Actuaries Gilt Database (www.ma.hw.ac.uk/~andrewc/gilts/, file BGSAmounts.xls).

1 percent, while yields on nominal government bonds fell from around 7 percent to 4 percent. Thus, this was a period in which both nominal and inflation-indexed Treasury bond yields were driven down by a large decline in long-term real interest rates. In 2008, in contrast, nominal Treasury yields continued to decline, while TIPS yields spiked above 3 percent toward the end of the year.

The bottom panel of figure 2 shows a comparable history for the United Kingdom since the early 1990s. To facilitate comparison of the two plots, the beginning of the U.S. sample period is marked with a vertical line. The downward trend in inflation-indexed yields is even more dramatic over this longer period. U.K. inflation-indexed gilts also experienced a dramatic yield spike in the fall of 2008.

Figure 2. Yields on Ten-Year Nominal and Inflation-Indexed Government Bonds, 1991–2009[a]

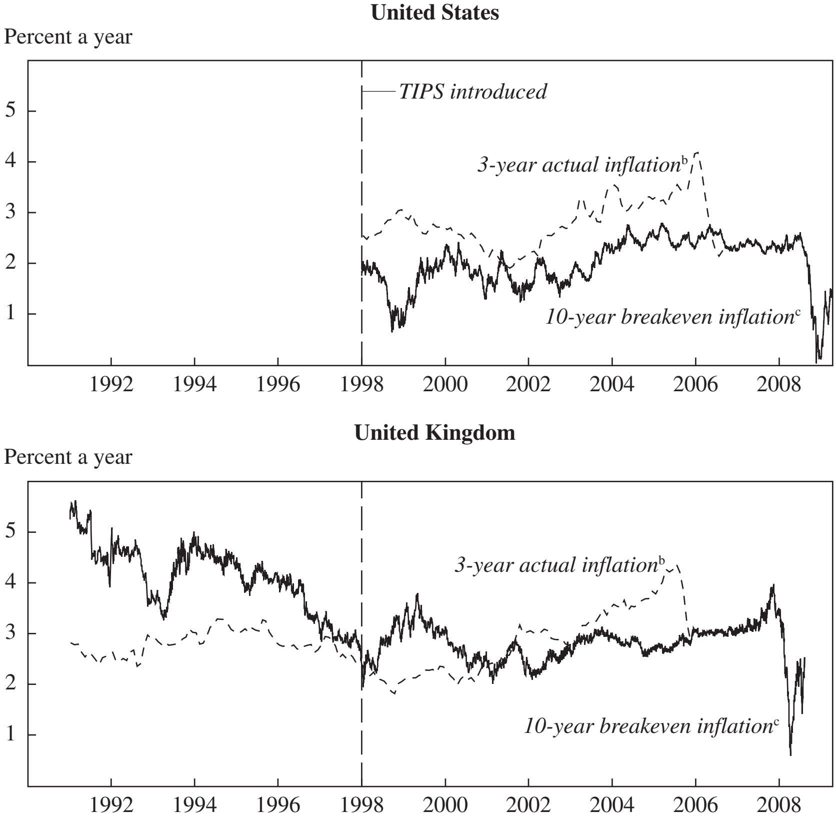


Source: Authors calc ulations using data from Bloomberg and Heriot-Watt/Faculty and Institute of Actuaries Gilt Database; see the online appendix (kuznets.fas.harvard.edu/~campbell/papers.html) for details.

a. Yields are calculated from spliced yields and price data of individual issuances.

The top panel of figure 3 plots the 10-year breakeven inflation rate, the difference between 10-year nominal and inflation-indexed Treasury bond yields. The breakeven inflation rate was fairly volatile in the first few years of the TIPS market; it then stabilized between 1.5 and 2.0 percent a year in the early years of this decade before creeping up to about 2.5 percent from 2004 through 2007. In 2008 the breakeven inflation rate collapsed, reaching almost zero at the end of the year. The figure also shows, for the early years of the sample, the subsequently realized 3-year inflation rate. After the first

Figure 3. Breakeven Inflation Rates Implied by Ten-Year Nominal Inflation-Indexed Bond Yields, and Actual Three-Year Inflation, 1991–2009[a]



Source: Authors' calculations from Bloomberg and Bureau of Labor Statistics data; see the online appendix for details.

a. Bond yields are computed from spliced yields and price data of individual issuances.

b. Annualized percent change in the consumer price index over the preceding 3 years.

c. Difference between 10-year yields of nominal and inflation-indexed bonds; monthly data.

couple of years, in which there is little relationship between breakeven and subsequently realized inflation, a slight decrease in breakeven inflation between 2000 and 2002, followed by a slow increase from 2002 to 2006, is matched by similar gradual changes in realized inflation. Although this is not a rigorous test of the rationality of the TIPS market—apart from anything else, the bonds are forecasting inflation over 10 years, not 3 years—it does suggest that inflation forecasts influence the relative pricing of TIPS and nominal Treasury bonds. We explore this issue in greater detail in the next section.

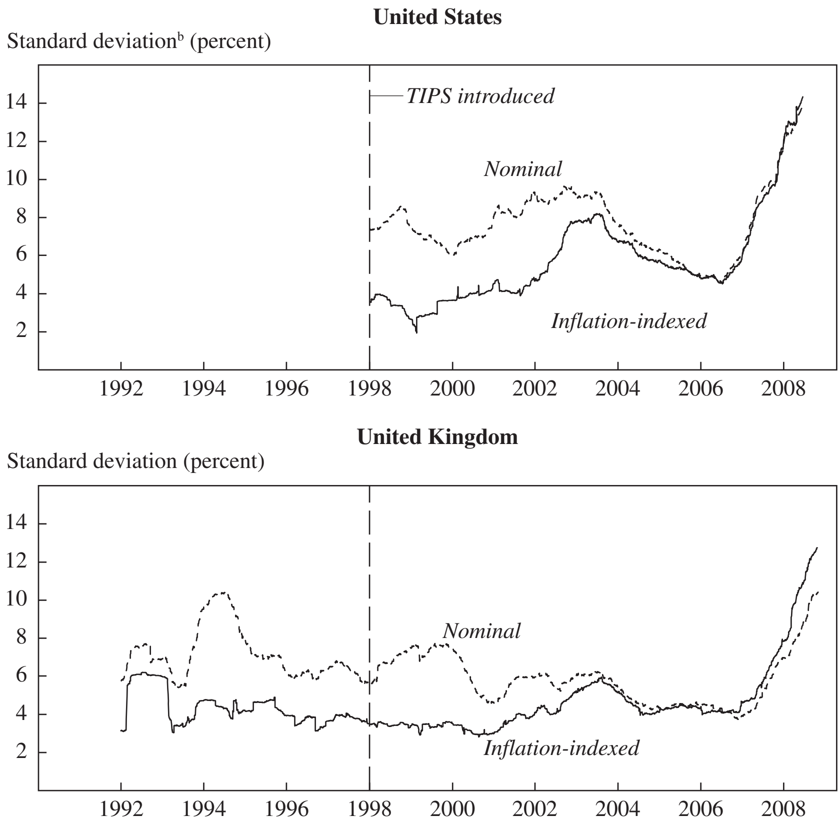
The bottom panel of figure 3 depicts the breakeven inflation history for the United Kingdom. It shows a strong decline in the late 1990s, probably associated with the granting of independence to the Bank of England by the newly elected Labour government in 1997, and a steady upward creep from 2003 to early 2008, followed by a collapse in 2008 comparable to that in the United States. Realized inflation in the United Kingdom also fell in the 1990s, albeit less dramatically than breakeven inflation, and rose in the mid-2000s.

The top panel of figure 4 examines the short-run volatility of TIPS returns. Using daily government bond prices, with the appropriate correction for coupon payments, we calculate daily nominal return series for the on-the-run 10-year TIPS. This graph plots the annualized standard deviation of this series within a centered moving one-year window. For comparison, it also shows the corresponding annualized standard deviation for 10-year nominal Treasury bond returns, calculated from Bloomberg yield data on the assumption that the nominal bonds trade at par. The striking message of this graph is that TIPS returns have become far more volatile in recent years. In the early years, until 2002, the short-run volatility of 10-year TIPS was only about half that of 10-year nominal Treasury bonds, but the two standard deviations converged between 2002 and 2004 and have been extremely similar since then. The annualized standard deviations of both bonds ranged between 5 and 8 percent between 2004 and 2008 and then increased dramatically to almost 14 percent.

Mechanically, two variables drive the volatility of TIPS returns. The more important of these is the volatility of TIPS yields, which has increased over time; in recent years it has been very similar to the volatility of nominal Treasury bond yields as breakeven inflation has stabilized. A second, amplifying factor is the duration of TIPS, which has increased as TIPS yields have declined.[3] The same two variables determine the very similar volatility patterns shown in the bottom panel of figure 4 for the United Kingdom.

3. The duration of a bond is the average time to payment of its cash flows, weighted by the present values of those cash flows. Duration also equals the elasticity of a bond's price with respect to its gross yield (one plus its yield in natural units). A coupon bond has duration less than its maturity, and its duration increases as its yield falls. Since TIPS yields are lower than nominal bond yields, TIPS have greater duration for the same maturity, and hence a greater volatility of returns for the same yield volatility, but the differences in volatility explained by duration are quite small.

Figure 4. Volatility of Ten-Year Nominal and Inflation-Indexed Government Bond Returns, 1992–2009[a]



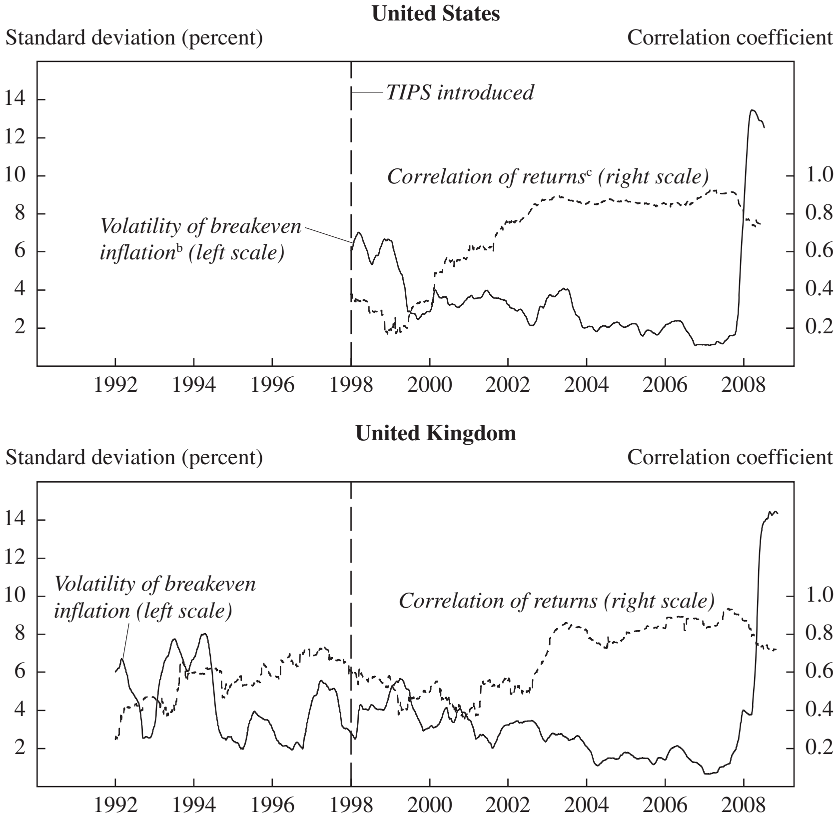
Source: Authors' calculations from Bloomberg data; see the online appendix for details.

a. Bond yields are computed from spliced yields and price data of individual issuances.

b. Standard deviation of daily returns on government bonds with 10 years to maturity, over a one-year centered moving window.

The top panel of figure 5 plots the annualized standard deviation of 10-year breakeven inflation (measured in terms of the value of a bond position long a 10-year nominal Treasury bond and short a 10-year TIPS). This standard deviation trended downward from 7 percent in 1998 to about 1 percent in 2007 before spiking above 13 percent in 2008. To the extent that breakeven inflation represents the long-term inflation expectations of market participants, these expectations stabilized during most of the sample period but moved dramatically in 2008. Such a destabilization of

Figure 5. Volatility of Ten-Year Breakeven Inflation and Correlation of Nominal and Inflation-Indexed Government Bond Returns, 1992–2009[a]



Source: Authors' calculations from Bloomberg data; see the online appendix for details.

a. Bond yields are computed from spliced yields and price data of individual issuances.

b. Standard deviation of the daily 10-year breakeven inflation rate, measured in terms of the value of a position long a 10-year nominal government bond and short a 10-year inflation-indexed bond, over a one-year moving window.

c. Correlation of daily inflation-indexed and nominal bond returns within a one-year moving window.

inflation expectations should be a matter of serious concern to the Federal Reserve, although, as we discuss in section IV, institutional factors may have contributed to the movements in breakeven inflation during the market disruption of late 2008. The bottom panel of figure 5 suggests that the Bank of England should be equally concerned by the recent destabilization of the yield spread between nominal and inflation-indexed gilts.

Figure 5 also plots the correlations of daily inflation-indexed and nominal government bond returns within a one-year moving window. Early in the period, the correlation for U.S. bonds was quite low at about 0.2, but it increased to almost 0.9 by the middle of 2003 and stayed there until 2008. In the mid-2000s TIPS behaved like nominal Treasuries and did not exhibit independent return variation. This coupling of TIPS and nominal Treasuries ended in 2008. The same patterns are visible in the U.K. data.

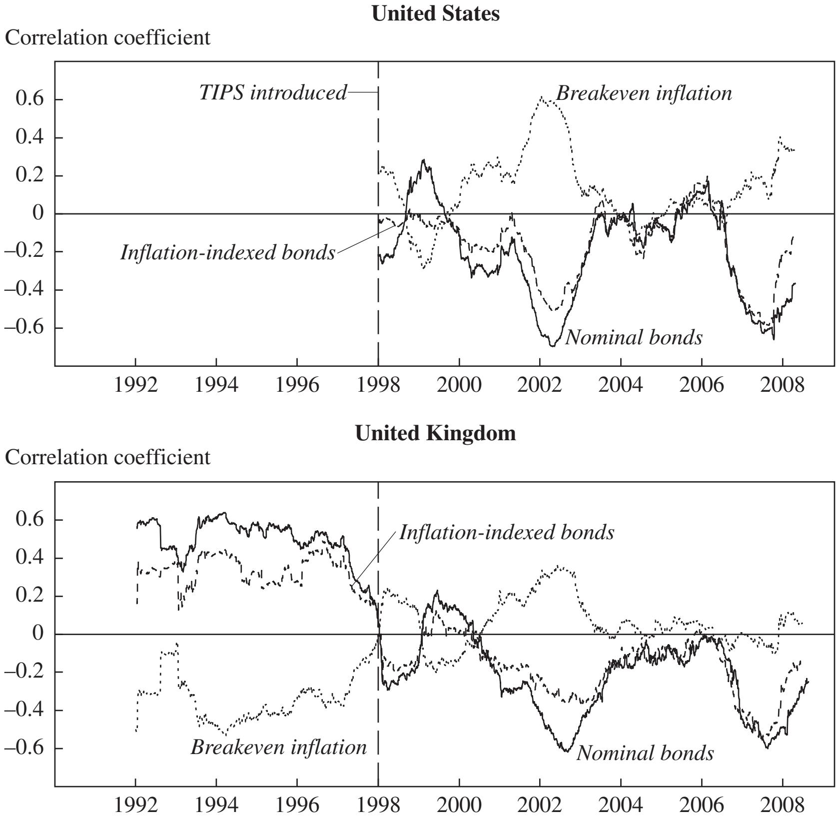
Although TIPS have been volatile assets, this does not necessarily imply that they should command large risk premiums. According to rational asset pricing theory, the risk premium on an asset should be driven by the covariance of its returns with the marginal utility of consumption rather than by the variance of returns. One common proxy for marginal utility, used in the CAPM, is the return on an aggregate equity index. Figure 6 plots the correlations of daily inflation-indexed bond returns, nominal government bond returns, and breakeven inflation returns with daily returns on aggregate U.S. and U.K. stock indexes, again within a centered moving one-year window. Figure 7 repeats this exercise for betas (regression coefficients of daily bond returns and breakeven inflation on the same stock indexes).

All these figures tell a similar story. During the 2000s there has been considerable instability in both countries in the correlations between government bonds of both types and stock returns, but these correlations have been predominantly negative, implying that government bonds can be used to hedge equity risk. To the extent that the CAPM describes risk premiums across asset classes, government bonds should have predominantly negative rather than positive risk premiums. The negative correlation is particularly strong for nominal government bonds, because breakeven inflation has been positively correlated with stock returns, especially during 2002–03 and 2007–08. Campbell, Sunderam, and Viceira (2009) build a model in which a changing correlation between inflation and stock returns drives changes in the risk properties of nominal Treasury bonds. That model assumes a constant equity market correlation for TIPS and thus cannot explain the correlation movements shown for TIPS in figures 6 and 7. In section III we explore the determination of TIPS risk premiums in greater detail.

II. Inflation-Indexed Bond Yields and the Dynamics of Short-Term Real Interest Rates

To understand the movements of inflation-indexed bond yields, it is essential first to understand how changes in short-term real interest rates propagate along the real term structure. Declining yields for inflation-indexed bonds in the 2000s may not be particularly surprising given that short-term real interest rates have also been low in this decade.

Figure 6. Correlations of Ten-Year Government Bond Returns and Breakeven Inflation Rates with Equity Returns, 1992–2009[a]

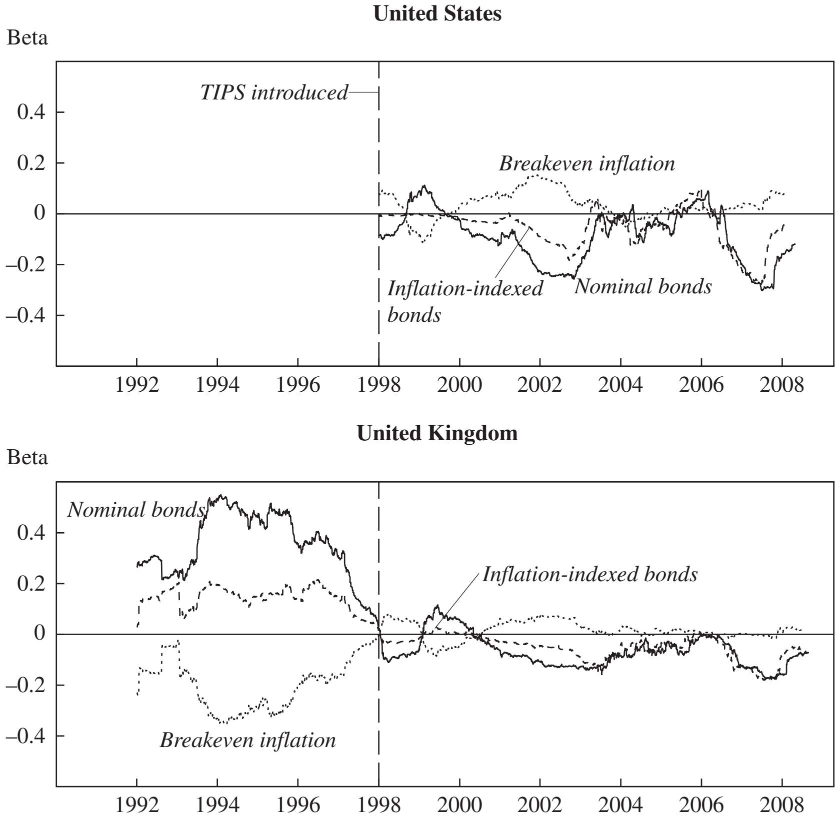


Source: Authors' calculations from Bloomberg and Center for Research in Security Prices data; see the online appendix for details.

a. Correlations between nominal returns on the stock index of the indicated country (CRSP Value-Weighted Index for the United States, FTSE-100 for the United Kingdom) and either nominal 10-year returns on the indicated bond type (computed from spliced yields and price data of individual issuances) or returns in the breakeven inflation rate (the difference between nominal bond returns and inflation-indexed bond returns).

Before TIPS were introduced in 1997, Campbell and Shiller (1997) used a time-series model for the short-term real interest rate to create a hypothetical TIPS yield series under the assumption that the expectations theory of the term structure in logarithmic form, with zero log risk premiums, describes inflation-indexed bond yields. (This does not require the assumption that the expectations theory describes nominal bond yields, a model that

Figure 7. Betas of Ten-Year Government Bond Returns and Breakeven Inflation Rates with Equity Returns, 1992–2009[a]



Source: Authors' calculations from Bloomberg and Center for Research in Security Prices data; see the online appendix for details.

a. Coefficients from a regression of either nominal 10-year returns on the indicated bond type (computed from spliced yields and price data of individual issuances) or the breakeven inflation rate (the difference between nominal bond returns and inflation-indexed bond returns) on nominal returns on the stock index of the indicated country (CRSP Value-Weighted Index for the United States, FTSE-100 for the United Kingdom).

has often been rejected in U.S. data.) In this section we update Campbell and Shiller's analysis and ask how well the simple expectations theory describes the 12-year history of TIPS yields.

Campbell and Shiller (1997) estimated a VAR model on quarterly U.S. data over 1953–94. Their basic VAR included the ex post real return on a 3-month nominal Treasury bill, the nominal bill yield, and the once-

Table 1. Results of VAR Estimation and Observed and Hypothetical Moments of Ten-Year Inflation-Indexed Bond Yields, United States[a]

	Dependent variable		
Independent variable	*Inflation-indexed bill return*	*Nominal bill yield*	*Inflation*[b]
Inflation-indexed bill return	–0.06	0.01	–0.21
	(0.10)	(0.02)	(0.10)
Nominal bill yield	0.62	0.95	0.57
	(0.17)	(0.04)	(0.16)
Inflation	0.09	–0.04	0.58
	(0.08)	(0.02)	(0.08)
Constant	–0.005	0.001	0.007
	(0.002)	(0.0005)	(0.002)
R^2	0.26	0.91	0.63
Moments of 10-year inflation-indexed bond yields	*Observed*		*Hypothetical*
Mean	2.66		1.04
Standard deviation	0.95		0.39
Correlation		0.71	

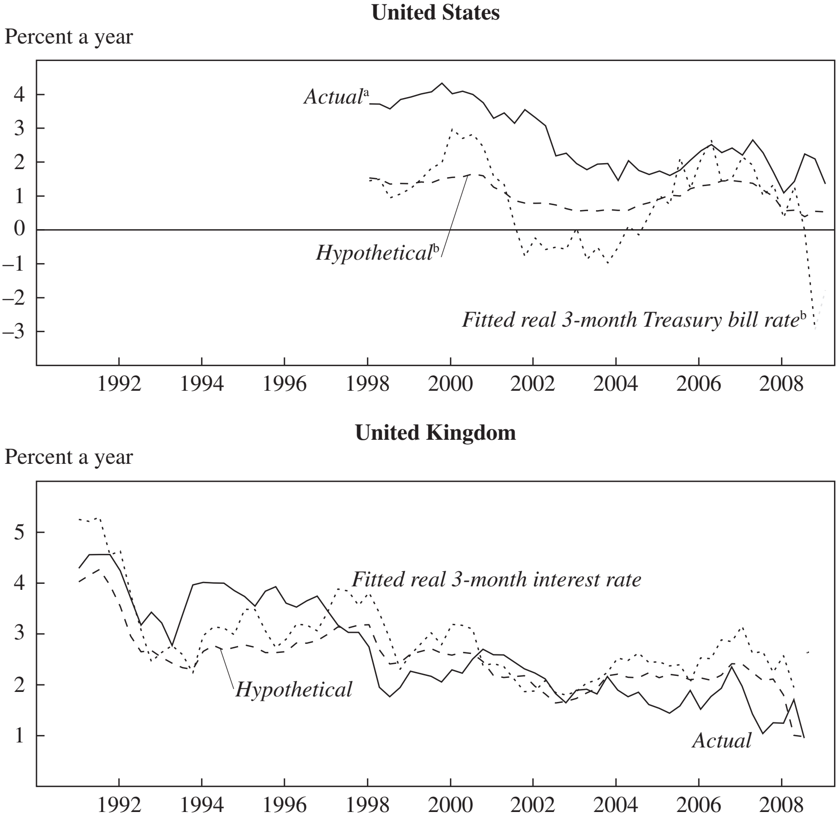
Source: Authors' regressions. Independent variables are lagged one period.
a. Numbers in parentheses are standard errors.
b. Non–seasonally adjusted all-urban-consumer price index (NSA CPI-U).

lagged one-year inflation rate. They solved the VAR forward to create forecasts of future quarterly real interest rates at all horizons, and then aggregated the forecasts to generate the implied long-term inflation-indexed bond yield.

Table 1 repeats this analysis for 1982–2008. The top panel reports the estimated VAR coefficients, and the bottom panel reports selected sample moments of the hypothetical VAR-implied 10-year TIPS yields, and for comparison the same moments of observed TIPS yields, over the period since TIPS were introduced. The table delivers several interesting results.

First, the hypothetical yields are considerably lower on average than the observed yields, with a mean of 1.04 percent compared with 2.66 percent. This implies that on average, investors demand a risk or liquidity premium for holding TIPS rather than nominal Treasuries. Second, hypothetical yields are more stable than observed yields, with a standard deviation of 0.39 percent as opposed to 0.95 percent. This reflects the fact that observed yields have declined more dramatically since 1997 than have hypothetical yields. Third, hypothetical and observed yields have a relatively high correlation of 0.71, even though no TIPS data were used to construct the hypothetical

Figure 8. Hypothetical and Actual Yields on Ten-Year Inflation-Indexed Bonds



Source: Authors' calculations from Bloomberg, Center for Research in Security Prices, and Bureau of Labor Statistics data; see the online appendix for details.

a. Quarterly averages of 10-year TIPS yields (from the top panel of figure 2).

b. Extracted from an estimated VAR(1) model in quarterly U.S. data over 1953–94 on the ex post real return on a 3-month nominal Treasury bill, the nominal bill yield, and the lagged one-year inflation rate.

yields. Real interest rate movements do have an important effect on the TIPS market, and the VAR system is able to capture much of this effect.

The top panel of figure 8 shows these results in graphical form, plotting the history of the observed TIPS yield, the hypothetical VAR-implied TIPS yield, and the VAR estimate of the ex ante short-term real interest rate. The sharp decline in the real interest rate in 2001 and 2002 drives down the hypothetical TIPS yield, but the observed TIPS yield is more volatile and declines more strongly. The gap between the observed TIPS yield and the

Table 2. Results of VAR Estimation and Observed and Hypothetical Moments of Ten-Year Inflation-Indexed Bond Yields, United Kingdom[a]

	Dependent variable		
Independent variable	*Inflation-indexed bill return*	*Nominal bill yield*	*Inflation[b]*
Inflation-indexed bill return	0.09	–0.04	–0.39
	(0.09)	(0.03)	(0.09)
Nominal bill yield	0.42	1.07	0.82
	(0.19)	(0.05)	(0.18)
Inflation	0.02	–0.03	0.66
	(0.07)	(0.02)	(0.07)
Constant	0.0001	0.0002	0.0007
	(0.0019)	(0.0005)	(0.0018)
R^2	0.22	0.93	0.87
Moments of 10-year inflation-indexed bond yields	*Observed*		*Hypothetical*
Mean	2.64		2.49
Standard deviation	1.00		0.61
Correlation		0.77	

Source: Authors' regressions. Independent variables are lagged one period.
a. Numbers in parentheses are standard errors.
b. Retail price index.

hypothetical yield shrinks fairly steadily over the sample period until the very end, when the 2008 spike in the observed yield widens the gap again. These results suggest that when they were first issued, TIPS commanded a high risk or liquidity premium, which then declined until 2008.

Table 2 and the bottom panel of figure 8 repeat these exercises for the United Kingdom. Here the hypothetical and observed yields have similar means (2.64 and 2.49 percent, respectively), but again the standard deviation is lower for the hypothetical yield, at 0.61 percent, than for the observed yield, at 1.00 percent. The two yields have a high correlation of 0.77. The graph shows that the VAR model captures much of the decline in inflation-indexed gilt yields since the early 1990s. It is able to do this because the estimated process for the U.K. ex ante real interest rate is highly persistent, so that the decline in the real rate over the sample period translates almost one for one into a declining yield on long-term inflation-indexed gilts. However, for the same reason the model cannot account for variations in the spread between the short-term expected real interest rate and the long-term inflation-indexed gilt yield.

It is notable that the expectations hypothesis of the real term structure does not explain the low average level of inflation-indexed gilt yields since 2005.

A new U.K. accounting standard introduced in 2000, FRS17, may account for this. As Viceira and Mitsui (2003) and Dimitri Vayanos and Jean-Luc Vila (2007) explain, FRS17 requires U.K. pension funds to mark their liabilities to market, using discount rates derived from government bonds. The standard was implemented, after some delay, in 2005, and it greatly increased the demand for inflation-indexed gilts from pension funds seeking to hedge their inflation-indexed liabilities.

III. The Systematic Risks of Inflation-Indexed Bonds

The yield history and VAR analysis presented in the previous two sections suggest that U.S. and U.K. inflation-indexed bonds had low risk premiums in the mid-2000s, but the former, at least, had higher risk premiums when they were first issued. In this section we use asset pricing theory to ask what fundamental properties of the macroeconomy might lead to high or low risk premiums on inflation-indexed bonds. We first use the consumption-based asset pricing framework and then present a less structured empirical analysis that relates bond risk premiums to changing covariances of bonds with stocks.

III.A. Consumption-Based Pricing of Inflation-Indexed Bonds

A standard paradigm for consumption-based asset pricing assumes that a representative investor has Epstein-Zin (1989, 1991) preferences. This preference specification, a generalization of power utility, allows the coefficient of relative risk aversion γ and the elasticity of intertemporal substitution (EIS) ψ to be separate free parameters, whereas power utility restricts one to be the reciprocal of the other. Under the additional assumption that asset returns and consumption are jointly log normal and homoskedastic, the Epstein-Zin Euler equation implies that the risk premium *RP* on any asset *i* over the short-term safe asset is

$$RP_i \equiv E_t\left[r_{i,t+1}\right] - r_{f,t+1} + \frac{\sigma_i^2}{2} = \theta\frac{\sigma_{ic}}{\psi} + \left(1-\theta\right)\sigma_{iw}. \qquad (1)$$

In words, the risk premium is defined to be the expected excess log return on the asset over the risk-free log return r_f, plus one-half its variance to convert from a geometric average to an arithmetic average, that is, to correct for Jensen's inequality. The preference parameter $\theta \equiv (1-\gamma)/[1-(1/\psi)]$; in the power utility case, $\gamma = 1/\psi$, so that $\theta = 1$. According to this formula, the risk premium on any asset is a weighted average of two conditional covariances, the consumption covariance σ_{ic} (scaled by the reciprocal of the EIS), which gets full weight in the power utility case, and the wealth covariance σ_{iw}. The risk premium is constant over time by the assumption of homoskedasticity.

It is tempting to treat the consumption covariance and the wealth covariance as two separate quantities, but this ignores the fact that consumption and wealth are linked by the intertemporal budget constraint and by a time-series Euler equation. By using these additional equations, one can substitute either consumption (Campbell 1993) or wealth (Restoy and Weil 1998) out of the formula for the risk premium.

The first approach explains the risk premium using covariances with the current market return and with news about future market returns; this might be called "CAPM+," as it generalizes the insight about risk that was first formalized in the CAPM. Campbell (1996) and Campbell and Tuomo Vuolteenaho (2004) pursue this approach, which can also be regarded as an empirical version of Robert Merton's (1973) intertemporal CAPM.

The second approach explains the risk premium using covariances with current consumption growth and with news about future consumption growth; this might be called "CCAPM+," as it generalizes the insight about risk that is embodied in the consumption-based CAPM with power utility. This approach has generated a large asset pricing literature in recent years (for example, Bansal and Yaron 2004; Bansal, Khatchatrian, and Yaron 2005; Piazzesi and Schneider 2007; Bansal, Kiku, and Yaron 2007; Bansal, Dittmar, and Kiku 2009; Hansen, Heaton, and Li 2008). Some of this recent work adds heteroskedasticity to the simple homoskedastic model discussed here.

The CAPM+ approach delivers an approximate formula for the risk premium on any asset as

$$RP_i = \gamma\sigma_{iw} - (\gamma - 1)\sigma_{i,TIPS},$$

where σ_{iw} is the covariance of the unexpected return on asset i with the return on the aggregate wealth portfolio, and $\sigma_{i,TIPS}$ is the covariance with the return on an inflation-indexed perpetuity.

The intuition, which dates back to Merton (1973), is that conservative long-term investors value assets that deliver high returns at times when investment opportunities are poor. Such assets hedge investors against variation in the sustainable income stream that is delivered by a given amount of wealth. In a homoskedastic model, risk premiums are constant, and the relevant measure of long-run investment opportunities is the yield on an inflation-indexed bond. Thus, the covariance with the return on an inflation-indexed perpetuity captures the intertemporal hedging properties of an asset. In equilibrium, an asset that covaries strongly with an inflation-indexed perpetuity will offer a low return as the price of the desirable insurance it offers.

Applying this formula to the inflation-indexed perpetuity itself, we find that

$$RP_{TIPS} = \gamma\sigma_{TIPS,w} - (\gamma - 1)\sigma^2_{TIPS}.$$

In words, the risk premium on a long-term inflation-indexed bond is increasing in its covariance with the wealth portfolio, as in the traditional CAPM, but decreasing in the variance of the bond return whenever the risk aversion of the representative agent is greater than 1. Paradoxically, the insurance value of inflation-indexed bonds is higher when these bonds have high short-term volatility, because in this case they hedge important variability in investment opportunities. In a traditional model with a constant real interest rate, inflation-indexed bonds have constant yields; but in this case there is no intertemporal hedging to be done, and the traditional CAPM can be used to price all assets, including inflation-indexed bonds.

The CCAPM+ approach can be written as

$$RP_i = \gamma\sigma_{ic} + \left(\gamma - \frac{1}{\psi}\right)\sigma_{ig}, \tag{2}$$

where σ_{ig} is the covariance of the unexpected return on asset i with revisions in expected future consumption growth $\tilde{g}_{t+1}$, defined by

$$\tilde{g}_{t+1} \equiv (E_{t+1} - E_t)\sum_{j=1}^{\infty}\rho^j \Delta c_{t+1+j}. \tag{3}$$

In equation 2 the risk premium on any asset is the coefficient of risk aversion γ times the covariance of that asset with consumption growth, plus $(\gamma - 1/\psi)$ times the covariance of the asset with revisions in expected future consumption growth, discounted at a constant rate ρ. The second term is zero if $\gamma = 1/\psi$, the power utility case, or if consumption growth is unpredictable so that there are no revisions in expected future consumption growth. Evidence on the equity premium and the time-series behavior of real interest rates suggests that $\gamma > 1/\psi$. This implies that controlling for assets' contemporaneous consumption covariance, investors require a risk premium to hold assets that pay off when expected future consumption growth increases. Ravi Bansal and Amir Yaron (2004) use the phrase "risks for the long run" to emphasize this property of the model.

What does this model imply about the pricing of an inflation-indexed perpetuity? When expected real consumption growth increases by 1 percentage point, the equilibrium real interest rate increases by $1/\psi$ percentage points, and thus the return on the inflation-indexed perpetuity is given by[4]

$$r_{TIPS,t+1} = -\frac{1}{\psi}\tilde{g}_{t+1}. \tag{4}$$

Combining equation 2 with equation 4, one can solve for the risk premium on the inflation-indexed perpetuity:

$$RP_{TIPS} = \gamma\left(-\frac{1}{\psi}\right)\sigma_{cg} + \left(\gamma - \frac{1}{\psi}\right)\left(-\frac{1}{\psi}\right)\sigma_g^2. \tag{5}$$

With power utility, only the first term in equation 5 is nonzero. This case is described by Campbell (1986). In a consumption-based asset pricing model with power utility, assets are risky if their returns covary positively with consumption growth. Since bond prices rise when interest rates fall, bonds are risky assets if interest rates fall in response to consumption growth. Because equilibrium real interest rates are positively related to expected future consumption growth, this is possible only if positive consumption shocks drive expected future consumption growth downward, that is, if consumption growth is negatively autocorrelated. In an economy with temporary downturns in consumption, equilibrium real interest rates rise and TIPS prices fall in recessions, and therefore investors require a risk premium to hold TIPS.

In the presence of persistent shocks to consumption growth, by contrast, consumption growth is positively autocorrelated. In this case recessions not only drive down current consumption but also lead to prolonged periods of slow growth, driving down real interest rates. In such an economy the prices of long-term inflation-indexed bonds rise in recessions, making them desirable hedging assets with negative risk premiums.

This paradigm suggests that the risk premium on TIPS will fall if investors become less concerned about temporary business-cycle shocks, and more concerned about shocks to the long-term consumption growth rate.

4. A more careful derivation of this expression can be found in Campbell (2003, p. 841), equation 41.

It is possible that such a shift in investor beliefs did take place during the late 1990s and 2000s, as the Great Moderation mitigated concerns about business-cycle risk (Bernanke 2004; Blanchard and Simon 2001; Kim and Nelson 1999; McConnell and Perez-Quiros 2000; Stock and Watson 2003) while long-term uncertainties about technological progress and climate change became more salient. Of course, the events of 2007–08 have brought business-cycle risk to the fore again. The movements of inflation-indexed bond yields have been broadly consistent with changing risk perceptions of this sort.

The second term in equation 5 is also negative under the plausible assumption that $\gamma > 1/\psi$, and its sign does not depend on the persistence of the consumption process. However, its magnitude does depend on the volatility of shocks to long-run expected consumption growth. Thus, increasing uncertainty about long-run growth drives down inflation-indexed bond premiums through this channel as well.

Overall, the Epstein-Zin paradigm suggests that inflation-indexed bonds should have low or even negative risk premiums relative to short-term safe assets, consistent with the intuition that these bonds are the safe asset for long-term investors.

III.B. Bond Risk Premiums and the Bond-Stock Covariance

The consumption-based analysis of the previous section delivers insights but also has weaknesses. The model assumes constant second moments and thus implies constant risk premiums; it cannot be used to track changing variances, covariances, or risk premiums in the inflation-indexed bond market. Although one could generalize the model to allow time-varying second moments, as in the long-run risks model of Bansal and Yaron (2004), the low frequency of consumption measurement makes it difficult to implement the model empirically. In this section we follow a different approach, writing down a model of the stochastic discount factor (SDF) that allows us to relate the risk premiums on inflation-indexed bonds to the covariance of these bonds with stock returns.

To capture the time-varying correlation of returns on inflation-indexed bonds with stock returns, we propose a highly stylized term structure model in which the real interest rate is subject to conditionally heteroskedastic shocks. Conditional heteroskedasticity is driven by a state variable that captures time variation in aggregate macroeconomic uncertainty. We build our model in the spirit of Campbell, Sunderam, and Viceira (2009), who emphasize the importance of changing macroeconomic conditions for an understanding of time variation in systematic risk and in the correlations of returns on fundamental asset classes. Our model modifies their quadratic term structure model to allow for heteroskedastic shocks to the real rate.

We assume that the log of the real SDF, $m_{t+1} = \log M_{t+1}$, can be described by

$$(6) \qquad -m_{t+1} = x_t + \frac{1}{2}\sigma_m^2 + \varepsilon_{m,t+1},$$

where x_t follows a conditionally heteroskedastic AR(1) process,

$$(7) \qquad x_{t+1} = \mu_x\left(1 - \varphi_x\right) + \varphi_x x_t + v_t \varepsilon_{x,t+1} + \varepsilon'_{x,t+1},$$

and v_t follows a standard AR(1) process,

$$(8) \qquad v_{t+1} = \mu_v\left(1 - \varphi_v\right) + \varphi_v v_t + \varepsilon_{v,t+1}.$$

The shocks $\varepsilon_{m,t+1}$, $\varepsilon_{x,t+1}$, $\varepsilon'_{x,t+1}$, and $\varepsilon_{v,t+1}$ have zero means and are jointly normally distributed with a constant variance-covariance matrix. We assume that $\varepsilon'_{x,t+1}$ and $\varepsilon_{v,t+1}$ are orthogonal to each other and to the other shocks in the model. We adopt the notation σ_i^2 to describe the variance of shock ε_i, and σ_{ij} to describe the covariance between shock ε_i and shock ε_j. The conditional volatility of the log SDF (σ_m) describes the price of aggregate market risk, or the maximum Sharpe ratio in the economy, which we assume to be constant.[5]

The online appendix to this paper (see footnote 1) shows how to solve this model for the real term structure of interest rates. The state variable x_t is equal to the log short-term real interest rate, which follows an AR(1) process whose conditional variance is driven by the state variable v_t.

In a standard consumption-based power utility model of the sort discussed in the previous subsection, v_t would capture time variation in the dynamics of consumption growth. When v_t is close to zero, shocks to the real interest rate are uncorrelated with the SDF; in a power utility model, this would imply that shocks to future consumption growth are uncorrelated with shocks to the current level of consumption. As v_t moves away from zero, the volatility of the real interest rate increases and its covariance with the SDF becomes more positive or more negative. In a power utility model,

5. Campbell, Sunderam, and Viceira (2009) consider a much richer term structure model in which σ_m^2 is time varying. They note that in that case the process for the log real SDF admits an interpretation as a reduced form of structural models such as those of Bekaert, Engstrom, and Grenadier (2006) and Campbell and Cochrane (1999) in which aggregate risk aversion is time varying. Campbell, Sunderam, and Viceira find that time-varying risk aversion plays only a limited role in explaining the observed variation in bond risk premiums. For simplicity, we set σ_m^2 constant.

this corresponds to a covariance between consumption shocks and future consumption growth that is either positive or negative, reflecting either momentum or mean reversion in consumption. Broadly speaking, one can interpret v_t as a measure of aggregate uncertainty about long-run growth in the economy. At times when that uncertainty increases, real interest rates become more volatile.

Solving the model for the real term structure of interest rates, we find that the log price of an n-period inflation-indexed bond is linear in the short-term real interest rate x_t, with coefficient $B_{x,n}$, and quadratic in aggregate economic uncertainty v_t, with linear coefficient $B_{v,n}$ and quadratic coefficient $C_{v,n}$. An important property of this model is that bond risk premiums are time varying. They are approximately linear in v_t, where the coefficient on v_t is proportional to σ_m^2.

A time-varying conditional covariance between the SDF and the real interest rate implies that the conditional covariance between inflation-indexed bonds and risky assets such as equities should also vary over time as a function of v_t. To see this, we now introduce equities into the model. To keep things simple, we assume that the unexpected log return on equities is given by

$$r_{e,t+1} - E_t r_{e,t+1} = \beta_{em} \varepsilon_{m,t+1}. \qquad (9)$$

This implies that the equity premium equals $\beta_{em}\sigma_m^2$, the conditional standard deviation of stock returns is $\beta_{em}\sigma_m$, and the Sharpe ratio on equities is σ_m. Equities deliver the maximum Sharpe ratio because they are perfectly correlated with the SDF. Thus, we are imposing the restrictions of the traditional CAPM, ignoring the intertemporal hedging arguments stated in the previous subsection.

The covariance between stocks and inflation-indexed bonds is given by

$$\text{cov}_t\left(r_{e,t+1}, r_{n,t+1}\right) = B_{x,n-1}\beta_{em}\sigma_{mx}v_t, \qquad (10)$$

which is proportional to v_t. This proportionality is also a reason why we consider two independent shocks to x_t. In the absence of a homoskedastic shock $\varepsilon'_{x,t}$ to x_t, our model would imply that the conditional volatility of the short-term real interest rate would be proportional to the conditional covariance of stock returns with returns on inflation-indexed bonds. However, although the two conditional moments appear to be correlated in the data, they are not perfectly correlated, still less proportional to one another.

We estimate this term structure model by applying the nonlinear Kalman filter procedure described in Campbell, Sunderam, and Viceira (2009) to data on zero-coupon inflation-indexed bond yields, from Refet Gürkaynak, Brian Sack, and Jonathan Wright (2008) for the period 1999–2008, and total returns on the value-weighted U.S. stock market portfolio, from CRSP data.[6] Because the U.S. Treasury does not issue TIPS with short maturities, and there are no continuous observations of yields on near-to-maturity TIPS, this dataset does not include short-term zero-coupon TIPS yields. To approximate the short-term real interest rate, we use the ex ante short-term real interest rate implied by our VAR approach described in section II.

Our estimation makes several identifying and simplifying assumptions. First, we identify σ_m using the long-run average Sharpe ratio for U.S. equities, which we set to 0.23 on a quarterly basis (equivalent to 0.46 on an annual basis). Second, we identify β_{em} as the sample standard deviation of equity returns in our sample period (0.094 per quarter, or 18.9 percent per year) divided by σ_m, for a value of 0.41. Third, we exactly identify x_t with the ex ante short-term real interest rate estimated from the VAR model of the previous section, which we treat as observed, adjusted by a constant. That is, we give the Kalman filter a measurement equation that equates the VAR-estimated short-term real interest rate to x_t with a free constant term but no measurement error. The inclusion of the constant term is intended to capture liquidity effects that lower the yields on Treasury bills relative to the longer-term real yield curve.

Fourth, because the shock $\varepsilon_{x,t+1}$ is always premultiplied by v_t, we normalize σ_x to 1. Fifth, we assume that there is perfect correlation between the shock $\varepsilon_{x,t+1}$ and the shock $\varepsilon_{m,t+1}$ to the SDF; equivalently, we set σ_{mx} equal to 0.23. This delivers the largest possible time variation in inflation-indexed bond risk premiums and thus maximizes the effect of changing risk on the TIPS yield curve. Sixth, we treat equation 10 as a measurement equation with no measurement error, where we replace the covariance on the left-hand side of the equation with the realized monthly covariance of returns on 10-year zero-coupon TIPS with returns on stocks. We estimate the monthly realized covariance using daily observations on stock returns and on TIPS returns from the Gürkaynak-Sack-Wright dataset. Since β_{em} and σ_{mx} have been already exactly identified, this is equivalent to identifying the process v_t with a scaled version of the covariance of returns on TIPS and stocks.

6. The CRSP (Center for Research in Security Prices) data cover all three major U.S. stock exchanges. Gürkaynak, Sack, and Wright estimate zero-coupon TIPS yields by fitting a flexible functional form, a generalization of Nelson and Siegel (1987) suggested by Svensson (1994), to the instantaneous forward rates implied by off-the-run TIPS yields. From fitted forward rates it is straightforward to obtain zero-coupon yields.

Table 3. Parameter Estimates for Alternative Risk Models

		Restricted models	
Parameter	*Full model*	*Constant-covariance model*	*Persistent-risk model*
φ_x	0.94	0.93	0.95
μ_x	0.0028	0.0104	0.0034
φ_v	0.77	NA[a]	Set to 1
μ_v	-2.01×10^{-5}	NA	0.0010
σ_m	Set to 0.23	Set to 0.23	Set to 0.23
σ_x	Set to 1	0.0031	Set to 1
σ_{mx}	0.23	7.23×10^{-4}	0.23
σ_x'	0.0048	NA	0.0031
σ_v	0.0003	NA	0.0004
β_{em}	Set to 0.41	NA	Set to 0.41
σ_{yield}	1.16×10^{-6}	1.12×10^{-4}	9.14×10^{-6}
σ_{cov}	4.74×10^{-4}	NA	5×10^{-4}
Premium	0.0157	0.0016	0.00160

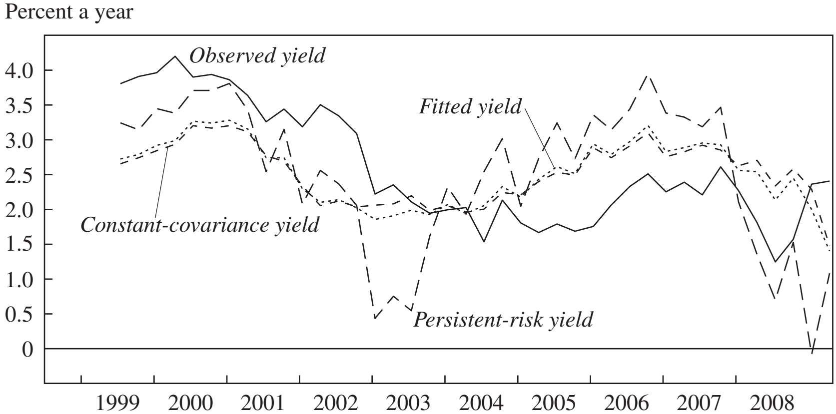
Source: Authors' calculations.
a. NA, not applicable. See the text for descriptions of the models.

We include one final measurement equation for the 10-year zero-coupon TIPS yield using the model's solution for this yield and allowing for measurement error. The identifying assumptions we have made imply that we are exactly identifying x_t with the ex ante short-term real interest rate, v_t with the realized covariance of returns on TIPS and stocks, and the log SDF with stock returns. Thus, our estimation procedure in effect generates hypothetical TIPS yields from these processes and compares them with observed TIPS yields.

Table 3 reports the parameter estimates from our full model and two restricted models. The first of these two models, reported in the second column, drops the measurement equation for the realized stock-bond covariance and assumes that the stock-bond covariance is constant, and hence that TIPS have a constant risk premium, as in the VAR model of section II. The second restricted model, reported in the last column, generates the largest possible effects of time-varying risk premiums on TIPS yields by increasing the persistence of the covariance state variable v_t from the freely estimated value of 0.77, which implies an eight-month half-life for covariance movements, to the largest permissible value of 1.

Figure 9 shows how these three variants of our basic model fit the history of the 10-year TIPS yield. The yields predicted by the freely estimated model of changing risk and by the restricted model with a constant bond-stock covariance are almost on top of one another, diverging only slightly

Figure 9. Real Ten-Year Inflation-Indexed Bond Yields Implied by Alternative Risk Models, United States, 1998–2009[a]



Source: Authors' calculations based on data for yields from Gürkaynak, Sack, and Wright (2008) and for stock returns fom the Center for Research in Security Prices.
a. See the text for descriptions of the models.

in periods such as 2003 and 2008 when the realized bond-stock covariance was unusually negative. This indicates that changing TIPS risk is not persistent enough to have a large effect on TIPS yields. Only when we impose a unit root on the process for the bond-stock covariance do we obtain large effects of changing risk. This model implies that TIPS yields should have fallen more dramatically than they did in 2002–03, and again in 2007, when the covariance of TIPS with stocks turned negative. The persistent-risk model does capture observed TIPS movements in the first half of 2008, but it dramatically fails to capture the spike in TIPS yields in the second half of 2008.

Over all, this exploration of changing risk, as captured by the changing realized covariance of TIPS returns and aggregate stock returns, suggests that variations in risk play only a supporting role in the determination of TIPS yields. The major problem with a risk-based explanation for movements in the inflation-indexed yield curve is that the covariance of TIPS and stocks has moved in a transitory fashion, and thus should not have had a large effect on TIPS yields unless investors were expecting more persistent variation and were surprised by an unusual sequence of temporary changes in risk.

These results contrast with those reported by Campbell, Sunderam, and Viceira (2009), who find that persistent movements in the covariance between inflation and stock returns have had a powerful influence on the nominal U.S. Treasury yield curve. They find that U.S. inflation was negatively correlated with stock returns in the late 1970s and early 1980s, when the major downside risk for investors was stagflation; it has been positively correlated with stock returns in the 2000s, when investors have been more concerned about deflation.[7] As a result, Campbell, Sunderam, and Viceira argue that the inflation risk premium was positive in the 1970s and 1980s but has been negative in the 2000s, implying even lower expected returns on nominal Treasury bonds than on TIPS. The movements in inflation risk identified by Campbell, Sunderam, and Viceira are persistent enough to have important effects on the shape of the nominal U.S. Treasury yield curve, reducing its slope and concavity relative to what was typical in the 1970s and 1980s.

IV. The Crisis of 2008 and Institutional Influences on TIPS Yields

In 2008, as the subprime crisis intensified, the TIPS yield became highly volatile and appeared to become suddenly disconnected from the yield on nominal Treasuries. At the beginning of 2008, the 30-year TIPS yield as reported by the Federal Reserve Bank of St. Louis fell to extremely low levels, as low as 1.66 percent on January 23, 2008. Shorter-maturity TIPS showed even lower yields, and in the spring and again in the summer of 2008 some of these yields became negative, falling below –0.5 percent, reminding market participants that zero is not the lower bound for inflation-indexed bond yields. The fall of 2008 then witnessed an unprecedented and short-lived spike in TIPS yields, peaking at the end of October 2008 when the 30-year TIPS yield reached 3.44 percent.

These extraordinary short-run movements in TIPS yields are mirrored in the 10-year TIPS yield shown in figure 2. The extremely low TIPS yield in early 2008 was given a convenient explanation by some market observers, namely, that investors were panicked by the apparently heightened risks in financial markets due to the subprime crisis and sought safety at just about any price. But if this is the correct explanation, the massive surge in the TIPS yield later in that year remains a mystery. This leap upward was puzzling, since it was not observed in nominal bond yields and so marked a massive drop in the breakeven inflation rate, as seen in figure 3. The U.K. market behaved in similar fashion.

7. The top panel of figure 6 illustrates the positive correlation of U.S. inflation and stock returns during the 2000s, and the bottom panel shows that this correlation has changed sign in the United Kingdom since the early 1990s.

The anomalous sudden jump in inflation-indexed bond yields came as a total surprise to market participants. Indeed, just as the jump was occurring in October 2008, some observers were saying that because inflation expectations had become extremely stable, TIPS and nominal Treasury bonds were virtually interchangeable. For example, Marie Brière and Ombretta Signori concluded, in a paper published in March 2009 (p. 279), "Although diversification was a valuable reason for introducing IL [inflation-linked] bonds in a global portfolio before 2003, this is no longer the case." The extent of this surprise suggests that the rise in the TIPS yield, and its decoupling from nominal Treasury yields, had something to do with the systemic nature of the crisis that beset U.S. financial institutions in 2008.

Indeed, the sharp peak in the TIPS yield and the accompanying steep drop in the breakeven inflation rate occurred shortly after an event that some observers blame for the anomalous behavior of TIPS yields. This was the bankruptcy of the investment bank Lehman Brothers, announced on September 15, 2008. The unfolding of the Lehman bankruptcy proceedings also took place over the same interval of time during which the inflation-indexed bond yield made its spectacular leap upward.

Lehman's bankruptcy was an important event, the first bankruptcy of a major investment bank since that of Drexel Burnham Lambert in 1990. That is not to say that other investment banks did not also get into trouble in the meantime, especially during the subprime crisis. But the federal government had always stepped in to allay fears. Bear Stearns was sold to the commercial bank J.P. Morgan in March 2008 in a deal arranged and financed by the government. Bank of America announced its purchase of Merrill Lynch on September 14, 2008, again with government financial support. Yet the government decided to let Lehman fail, and investors may have interpreted this event as indicative of future government policy that might spell major changes in the economy.

One conceivable interpretation of the events that followed the Lehman bankruptcy announcement is that the market viewed the bankruptcy as a macroeconomic indicator, a sign that the economy would be suddenly weaker. This could have implied a deterioration in the government's fiscal position, justifying an increase in expected future real interest rates and therefore in the long-term real yield on Treasury debt, as well as a decline in inflation expectations, thus explaining the drop in breakeven inflation.

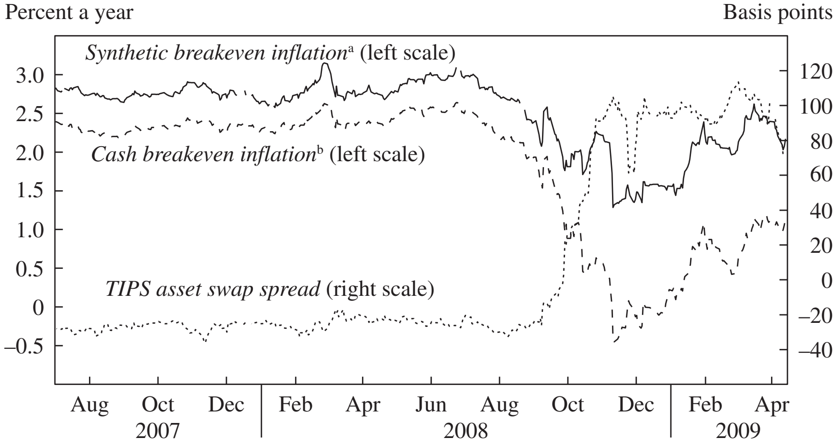
However, many observers doubt that the perceived macroeconomic impact of just this one bankruptcy could bring about such a radical change in expectations about real interest rates and inflation. At one point in 2008 the breakeven seven-year inflation rate reached −1.6 percent. According to Gang Hu and Mihir Worah (2009, p. 1), bond traders at PIMCO, "The market did not believe that it was possible to realize that kind of real rate or sustained deflation."

Another interpretation is that there was a shift in the risk premium for inflation-indexed bonds. In terms of our analysis above, this could be a change in the covariance of TIPS returns with consumption or wealth. But such a view sounds even less plausible than the view that the Lehman effect worked through inflation expectations. We have shown that the observed fluctuations in the covariances of TIPS returns with other variables are hard to rationalize even after the fact, and so it is hard to see why the market would have made a major adjustment in this covariance.

Hu and Worah (2009, pp. 1, 3) conclude instead that, "the extremes in valuation were due to a potent combination of technical factors. . . . Lehman owned Tips as part of repo trades or posted Tips as counterparty collateral. Once Lehman declared bankruptcy, both the court and its counterparty needed to sell these Tips for cash." The traders at PIMCO saw then a flood of TIPS on the market, for which there appeared to be few buyers. Distressed market makers were not willing to risk taking positions in these TIPS; their distress was marked by a crisis-induced sudden and catastrophic widening, by October 2008, in TIPS bid-asked spreads. Making the situation worse was the fact that some institutional investors in TIPS had adopted commodity overlay strategies that forced them to sell TIPS because of the fall at that time in commodity prices. Moreover, institutional money managers had to confront a sudden loss of client interest in relative value trades. Such trades, which take advantage of unusual price differences between securities with related fundamentals, might otherwise have exploited the abnormally low breakeven inflation.

An important clue about the events of fall 2008 is provided by the diverging behavior of breakeven inflation rates in the TIPS cash market and breakeven inflation rates implied by zero-coupon inflation swaps during the months following the Lehman bankruptcy. Zero-coupon inflation swaps are derivatives contracts in which one party pays the other cumulative CPI (consumer price index) inflation over the term of the contract at maturity, in exchange for a predetermined fixed rate. This rate is known as the "synthetic" breakeven inflation rate, because if inflation grew at this fixed rate over the life of the contract, the net payment on the contract at maturity would be zero. As with the "cash" breakeven inflation rate implied by TIPS and nominal Treasury bonds, this rate reflects both expected inflation over the relevant period and an inflation risk premium.

Figure 10. Breakeven Inflation Rates and Asset Swap Spreads on TIPS, July 2007–April 2009



Source: Authors' calculations based on data from Barclays Capital.
a. Synthetic breakeven inflation rate derived from interest rates on zero-coupon inflation swaps.
b. Breakeven inflation rate derived from differences in yields on nominal government bonds and TIPS.

Figure 10 plots the cash breakeven inflation rate implied by off-the-run (as opposed to newly issued, or on-the-run) TIPS and nominal Treasury bonds maturing in July 2017, and the synthetic breakeven inflation rate for the 10-year zero-coupon inflation swap, from July 2007 through April 2009. The figure also plots the TIPS asset swap spread, explained below. The two breakeven rates track each other very closely until mid-September 2008, with the synthetic breakeven inflation rate about 35 to 40 basis points above the cash breakeven inflation rate on average.

This difference in breakeven rates is typical under normal market conditions. According to analysts, it reflects among other things the cost of manufacturing pure inflation protection in the United States. Most market participants supplying inflation protection in the U.S. inflation swap market are leveraged investors such as hedge funds and banks' proprietary trading desks. These investors typically hedge their inflation swap positions by simultaneously taking long positions in TIPS and short positions in nominal Treasuries in the asset swap market. A buying position in an asset swap is functionally similar to a leveraged position in a bond. In an asset swap, one party pays the cash flows on a specific bond and receives in exchange interest at the London interbank offer rate (LIBOR) plus a spread known as the asset swap spread. Typically this spread is negative and larger in absolute magnitude for nominal Treasuries than for TIPS. Thus, leveraged investors selling inflation protection in an inflation swap face a positive financing cost derived from their long-TIPS, short-nominal Treasuries position.

Figure 10 shows that starting in mid-September 2008, cash breakeven inflation rates fell dramatically while synthetic rates did not fall nearly as much; at the same time TIPS asset swap spreads increased from their normal level of about −35 basis points to about +100 basis points. Although not shown in the figure, nominal Treasury asset swap spreads remained at their usual levels. That is, financing long positions in TIPS became extremely expensive relative to historical levels just as their cash price fell abruptly.

There is no reason why declining inflation expectations should directly affect the cost of financing long positions in TIPS relative to nominal Treasuries. The scenario that these two simultaneous changes suggest instead is one of intense selling in the cash market and insufficient demand to absorb those sales—as described by Hu and Worah—and simultaneously another shortage of capital to finance leveraged positions in markets other than that for nominal Treasuries; that is, the bond market events of the fall of 2008 may have been a "liquidity" episode.

Under this interpretation, the synthetic breakeven inflation rate was at the time a better proxy for inflation expectations in the marketplace than the cash breakeven inflation rate, despite the fact that in normal times the inflation swap market is considerably less liquid than the cash TIPS market. The synthetic breakeven inflation rate declined from about 3 percent a year to about 1.5 percent at the trough. This long-run inflation expectation is perhaps more plausible than the 10-year expectation of zero inflation reflected in the cash market for off-the-run bonds maturing in 2017.

Interestingly, cash breakeven inflation rates also diverged between on-the-run and off-the-run TIPS with similar maturities during this period. The online appendix shows that breakeven rates based on on-the-run TIPS were lower than those based on off-the-run TIPS. This divergence reflected another feature of TIPS that causes cash breakeven inflation rates calculated from on-the-run TIPS to be poor proxies for inflation expectations in the face of deflation risk. Contractually, TIPS holders have the right to redeem their bonds at maturity for the greater of either par value at issuance or that value plus accrued inflation during the life of the bond. Thus, when there is a risk of deflation after a period of inflation, new TIPS issues offer better deflation protection than older ones. Accordingly, on-the-run TIPS should be more expensive than off-the-run TIPS, and thus their real yields should be lower. Breakeven inflation rates derived from on-the-run TIPS must be adjusted upward for this deflation protection premium to arrive at a measure of inflation expectations.

We view the experience with TIPS yields after the Lehman bankruptcy as reflecting a highly abnormal market situation, where liquidity problems suddenly created severe financial anomalies. This may seem to imply that one can regard the recent episode as unrepresentative and ignore the observations from these dates. However, investors in TIPS who would like to regard them as the safest long-term investment must consider the extraordinary short-term volatility that such events have given their yields.

V. The Uses of Inflation-Indexed Bonds

We conclude by drawing out some implications of the recent experience with inflation-indexed bonds for both investors and policymakers.

V.A. Implications for Investors

The basic case for investing in inflation-indexed bonds, stated by Campbell and Shiller (1997) and further developed by Michael Brennan and Yihong Xia (2002), Campbell and Viceira (2001, 2002), Campbell, Yeung Lewis Chan, and Viceira (2003), and Jessica Wachter (2003), is that these bonds are the safe asset for long-term investors. An inflation-indexed perpetuity delivers a known stream of real spending power to an infinite-lived investor, and a zero-coupon inflation-indexed bond delivers a known real payment in the distant future to an investor who values wealth at that single horizon. This argument makes no assumption about the time-series variation in yields, and so it is not invalidated by the gradual long-term decline in inflation-indexed bond yields since the 1990s, the mysterious medium-run variations in TIPS yields relative to short-term real interest rates, the spike in yields in the fall of 2008, or the high daily volatility of TIPS returns.

There are, however, two circumstances in which other assets can substitute for inflation-indexed bonds to provide long-term safe returns. First, if the breakeven inflation rate is constant, as will be the case when the central bank achieves perfect anti-inflationary credibility, then nominal bonds are perfect substitutes for inflation-indexed bonds, and conventional government bonds will suit the preferences of conservative long-term investors. For a time in the mid-2000s, it looked as if this nirvana of central bankers was imminent, but the events of 2008 dramatically destabilized inflation expectations and reaffirmed the distinction between inflation-indexed and nominal bonds.

Second, if the ex ante real interest rate is constant, as Eugene Fama (1975) famously asserted, then long-term investors can roll over short-term

Treasury bills to achieve almost perfectly certain long-term real returns. Because inflation uncertainty is minimal over a month or a quarter, Treasury bills expose investors to minimal inflation risk. In general, they do expose investors to the risk of persistent variation in the real interest rate, but this risk is absent if the real interest rate is constant over time.

Investors can tell whether this happy circumstance prevails by forecasting realized real returns on Treasury bills and measuring the movements of their forecasts, as we did in figure 8, or more simply by measuring the volatility of inflation-indexed bond returns. If inflation-indexed bonds have yields that are almost constant and returns with almost no volatility, then Treasury bills are likely to be good substitutes.[8] Seen from this point of view, the high daily volatility of inflation-indexed bond returns illustrated in figure 4, far from being a drawback, demonstrates the value of inflation-indexed bonds for conservative long-term investors.

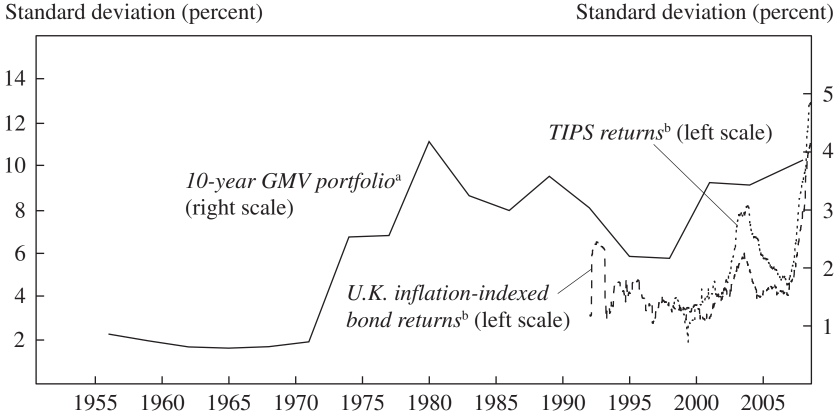
A simple quantitative measure of the usefulness of inflation-indexed bonds is the reduction in the long-run standard deviation of a portfolio that these bonds permit. One can estimate this reduction by calculating the long-run standard deviation of a portfolio of *other* assets chosen to minimize long-run risk (what we call the global minimum variance, or GMV, portfolio). This is the smallest risk that long-run investors can achieve if inflation-indexed bonds are unavailable. Once inflation-indexed bonds become available, the minimum long-run risk portfolio consists entirely of these bonds and has zero long-run risk. Thus, the difference between the minimized long-run standard deviation of the GMV portfolio and zero measures the risk reduction that inflation-indexed bonds make possible.[9]

We constructed a 10-year GMV portfolio consisting of U.S. stocks, nominal 5-year Treasury bonds, and 3-month Treasury bills. To derive the composition of this portfolio and its volatility at each horizon, we used the long-horizon mean-variance approach described in Campbell and Viceira (2005) and its companion technical guide (Campbell and Viceira 2004). We estimated a VAR(1) system for the ex post real return on Treasury bills

8. Strictly speaking, this argument assumes that real yields are described by the expectations hypothesis of the term structure, so that constant short-term real interest rates imply constant long-term real yields. Volatile risk or liquidity premiums on inflation-indexed bonds could make their yields volatile even if short-term real interest rates are constant. However, it is quite unlikely that time variation in risk or liquidity premiums would stabilize the yields on inflation-indexed bonds in an environment of time-varying real interest rates.

9. As an alternative approach, Campbell, Chan, and Viceira (2003) calculate the utility of an infinite-lived investor who has access to stocks, nominal bonds, and bills, and the utility gain when this investor can also hold an inflation-indexed perpetuity. We do not update this more complex calculation here.

Figure 11. Volatility of Returns on the Global Minimum Variance Portfolio and on Inflation-Indexed Government Bonds



Source: Authors' calculations from Bloomberg and Center for Research in Security Prices data.

a. Annualized 10-year standard deviation of the 10-year global minimum variance portfolio of U.S. stocks, nominal 5-year Treasury bonds, and 3-month Treasury bills, computed from a VAR model as described in the text.

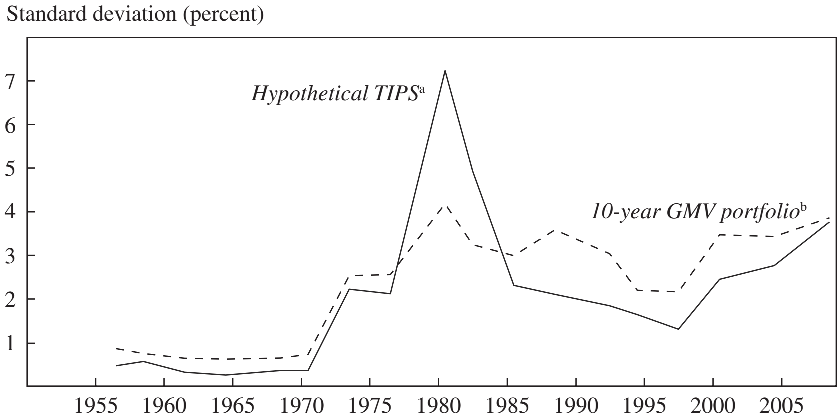
b. Annualized standard deviation of daily returns.

and the excess log return on stocks and nominal bonds. The system also includes variables known to forecast bond and equity risk premiums: the log dividend-price ratio, the yield on Treasury bills, and the spread between that yield and the 5-year Treasury bond yield. From this system we extracted the conditional variance-covariance of 10-year returns using the formulas in Campbell and Viceira (2004) and found the portfolio that minimizes this variance.

Instead of estimating a single VAR system for our entire quarterly sample, 1953Q1–2008Q4, we estimated two VAR systems, one for 1953Q1–1972Q4 and another for 1973Q1–2008Q4. We split the sample this way because we are concerned that the process for inflation and the real interest rate might have changed during the period as a whole. The conditional long-horizon moments of returns also depend on the quarterly variance-covariance matrix of innovations, which we estimated using 3-year windows of quarterly data. Within each window and VAR sample period, we combined the variance-covariance matrix with the full-sample estimate of the slope coefficients to compute the 10-year GMV portfolio and its annualized volatility.

Figure 11 compares the estimated standard deviation of the GMV portfolio with the annualized daily standard deviations of TIPS and inflation-

Figure 12. Volatility of Returns on the Global Minimum Variance Portfolio and of Hypothetical Quarterly TIPS Returns



Source: Authors' calculations from Bloomberg and Center for Research in Security Prices data.

a. Annualized standard deviation of quarterly returns.

b. Annualized 10-year standard deviation of the 10-year global minimum variance portfolio of U.S. stocks, nominal 5-year Treasury bonds, and 3-month Treasury bills, computed from a VAR model as described in the text.

indexed gilts over the period where these bonds exist. Figure 12 compares the same GMV standard deviation with the estimated standard deviation of hypothetical TIPS returns, constructed from the VAR system using the method of Campbell and Shiller (1997) and section II of this paper, which assumes the log expectations hypothesis for inflation-indexed bonds. The annualized 10-year standard deviation of the 10-year GMV portfolio is fairly low in the 1960s, at around 1 percent a year. This is the period that led Fama (1975) to assert that the ex ante real interest rate is constant over time. Starting in the 1970s, however, persistent movements in the real interest rate cause the standard deviation to rise rapidly to about 4 percent a year. The standard deviation drops back to about 2 percent in the mid-1990s, but by 2008 it is once again at a historical high of 4 percent. These numbers imply that inflation-indexed bonds substantially reduce risk for long-term investors.

Both comparisons show that, historically, the minimum long-run risk that can be achieved using other assets has been high when short-term TIPS returns have been volatile. In other words, inflation-indexed bonds are particularly good at reducing long-run risk whenever their short-run risk is high. Such a result may seem paradoxical, but it follows directly from the fact that the need for inflation-indexed bonds for long-term safety is greater when real interest rates vary persistently over time.[10]

Inflation-indexed bonds also play an important role for institutional investors who need to hedge long-term real liabilities. Pension funds and insurance companies with multiyear commitments should use inflation-indexed bonds to neutralize the swings in the present value of their long-dated liabilities due to changes in long-term real interest rates. Of course, these swings become apparent to institutional investors only when they discount real liabilities using market real interest rates, as the United Kingdom has required in recent years. The resulting institutional demand for inflation-indexed gilts seems to have been an important factor driving down their yields (Viceira and Mitsui 2003; Vayanos and Vila 2007).

The total demand of long-term investors for inflation-indexed bonds will depend not only on their risk properties, but also on their expected returns relative to other available investments and on the risk tolerance of the investors. An aggressive long-term investor might wish to short inflation-indexed bonds and invest the proceeds in equities, since stocks have only very rarely underperformed bonds over three or more decades in U.S. and U.K. data. In 2008 it was reported that Clare College, University of Cambridge, was planning to undertake such a strategy.[11] However, Campbell, Chan, and Viceira (2003) estimated positive long-term demand for inflation-indexed bonds by long-term investors who also have the ability to borrow short term or to issue long-term nominal bonds.

Long-term inflation-indexed bonds may be of interest to some short-term investors. Given their high short-run volatility, however, short-term investors will wish to hold these bonds only if they expect to receive high excess returns over Treasury bills (as might reasonably have been the case in 1999–2000 or during the yield spike of the fall of 2008), or if they hold other assets, such as stocks, whose returns can be hedged by an inflation-indexed bond position. We have shown evidence that TIPS and inflation-indexed gilts did hedge stock returns during the downturns of the early 2000s and the late 2000s, and this should make them attractive to short-term equity investors.

10. This point is related to the asset pricing result discussed in section III.A, namely, that when one controls for the stock market covariance of inflation-indexed bonds, the equilibrium risk premium on these bonds for a conservative, infinite-lived, representative investor is declining in their variance.

11. David Turner, "College to Invest 15m Loan in Shares," *Financial Times,* October 27, 2008.

The illiquidity of inflation-indexed bonds is often mentioned as a disadvantage. But in developed countries these bonds are illiquid only relative to the same countries' nominal government bonds, which, along with foreign exchange, are the most liquid financial assets. Compared with almost any other long-term investment vehicle, inflation-indexed government bonds are extremely cheap to trade. In addition, long-term buy-and-hold investors should care very little about transactions costs since they will rarely need to turn over their bond positions.

V.B. Implications for Policymakers

In managing the public debt, the Treasury seeks to minimize the average cost of debt issuance while paying due regard to risk, including refinancing risk. It is commonly thought that short-term Treasury bills are less expensive than long-term debt but that exclusive reliance on bills would impose an unacceptable refinancing risk, as bills must frequently be rolled over.

In the period since TIPS were introduced in 1997, they have proved to be an expensive form of debt ex post, because of the unexpected decline in real interest rates from the 1990s through early 2008. However, our analysis implies that the cost of TIPS should be lower than that of Treasury bills ex ante, because TIPS offer investors desirable insurance against future variation in real interest rates. This is the relevant consideration going forward, as Jennifer Roush, William Dudley, and Michelle Steinberg Ezer (2008) emphasize, and therefore governments should not be deterred from issuing inflation-indexed bonds by the high realized returns on their past issues.

In the current environment, with inflation positively correlated with stock prices, the inflation risk premium in nominal Treasury bonds is likely negative. This implies that long-term nominal debt should be even cheaper for the Treasury than TIPS. However, the correlation between inflation and stock prices has changed sign in the past (Campbell, Sunderam, and Viceira 2009), and it may easily do so again in the future.

Several other considerations also suggest that inflation-indexed bonds are a valuable form of public debt. First, to the extent that particular forms of debt have different investment clienteles, all with downward-sloping demand curves for bonds, it is desirable to diversify across different forms so as to tap the largest possible market for government debt (Greenwood and Vayanos 2008; Vayanos and Vila 2007).

Second, inflation-indexed bonds can be used to draw inferences about bond investors' inflation expectations, and such information is extremely valuable for monetary policymakers.[12] It is true that market disruptions, such as those that occurred in the fall of 2008, complicate the measurement of inflation expectations, but our analysis shows that it is possible to derive meaningful information even in these extreme conditions.

Finally, inflation-indexed bonds provide a safe real asset for long-term investors and promote public understanding of inflation. Fiscal authorities should take these public benefits into account as part of their broader mission to improve the functioning of their economies.

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12. Recent papers extracting information from the inflation-indexed yield curve include Beechey and Wright (2008), Christensen, Lopez, and Rudebusch (2009), D'Amico, Kim, and Wei (2008), Grishchenko and Huang (2008), and Haubrich, Pennacchi, and Ritchken (2008).

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Comments and Discussion

COMMENT BY

FREDERIC S. MISHKIN This paper by John Campbell, Robert Shiller, and Luis Viceira is excellent. Indeed, I would have titled it, "Everything You Always Wanted to Know about Inflation-Indexed Bond Markets, But Were Afraid to Ask."[1] The paper documents many key facts and puzzles about this market, including the following:

—the decline in long-term real yields on inflation-indexed bonds from the 1990s;

—the instability of real yields and returns on these bonds during the recent financial crisis;

—the negative correlation of returns on these bonds with those on stock prices, indicating that these bonds can be used to hedge equity risk;

—the fact that real yields on these bonds differ in different countries;

—the fact that the expectations hypothesis view that long-term real yields are driven by expectations of short-term real interest rates is supported by the data;

—but also the fact that risk and liquidity premiums on these bonds are very important and are volatile, suggesting that institutional factors matter a lot to their yields;

—the fact that long-term inflation-indexed bonds have high short-term risk;

—but also the fact that this is fully consistent with their being good long-term risk reducers.

1. For readers too young to remember, this is a takeoff on the title of a popular book and a Woody Allen movie from the 1970s.

The paper focuses on inflation-indexed bonds from the perspective of the investor. Given my comparative advantage as a former governor of the Federal Reserve, I will instead provide a different perspective by discussing why their analysis is so important for policymakers.

One of the most important issues for monetary policymakers is whether they can keep long-run inflation expectations anchored. Such anchoring is key to successful monetary policy for several reasons, and this is one of the reasons that I and many other monetary economists have argued strongly for some form of inflation targeting. First, anchoring long-run inflation expectations leads to more stable inflation outcomes. As I discussed in Mishkin (2007), long-run expectations of inflation on the part of households and firms are a key factor in determining the actual behavior of inflation. If these expectations are unstable, so, too, will be inflation. Moreover, the commitment that inflation targeting provides can play an important role in minimizing the risk of what Marvin Goodfriend (1993) has called "inflation scares," that is, episodes in which longer-term inflation expectations jump sharply in response to specific macroeconomic developments or monetary policy actions.

Second, anchoring long-run inflation expectations can help stabilize output and employment. Specifically, to counter a contractionary demand shock, the monetary authorities need to reduce the short-run nominal interest rate; however, the effectiveness of such a policy action may be hindered if long-run inflation expectations are not firmly anchored. For example, if the private sector becomes less certain about the longer-run inflation outlook, the resulting increase in the inflation risk premium could boost longer-term interest rates by more than the increase in expected inflation. The higher premium would in turn place upward pressure on the real cost of long-term financing for households and businesses (whose debt contracts are almost always expressed in nominal terms) and hence might partly offset any direct monetary stimulus. Thus, firmly anchoring inflation expectations can make an important contribution to the effectiveness of the central bank's actions aimed at stabilizing economic activity in the face of adverse demand shocks.

Third, anchoring long-run inflation expectations provides the central bank with greater flexibility to respond decisively to adverse demand shocks. Well-anchored expectations help ensure that an aggressive policy easing is not misinterpreted as signaling a shift in the central bank's inflation objective; they thereby minimize the possibility that long-run inflation expectations could move upward in response to the easing and lead to a rise in actual inflation. Well-anchored expectations are especially valuable in periods of financial market stress; at such times, prompt and decisive policy action may be required to prevent a severe contraction in economic activity that could further exacerbate the uncertainty and the stress, leading to a further deterioration in macroeconomic activity, and so on. Thus, by providing the central bank with greater flexibility in mitigating the risk of such an adverse feedback loop, well-anchored long-run inflation expectations play an important role in promoting financial stability as well as the stability of economic activity and inflation.

Fourth, well-anchored long-run inflation expectations can help prevent deflation from setting in—a particularly relevant consideration today. Deflation can severely weaken economic activity by triggering debt-deflation of the type described by Irving Fisher (1933), in which the falling price level increases the real indebtedness of firms, undermining their balance sheets.

Fifth, well-anchored long-run inflation expectations can help minimize the effects of an adverse cost shock such as a persistent rise in the price of energy. Generally speaking, such shocks tend to result in weaker economic activity as well as higher inflation. However, when long-run inflation expectations are firmly anchored, these shocks are likely to have only transitory effects on actual inflation, thus obviating the need to raise interest rates aggressively to keep inflation from rising. Thus, well-anchored long-run inflation expectations can help reduce output and employment fluctuations that impose unnecessary hardship on workers and on the economy more broadly.

The bottom line is that anchoring long-run inflation expectations is so important to successful monetary policy that the monetary authorities need to know what is happening to these expectations at all times. Indeed, when I was on the Federal Reserve Board, we spent a lot of time and effort trying to assess where long-run inflation expectations were heading, and we looked at several measures of these expectations. Surveys of households, such as the University of Michigan Inflation Expectation Survey, are one important source of information, but they have an important drawback. Research in the field of behavioral economics suggests that biases due to framing are likely to make survey measures of long-run inflation expectations unreliable. The problem is that when survey measures of short-run inflation expectations change, survey measures of long-run inflation expectations are likely to move with them, even if long-run expectations have not changed. This might happen because questions about both are asked at the same time, and the answer to the first question influences ("frames") the response to the second, resulting in a spurious co-movement between the two. Indeed, this is exactly what has happened recently. When oil prices rose, driving up inflation in terms of the consumer price index (CPI), not only did one-year inflation expectations move up in the Michigan survey, which makes sense, but so did measures of 5-to-10-year inflation expectations. Then, when CPI inflation and one-year survey expectations came back down, so, too, did the 5-to-10-year survey expectations. These temporary fluctuations in the 5-to-10-year survey measure were almost surely illusory.

A second measure of long-run inflation expectations comes from the Survey of Professional Forecasters (SPF). In recent years this measure has been rock steady. Of course, this may indicate that inflation expectations are firmly anchored, but it may instead be that the measure is failing to capture long-run inflation expectations that are in fact moving around.

Skepticism about survey measures is one reason why many economists, including myself, are more willing to trust expectations measures that are derived from financial markets data. After all, people buying or selling securities are putting their money where their mouth is—they thus have a strong incentive to base their decisions on their true forecasts. Here the inflation-indexed bond market provides exactly the information desired. The difference between interest rates on nominal government bonds and those on inflation-indexed bonds, or what the paper calls "breakeven inflation" and the Federal Reserve Board calls "inflation compensation," serves as a measure of inflation expectations. Such measures can be used as the canary in the coal mine to let monetary policymakers know if inflation expectations are becoming unanchored. Indeed, when I was at Board meetings, I would always ask Jonathan Wright, the other discussant of this paper, what he thought long-run breakeven measures of inflation were telling us about long-run inflation expectations.

As the paper points out, however, there is one big problem with using breakeven inflation measures from inflation-indexed bonds to assess whether long-run inflation expectations are becoming unanchored, namely, the presence of risk and liquidity premiums. The paper demonstrates that these premiums are substantial and seem to vary a lot. Sorting out what drives these premiums is thus key to helping policymakers evaluate what is happening to inflation expectations, and the paper attempts to do that.

The results in the paper raise three issues, however. First, the standard risk premium theories do not seem to explain much of the actual movements in inflation-indexed bond yields. Second, these theories suggest that inflation-indexed bonds should be good hedges against both consumption risk and equity risk, in which case inflation-indexed bonds should have a negative risk premium. Yet, to the contrary, they seem to have a positive risk premium. Both of these findings suggest that the existing theories do not tell us much about why liquidity and risk premiums vary. Third, it appears that a lot of the fluctuation in real yields on inflation-indexed bonds is due to institutional factors. This became very apparent during the recent period of financial market stress, when there were huge swings in these yields. However, as the paper points out, how these institutional factors affect real yields on these bonds is not well understood.

The paper's bottom line is that financial economists do not yet understand what causes the risk and liquidity premiums on inflation-indexed bonds to move around. This means that extracting information from these bonds about expected inflation is not easy.

A striking example of this problem was occurring at the time of this conference. As the paper shows, long-run breakeven inflation as measured by the difference in bond yields declined precipitously as the economy went into a tailspin. Does this mean that long-run inflation expectations became unanchored in the downward direction? If so, the situation was dangerous indeed, because it meant that deflation was more likely to set in, and aggressive monetary policy to prevent this unanchoring of inflation expectations was called for. Yet because one could not be sure what was happening to the risk and liquidity premiums on inflation-indexed bonds, neither could one be sure that this decline in breakeven inflation really meant that long-run inflation expectations had fallen.

Even though there was still some uncertainty about what inflation-indexed bonds were saying about long-run inflation expectations, I do think the sharp fall in breakeven inflation was cause for worry—that the dangers of deflation were real. To me this suggests that it is even more imperative that the Federal Reserve take steps to anchor inflation expectations better. This is why I have argued, both when I was a governor of the Federal Reserve and afterward,[2] that if ever there was a time for the Federal Reserve to announce an explicit, numerical inflation objective, that time is now.

2. Mishkin (2008); Frederic S. Mishkin, "In Praise of an Explicit Number for Inflation," *Financial Times,* January 12, 2009, p. 7.

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COMMENT BY

JONATHAN H. WRIGHT It is now just over a decade since the United States began issuing inflation-linked Treasury bonds. This paper by John Campbell, Robert Shiller, and Luis Viceira is a timely and excellent analysis of what has been learned from the pricing of these new securities and their counterparts in other countries. TIPS yields have been more volatile than might have been anticipated. Campbell, Shiller, and Viceira discuss the reasons why this is so before turning to the most topical issue, namely, explaining the behavior of TIPS in the recent financial crisis.

ARE RISK PREMIUMS ON INFLATION-INDEXED BONDS POSITIVE OR NEGATIVE? Abstracting for the moment from issues of liquidity, the yield on an inflation-linked bond is the sum of the average expected real short-term interest rate over the life of the bond and a risk premium. Campbell, Shiller, and Viceira use both a consumption-based model of asset pricing and a capital asset pricing model to argue that the risk premium on TIPS ought to be low or even negative. That would make them an ideal instrument for a Treasury seeking to minimize expected debt-servicing costs.

Some simple pieces of empirical evidence can be brought to bear on the question of the typical sign of the risk premium on such bonds. The average 5-to-10-year-forward TIPS yield from January 2003 to August 2008 was 2½ percent. If the risk premium on TIPS is zero or negative, this means that the expectation of r^*, the equilibrium real short-term interest rate, must be at least 2½ percent (abstracting from any liquidity premium, but this was a time when TIPS liquidity was generally good). This seems a rather high number. Expectations of real short-term interest rates 5 to 10 years hence, computed from the twice-yearly Blue Chip survey of economic forecasters, are volatile but were around 2 percent over this period. This reasoning suggests that risk premiums on TIPS are positive.

Table 1. Average Slopes of Forward Yield Curves on Nominal and Inflation-Linked Government Bonds[a]

Basis points

Bond	*United Kingdom*	*United States*
Nominal	0.5	28.2
Inflation-linked	–6.5	13.7

Sources: Bank of England data; Federal Reserve research data (Gürkaynak, Sack, and Wright 2007, forthcoming).

a. Spread of six-year-ahead over five-year-ahead continuously compounded instantaneous forward rates for U.K. and U.S. yield curves; the spread is averaged over all days from the start of January 2003 to the end of August 2008.

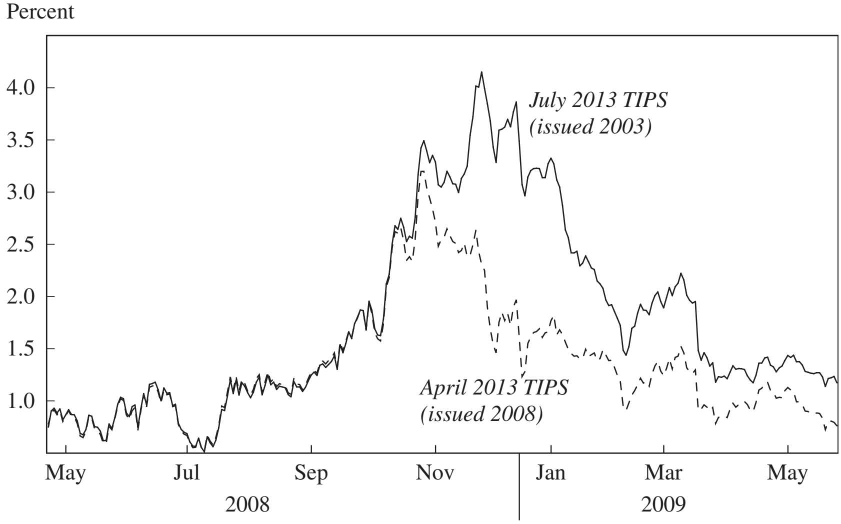
Another simple calculation uses the slope of the yield curve for inflation-linked bonds. In normal circumstances one might suppose that expectations of real short-term interest rates 5 to 10 years hence are fairly flat. If the forward TIPS yield curve at those horizons slopes up, that would suggest that term premiums are positive, and if the curve slopes down, it would suggest that they are negative. Table 1 shows the average slopes of the forward (five to six years out) yield curves on nominal and inflation-linked bonds in the United States and in the United Kingdom over the period from January 2003 to August 2008.[1] In the United Kingdom the yield curve for nominal bonds slopes up whereas the yield curve for inflation-linked gilts slopes down—evidence for the view expressed in the paper. In the United States the evidence is not so clear: the inflation-linked curve is flatter than the nominal one, but both slope up.

Taken together, this simple evidence does not seem to me to support the view that risk premiums on TIPS have typically been negative, although I agree that they are much lower than their nominal counterparts.

THE TIPS MARKET AND THE FINANCIAL CRISIS. Since the collapse of Lehman Brothers in September 2008, yields on inflation-linked and nominal bonds have decoupled and have been exceptionally volatile. The yields on some inflation-linked bonds rose above their nominal counterparts, making the breakeven inflation rate negative. This could represent either a fear of deflation or special demand for the comparative liquidity of nominal securities. Knowing which it is matters a lot. Indeed, it is surely the most important thing to understand from the TIPS market right now. It is a hard question to answer, but there are some clues.

1. Piazzesi and Schneider (2007) did a similar comparison for an earlier sample period.

Figure 1. Yields on Two TIPS of Comparable Maturity but Differing Issue Dates, 2008–09



Source: Bloomberg data.

TIPS bonds have the feature that the principal repayment cannot be less than the face value of the bond, even if the price level falls over the life of the bond. This gives TIPS an option-like feature in which the "strike price" is the reference CPI (that is, the price level at the time that the bond is issued). For a newly issued bond, any deflation will result in this option being in the money. For a bond issued, say, five years ago, however, deflation has to be very severe—enough to unwind all the cumulative inflation over the past five years—before this deflation option has any value.

This means that one can obtain information on the perceived probability of deflation by comparing the real yields on pairs of TIPS with comparable maturity dates but different reference CPIs. Figure 1 plots the real yields on the April 2013 and July 2013 TIPS. These were issued in 2008 and 2003, and the reference CPIs are 211.37 and 183.66, respectively. Before September 2008, the real yields on these two bonds were comparable, as the deflation option was perceived to be too far out of the money to matter. But subsequently the spread soared to 2 percentage points. The natural interpretation is that investors started to put substantial odds on deflation taking hold, increasing the relative attractiveness of the more recently issued TIPS.

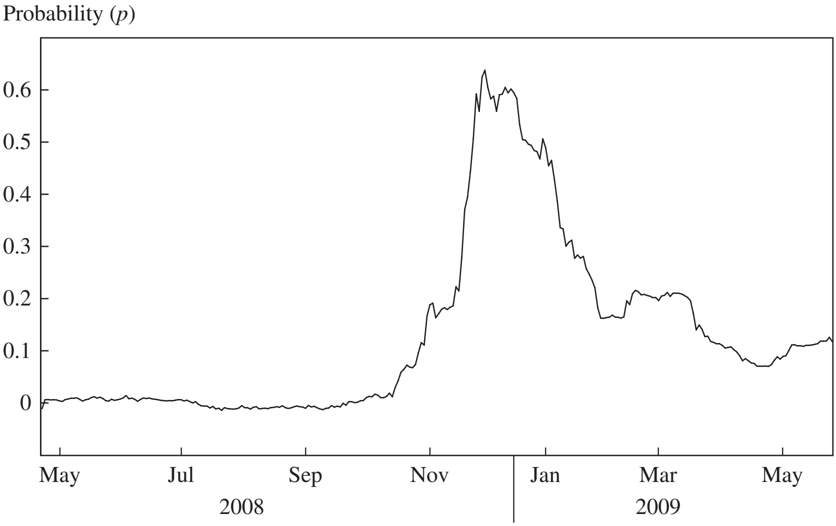
By comparing the yields on these two TIPS, one can calculate a lower bound on the implied probability of deflation over the period until 2013. This requires a number of strong assumptions, including risk neutrality.[2] But the calculation is based on comparing two TIPS yields, not a TIPS yield with a nominal yield, and so the technical factors that Campbell, Shiller, and Viceira cite as pushing down TIPS prices in the fall of 2008 should not distort this calculation, unless they affected one TIPS issue more than the other. Figure 2 shows how this implied probability of deflation evolved over time. From around zero before September 2008, it soared to over 60 percent before falling back to about 10 percent early in 2009. Again, the calculation embeds many strong assumptions, but it is only a lower bound, and so it seems reasonable to think that fear of deflation explains a significant part of the unusual behavior of TIPS last fall. That fear is now much reduced but has not entirely gone away.

Fear of deflation was surely not the only influence on inflation-linked bonds over this period; issues that come under the broad heading of liquidity were important, too. Campbell, Shiller, and Viceira make a compelling case that TIPS prices were depressed last fall as leveraged investors were

2. Here are the mechanics of the calculation. Pretend that the April 2013 and July 2013 TIPS are both zero-coupon bonds maturing June 1, 2013, and are identical apart from their reference CPIs. Let m denote the remaining time to maturity in years. Let x denote the CPI at the maturity date, and $f(x)$ and $F(x)$ the probability density and cumulative distribution functions of x, respectively. Assume that agents are risk-neutral. The reference CPIs are $x_u = 211.37$ and $x_l = 183.66$ for the April 2013 and the July 2013 bond, respectively, so that their principal repayments per dollar of face value are $\max(1, x/x_u)$ and $\max(1, x/x_l)$, respectively. Under these assumptions, the difference between the July 2013 and the April 2013 continuously compounded TIPS yields is $r = \frac{1}{m}\left\{\ln\frac{x_u}{x_l}F(x_l) + \int_{x_l}^{x_u}\ln\left(\frac{x_u}{x}\right)f(x)\mathrm{d}x\right\}$, which means that $r \leq \frac{1}{m}\left\{\ln\left(\frac{x_u}{x_l}\right)F(x_l) + \int_{x_l}^{x_u}\ln\left(\frac{x_u}{x_l}\right)f(x)\mathrm{d}x\right\} = \frac{1}{m}\ln\left(\frac{x_u}{x_l}\right)F(x_u)$. So the risk-neutral probability of deflation (that is, of the price index in 2013 being below $x_u = 211.37$, which is also approximately its current level) is bounded below as $F(x_u) \geq \frac{rm}{\ln(x_u/x_l)}$.

This is the probability shown in figure 2. The assumptions made are strong, and it is possible that part of the spread between the two TIPS represents instead a premium for the greater liquidity of the on-the-run issue, the April 2013 TIPS. However, there has never been much evidence of an on-the-run premium in the TIPS market, and qualitatively similar spreads between other pairs of TIPS issues with close maturity dates but different reference CPIs can also be observed since early fall 2008.

Figure 2. Probability of Deflation as Calculated from TIPS of Differing Issue Dates, 2008–09



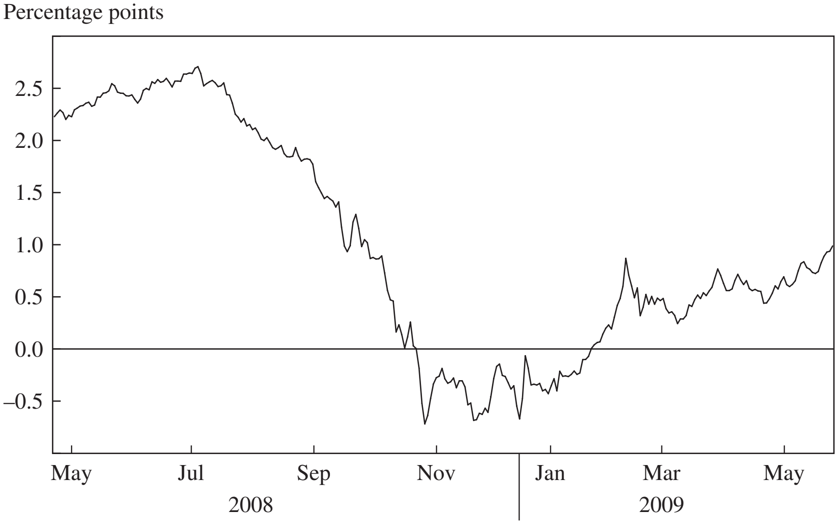
Source: Authors calc ulations.

forced to unwind large TIPS positions quickly.[3] Refet Gürkaynak, Brian Sack, and I (forthcoming) estimate that worsening liquidity pushed up five-year TIPS yields by more than a percentage point in the fall of 2008. The issue of liquidity can be seen starkly by comparing the yield on the April 2013 TIPS with the yield curve on nominal Treasury bonds. Because this TIPS was issued in 2008 (when the CPI was around its current level), and because the inflation adjustment to the TIPS principal cannot be negative, this particular TIPS effectively becomes a nominal security in the event of deflation,[4] while of course it pays off more than a nominal security in the event of inflation. Thus, the payoff on this security stochastically dominates the payoff on a nominal Treasury bond of corresponding

3. As Campbell, Shiller, and Viceira point out, the divergence between TIPS breakeven rates and rates quoted on inflation swaps is strongly suggestive of distressed TIPS sales. However, the inflation swaps market in the United States is tiny, with a trading volume roughly 1 percent of that in TIPS. One might be hesitant to read too much into prices from such a small and illiquid market.

4. This neglects the inflation adjustment to the coupon, which can be negative. The coupon rate on the April 2013 TIPS is tiny (five-eighths of a percentage point), and so even a sizable deflation should have only a small effect on the pricing of the security through coupon indexation.

Figure 3. Yield Spread between Nominal Treasury Bonds and the Most Recently Issued Five-Year TIPS[a]



Source: Bloomberg data and author's calculations using the Federal Reserve Board's smoothed yield curve.

a. Yield on nominal Treasury securities minus the yield on April 2013 TIPS (both securities of comparable maturity).

maturity. Figure 3 shows that the yield spread between the April 2013 TIPS and comparable-maturity nominal Treasury bonds went *negative* for an extended period in late 2008 and early 2009, and it was large and negative at times. This makes no sense from a standard asset pricing perspective, as it means that investors were leaving an arbitrage opportunity on the table. And even though the spread is now positive once again, it remains remarkably low given that there are surely sizable odds in favor of a pickup in inflation between now and 2013.

Lawrence Summers (1985) once quipped that financial economics entailed simply checking that two-quart bottles of ketchup sold for twice as much as one-quart bottles. Alas, it is not so any more—there have recently been many examples of investors seemingly leaving arbitrage opportunities unexploited. The comparison between the April 2013 TIPS yield and the nominal yield curve is one example. A second is the fact that the yield on old 30-year Treasury bonds is systematically higher than the yield on off-the-run 10-year notes of the same maturity. Another is that the yields on Resolution Funding Corporation (Refcorp) bonds, which are guaranteed by the Treasury,[5] are nonetheless substantially higher than yields on ordinary Treasury securities of comparable maturity.

All these Treasury market anomalies are conventionally treated as the effects of a "liquidity premium." For example, the cheapness of TIPS could be thought of as the compensation that investors demand for the poor liquidity of these instruments relative to nominal bonds. But TIPS are mainly bought by buy-and-hold investors, and bid-ask spreads on these securities are tiny. The cheapness of TIPS thus cannot really be rationalized as simply amortizing the transactions costs of a long-term investor. Moreover, as figure 4 shows, trading volume in TIPS (from the New York Federal Reserve Bank's survey of primary dealers) has declined but is still around its level in 2003. All this indicates to me that the TIPS liquidity premium has to have some explanation beyond just transactions costs. As Campbell, Shiller, and Viceira indicate, this explanation might be along the lines of a segmented market with arbitrageurs who rationally pass up hold-to-maturity arbitrage opportunities at times of market stress (Greenwood and Vayanos 2008; Shleifer and Vishny 1997).[6]

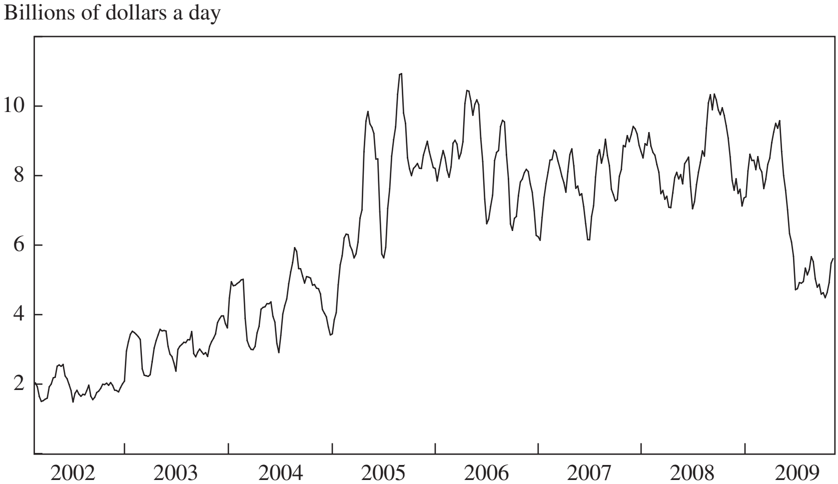
CENTRAL BANK PURCHASES OF TIPS. In standard equilibrium asset pricing models, a decision by the Federal Reserve to purchase bonds should do nothing to their price, unless expectations of future short-term interest rates are thereby affected (Eggertsson and Woodford 2003). Sufficiently large purchases would result in a corner solution in which the Federal Reserve owned all of the particular security being purchased, but the price would still be unaffected. However, if markets are segmented and highly illiquid, this story may break down.

The reaction to the announcement following the March 2009 Federal Open Market Committee (FOMC) meeting is a telling "event study" of the effects of central bank purchases. On that occasion the FOMC surprised market participants by announcing that the Federal Reserve would buy $300 billion in Treasury securities. The yield curves for both nominal and inflation-linked securities right before and after this announcement are shown in figure 5. Both moved down sharply, but the TIPS yield curve moved even more, especially at shorter maturities. The magnitude of this

5. This is not just the implicit guarantee that could be thought to apply to agency securities in general. Rather, Refcorp bonds have principal payments that are fully collateralized by nonmarketable Treasury securities and coupon payments that are guaranteed by the Treasury under the Financial Institutions Reform, Recovery, and Enforcement Act.

6. One way to improve TIPS market functioning might be to encourage the formation of a TIPS futures market. Such a market would make hedging cheaper and easier while improving liquidity in the cash market as well.

Figure 4. Trading Volume in TIPS, 2002–09[a]

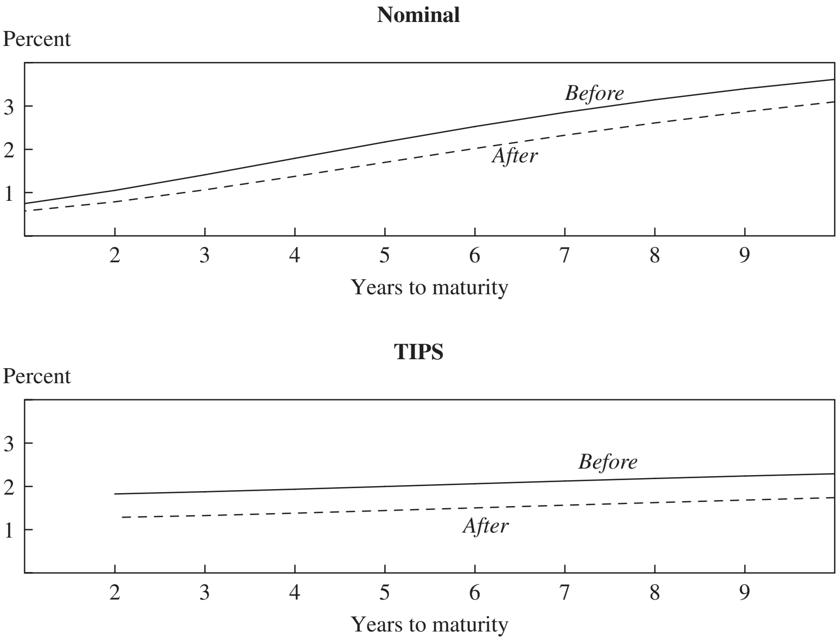


Source: Federal Reserve Bank of New York FR 2004 survey.
a. Eight-week moving average of interdealer volume in TIPS.

decline was far more than is consistent with what investors could have learned from the announcement about the expected path of future short-term interest rates. Other announcements of this sort by the Federal Reserve and by foreign central banks have had comparable effects. This indicates that central banks can indeed drive down longer-term interest rates by direct purchases of securities, at least at times of market stress. Of course, aggregate demand is more sensitive to the long-term interest rates paid by households and businesses than to Treasury yields. But lower Treasury rates could nonetheless spill over into private sector borrowing costs. More important, if changing asset supply affects prices in the Treasury market, then the same should be true in the markets for corporate bonds and mortgage-backed securities, meaning that the Federal Reserve could improve financial conditions by buying assets in these markets, too.

CONCLUSIONS. TIPS contain valuable information for economists and policymakers. In normal times they can be used to infer expectations of inflation and real short-term interest rates. They still can, but in the financial crisis that began last year, the most important information these securities provide is of how dysfunctional asset markets were and, to a large extent, still are. I emphasize two conclusions. First, in a financial crisis, markets are segmented and illiquid, and changes in effective asset supply brought about by Federal Reserve purchases can and evidently do have large effects on

Figure 5. Nominal and TIPS Yield Curves before and after the March 2009 FOMC Announcement[a]



Source: Federal Reserve Board estimates.
a. Data are as of the late afternoon of March 17 (before) and 18 (after).

prices. Second, policymakers and the press are often obsessed with finding the "market price" of extraordinarily opaque securities. TIPS are extremely simple securities. If, for whatever reason, the market cannot price TIPS coherently, then any faith in the ability of the market to come up with the textbook valuation of esoteric financial instruments seems quite misplaced.

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GENERAL DISCUSSION Matthew Shapiro agreed that market segmentation likely accounted for the spike in the TIPS yield in November. He suggested that hedge funds and other institutions were desperate for liquidity at that time. TIPS were among the few assets that were holding their value reasonably well, and so they were among the assets that got dumped on the market, thus revealing substantial segmentation between the market for indexed and that for nonindexed Treasury securities. Shapiro also suggested that with the breakdown of the barrier between fiscal and monetary policy observed in the response to the financial crisis, TIPS were an increasingly important tool for jointly disciplining fiscal and monetary policy. He speculated, however, that in the event of a hyperinflation, Congress might impose a windfall profits tax on the inflation indexation component of TIPS returns.

Ricardo Reis noticed that both expected inflation and the differential between TIPS and nominal bond yields had remained stable until around 2006, when the relationship started to break down. He compared this to the movement in oil prices shown in James Hamilton’s paper in this volume. Oil prices went up and then came down by a lot, which, Reis felt, could have changed perceptions of what was happening to oil prices even at a 10-year horizon. He proposed that expectations of movements in the price of oil might account for part of the risk and liquidity premiums observed in TIPS prices, given that the Federal Reserve targets core inflation, which excludes oil, whereas TIPS are indexed to overall inflation. Reis also suggested that much of CPI inflation is actually relative price inflation, which would impact TIPS’ hedging potential. His own research with Mark Watson found that 75 percent of annual variation, and 85 percent of quarterly variation, in the CPI is due to relative price changes. The results diminish over longer time horizons but are still in the range of 5 to 40 percent at a 10-year horizon. He suggested that relative price changes may also capture changes in the relative productivity of different sectors, providing a possible hedging opportunity in expected inflation based on relative productivity changes between sectors.

Alan Blinder observed that traditional monetary policy theory says that the central bank can manipulate nominal things but cannot manipulate real things, including real interest rates, and especially long-term real rates. He interpreted the evidence in the paper as showing that this theory is not just slightly wrong but very wrong. The paper's findings, in his view, are relevant to formulas such as the Taylor rule, where the real interest rate is usually assumed to be constant at 2 percent and it is the other factors that change. As a long-time advocate of inflation-linked bonds, Blinder had been excited when Campbell and Shiller's 1996 paper put an actual number on the likely interest rate savings to the Treasury. That paper, he recalled, said that TIPS should be cheaper for the Treasury because they were less risky to bondholders and would therefore pay a lower rate of return. In reality, they have not paid a lower rate, which, Blinder reasoned, was due to their lesser liquidity compared with nominal bonds. He wondered whether the main message of the paper was that economists have been focusing too much on risk and not enough on liquidity.

James Hamilton asked whether TIPS served equally well as nominal Treasuries as collateral for credit default swaps. John Campbell answered that he did not believe so but was unsure whether the difference was large and how much of the yield spread it would explain. He noted that there are other costs to using TIPS, such as larger "haircuts," which make their use as collateral less standard.

Benjamin Friedman expressed surprise that both the paper and the discussion thus far had proceeded entirely on a pre-tax basis. He suggested that differential taxation might impact TIPS' hedging properties, especially now that tax rates for individuals are lower on qualified dividends.

Michael Woodford commented on whether recent TIPS behavior indicated market segmentation. He felt this to be the most obvious explanation, but he disagreed with Jonathan Wright's hypothesis that market segmentation implies that Federal Reserve purchases of Treasury securities should be an effective way of stimulating aggregate demand. He instead proposed that as a result of market segmentation, a policy designed to lower TIPS yields (or other long-term Treasury yields) may change only the relationship of those yields to other real interest rates; the desired effect of such a policy, that of affecting the terms on which others can borrow, need not occur.

Justin Wolfers included himself among those economists who have always been hopeful that prices contain a lot of embedded information. Looking at the prices reported in the paper, however, he was glad that he was not a macrofinance economist looking for structural interpretations of price movements, because the conclusion he felt drawn to was that market prices are informative except when they are not. He recommended that the authors try to provide some guidance on determining under what circumstances TIPS prices will be uninformative.

Steven Davis was struck by the evidence for a market segmentation interpretation of TIPS behavior and said he would have liked to see a more thorough explanation of the extent, nature, and importance of that segmentation. He suggested that the authors conduct additional exercises that would help pinpoint where the segmentation occurs: is it between TIPS and nominal Treasuries, across different vintages and payoff horizons of TIPS themselves, or in markets that are thinly traded versus those that are not? Understanding this would be useful, he believed, in determining when drawing inferences from these securities about expectations and inflation might be more problematic. He also wanted to know whether the observed asset pricing anomalies occurred only in a very thinly traded, less important part of the market or were endemic to the system as a whole.

David Romer thought that segmentation was perhaps too easy an explanation and proposed instead that certain features of the market may dissuade people from arbitraging TIPS. It would be worth asking professional investors why TIPS do not provide a riskless opportunity or whether some sort of agency problem inhibits their purchase.

Gregory Mankiw addressed Alan Blinder's comment that a major argument for the creation of TIPS had been their lower cost of financing for the Treasury. He wondered whether that argument had been the primary one, and, if it had and now turned out to be wrong, whether Blinder felt that TIPS had been a mistake and should be phased out. Blinder responded that it had been the primary argument and that TIPS were a mistake from that perspective, but that TIPS should not therefore disappear, because they still provide a low-risk investment vehicle for investors, albeit at a cost to taxpayers.

Jonathan Wright addressed the question of whether purchases of large quantities of Treasuries would affect corporate borrowing and mortgage interest rates. The Federal Reserve's announcement of Treasury purchases had had some impact on these rates, but it was small. He suggested that the apparent market segmentation meant that the Federal Reserve could lower the interest rates paid by households and businesses more substantially, but only by buying assets that are riskier than Treasury securities, including securities with ratings below triple-A.

Janice Eberly remarked, in response to David Romer's comment, that a great deal of research is being conducted on markets for bonds similar to Treasuries that are trading at much higher premiums. For example, student loans, which are 97 percent guaranteed by the Treasury, trade at prices 200 basis points higher than Treasuries with the same maturity. The research she described is attempting to determine whether certain features of TIPS, like the deflation option, explain some of the difference, or whether characteristics of the other securities explain it, or whether market segmentation is the explanation.

Luigi Zingales further addressed David Romer's question by sharing answers given by a University of Chicago faculty member turned bond trader. The trader's explanation relied primarily on liquidity. After the Lehman Brothers collapse, the lenders who had to repossess the securities offered as collateral by Lehman discovered that they had to suffer losses when they liquidated a large amount of these relatively illiquid bonds. The differentiation in corporate bonds issued by the same entity makes the market for these securities segmented and thus less liquid. When many lenders dumped bonds on the market at the same time, they could not get full price because there were too few buyers. Without collateralized lending, it was more difficult to exploit arbitrage opportunities. As a result, many arbitrage opportunities became available. When many violations of arbitrage are occurring at the same time, Zingales thought it likely that traders with limited resources would focus on the low-hanging fruit, acting on the easiest and most profitable opportunities while ignoring others.

TIPS Liquidity Premium and Quantitative Easing

Laura Coroneo*

April 2, 2016

Abstract

In the context of a state-space model for nominal and TIPS yields, we identify the liquidity premium in the TIPS market as the common component in TIPS yields unspanned by nominal yields. Using daily US yields, we find that the TIPS liquidity premium explains up to 22% of the variation in TIPS yields and that it sharply spiked during the recent financial crisis. A counterfactual exercise shows that the QE2 program had only limited effects on the liquidity premium in the TIPS market.

JEL classification codes: C33, C53, E43, G12.

Keywords: *TIPS; Liquidity Premium; Factor models; Quantitative Easing*

*University of York, Department of Economics and Related Studies, Laura.Coroneo@york.ac.uk.

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1 Introduction

Treasury Inflation-Protected Securities (TIPS) have a smaller and less liquid market than US nominal Treasury bonds. Fleckenstein, Longstaff and Lustig (2014), D'Amico, Kim and Wei (2014) and Campbell and Viceira (2009), among others, find evidence of a liquidity premium component in TIPS, representing the compensation required by investors to hold a security that is less liquid than its nominal counterpart. However, despite the large literature supporting the existence of a liquidity premium component in TIPS, there is still little consensus about how to measure it.

In this paper, we propose a new measure of the liquidity premium in the TIPS market by disentangling the common variation in TIPS from the comovements in nominal and real rates. In the framework of a state-space model for nominal and TIPS yields, we identify the relative misspricing of TIPS with respect to nominal Treasury bonds as the common component in TIPS yields unspanned by nominal yields. This identifying assumption allows us to obtain a model-free measure of the liquidity premium in the TIPS market. The literature so far has not used this approach since in existing studies liquidity premia in TIPS are either computed using replicating portfolios (see Fleckenstein et al. (2014) and Christensen and Gillan (2013)), observable liquidity proxies (see Abrahams, Adrian, Crump and Moench (2013) and Pflueger and Viceira (2011)) or latent factors in the context of affine term structure models (see D'Amico et al. (2014)). Joint factor models for nominal and real yields that do not include a liquidity premium component have been proposed by Christensen, Lopez and Rudebusch (2010), Joyce, Lildholdt and Sorensen (2010) and Haubrich, Pennacchi and Ritchken (2012).

We estimate a joint state-space model for nominal and TIPS yields that treats the liquidity premium in the TIPS market as an unobservable component that we extract simultaneously with the yield curve factors. Our empirical model is a Dynamic Factor Model for nominal and TIPS yields with zero restrictions on the factor loadings of nominal yields on the TIPS liquidity factor. These zero restrictions capture the fact that the TIPS liquidity premium factor is unspanned by nominal yields. We obtain estimates of the TIPS liquidity premium factor by Quasi-Maximum

Likelihood using the Kalman filter and the EM algorithm.

Using daily US data from January, 2 2005 to December, 31 2014 we find that the TIPS liquidity factor explains up to 22% of the variation in short term TIPS yields and that it sharply spiked during the recent financial crisis. We also find that the liquidity premium in the TIPS market is Granger caused by measures of financial stress, such as market-wide illiquidity and corporate spreads. This implies that investors require a higher compensation for investing in TIPS rather than in nominal Treasuries when market conditions get worse, as during the recent financial crisis. In turn, we find that the liquidity premium in the TIPS market Granger causes the nominal yield curve factors and thus the nominal yield curve.

In the period from November, 23 2010 to June, 17 2011 the Federal Reserve implemented the Quantitative Easing (QE2) program which involved $600 billion purchases of Treasury securities, of which $26 billions were TIPS purchases. To assess the effect of the QE2 program on the liquidity premium in the TIPS market, we perform a counterfactual analysis. This is easily implementable in our framework regardless of the dimensionality of the conditioning variables, thanks to the use of the state-space representation and Kalman filtering. We construct a counterfactual path for the TIPS liquidity premium factor that does not incorporate the QE2 program. Results show that the counterfactual TIPS liquidity factor is on average higher than the realised TIPS liquidity factor, but the difference is only marginally significant when taking into account the accuracy of the counterfactual. We therefore conclude that the QE2 program had only a marginal effect on the liquidity premium in the TIPS market.

The paper is organised as follows. In Section 2, we define and identify the liquidity premium in the TIPS market. Section 4 outlines the estimation procedure and Section 4.1 describes how to perform counterfactual exercises in our framework. Section 3 introduces the data set. In Section 5 we report estimation results. Section 6 describes the Quantitative Easing programme and its effect on the liquidity premium in the TIPS market. Finally, Section 7 concludes and Appendix A contains some additional details about estimation.

2 Model

2.1 Decomposing nominal and TIPS yields

The yield of a nominal zero-coupon Treasury bond of any maturity can be decomposed into underlying real yield, inflation expectation and inflation risk premium. Denoting by $y^N_{t,\tau}$ the nominal yield with maturity τ, we can write

$$y^N_{t,\tau} = y^R_{t,\tau} + \pi^e_{t,t+\tau} + IP_{t,t+\tau} \tag{1}$$

where $y^R_{t,\tau}$ denotes the real yield with maturity τ, $\pi^e_{t,t+\tau}$ is the expected rate of inflation for the remaining life of the bond and $IP_{t,t+\tau}$ is the inflation risk premium.

The real yield $y^R_{t,\tau}$ can, in principle, be proxied by a Treasury Inflation Protected Security (TIPS) with the same maturity. However, while the market for nominal U.S. Treasuries is the most liquid financial market, TIPS only represent 10% of the outstanding U.S. Treasury debt. This implies that TIPS investors face liquidity risk due to the possibility that they may need to make portfolio adjustments after the initial auction or before maturity, being forced to buy or sell TIPS in the secondary market. For this reason, TIPS investors may demand a liquidity premium for holding an instrument that is less liquid than nominal Treasury securities. If we denote by $y^T_{t,\tau}$ the TIPS yield with maturity τ, we have

$$y^T_{t,\tau} = y^R_{t,\tau} + LP_{t,\tau} \tag{2}$$

where $LP_{t,\tau}$ is the liquidity premium at time t for the TIPS with maturity τ.

If the TIPS secondary market is sufficiently liquid, the liquidity premium is zero and Equations (1)-(2) imply that, all else equal, any change in TIPS yields should be reflected one-to-one into a change in nominal yields. The TIPS liquidity premium creates a wedge between TIPS yields and real interest rates. In particular, Equations (1)-(2) imply that any component that affects TIPS yields but not nominal Treasury yields is related to the TIPS liquidity premium. This observation allows us to identify the liquidity premium in the TIPS market as the common component in TIPS yields unspanned by nominal yields.

2.2 Liquidity premium in the TIPS market

The liquidity premium in the TIPS market measures the liquidity premium in the entire TIPS market. As such, it can be measured as the common factor in the liquidity premia of TIPS with different maturities. If we denote by L_t the liquidity premium in the TIPS market, then

$$LP_{t,\tau} = a_\tau^L + B_\tau^L L_t + \varepsilon_{t,\tau}^L \quad (3)$$

where a_τ^L is the maturity-specific intercept, B_τ^L contains the factor loadings of the liquidity premium of the TIPS with maturity τ on the liquidity premium factor and $\varepsilon_{t,\tau}^L$ represents the maturity specific component of the liquidity premium of the TIPS with maturity τ.

In order to extract the TIPS liquidity premium factor L_t in Equation (3), we model nominal and TIPS yields using a dynamic factor model. We assume that the yield curve of nominal Treasuries is described by a few latent yield curve factors, while the TIPS yield curve is driven by both the yield curve factors and the TIPS liquidity factor. In practice, following Equations (1)–(2), we identify the liquidity premium in the TIPS market L_t as the common component in TIPS yields unspanned by nominal yields.

Formally, we assume that nominal yields with different time to maturities are driven by a vector of $r_X \times 1$ of common latent factors X_t as follows

$$y_{t,\tau}^N = a_\tau^N + B_\tau^N X_t + \varepsilon_{t,\tau}^N \quad (4)$$

where a_τ^N is the maturity-specific intercept, B_τ^N contains the factor loadings of the nominal yield with maturity τ on the latent factors (common across maturities) and $\varepsilon_{t,\tau}^N$ represent the maturity-specific component of the nominal yield with maturity τ. In the same way, for real yields we have

$$y^R_{t,\tau} = a^R_\tau + B^R_\tau X_t + \varepsilon^R_{t,\tau} \tag{5}$$

where a^R_τ is the maturity-specific intercept, B^R_τ contains the factor loadings and $\varepsilon^R_{t,\tau}$ is the maturity-specific component of the real yield with maturity τ.

Let the vector $y^N_t = (y^N_{t,\tau^N_1}, \ldots, y^N_{t,\tau^N_n})'$ collect the nominal yields with maturities $(\tau^N_1, , \ldots, \tau^N_n)$ and the vector $y^T_t = (y^T_{t,\tau^T_1}, \ldots, y^T_{t,\tau^T_m})'$ collect the TIPS yields with maturities $(\tau^T_1, \ldots, \tau^T_m)$. Following equations (2)–(5), the joint model for nominal and TIPS yields can be written as

$$\begin{pmatrix} y^N_t \\ y^T_t \end{pmatrix} = \begin{pmatrix} a^N \\ a^T \end{pmatrix} + \begin{bmatrix} B^N & 0 \\ B^R & B^L \end{bmatrix} \begin{pmatrix} X_t \\ L_t \end{pmatrix} + \begin{pmatrix} \varepsilon^N_t \\ \varepsilon^T_t \end{pmatrix} \tag{6}$$

where $a^T = a^R + a^L$ and $\varepsilon^T_t = \varepsilon^R_t + \varepsilon^L_t$.

Equation (6) identifies two sets of latent factors: the yield curve factors X_t and the TIPS liquidity factor L_t. The yield curve factors are in line with the literature that exploits the high level of comovement of yields with different maturities to provide a parsimonious representation of the yield curve. This literature has proven that yield curve factor models are very successful in fitting the yield curve of nominal interest rates, see Litterman and Scheinkman (1991), Nelson and Siegel (1987), Duffee (2002) and Coroneo, Nyholm and Vidova-Koleva (2011). As for the liquidity factor, by noticing that TIPS are less liquid than nominal Treasuries, see Gürkaynak and Wright (2012) and Fleckenstein et al. (2014), we are able to identify the TIPS liquidity premium factor L_t as the driver of the wedge between real and TIPS yields. We implement this identification condition through the zero factor loading restrictions in Equation (6), which imply that the liquidity factor does not affect the current nominal yield curve, see Equations (1)–(2).

We allow the $(n + m)$ idiosyncratic components collected in $\varepsilon_t = \left[(\varepsilon^N_t)', (\varepsilon^T_t)'\right]'$ to follow independent univariate AR(1) processes

$$\varepsilon_t = A\varepsilon_{t-1} + v_t,\ v_t \sim N(0, R) \tag{7}$$

where A and R are diagonal matrices, implying that the common factors fully account for the joint correlation of the observations.

The $(r_X + 1) \times 1$ vector of zero mean latent factors follow a VAR(1)

$$\begin{pmatrix} X_t \\ L_t \end{pmatrix} = \begin{bmatrix} \Phi_{XX} & \Phi_{XL} \\ \Phi_{LX} & \Phi_{LL} \end{bmatrix} \begin{pmatrix} X_{t-1} \\ L_{t-1} \end{pmatrix} + \begin{pmatrix} u_t^X \\ u_t^L \end{pmatrix}, \tag{8}$$

where the innovations $u_t = \left[(u_t^X)', (u_t^L)'\right]'$ are normally distributed with zero mean and variance Q.

Finally, the innovations driving the common factors, u_t in Equation (8), and the residuals to the idiosyncratic components of the individual variables, v_t in Equation (7), are normally distributed and mutually independent. This implies that the common factors are not allowed to react to variable specific shocks.

3 Data and preliminary evidence

We use end-of-day yield curve data spanning the period January, 2 2005 to December, 31 2014, for a total of 2,339 observations. Nominal yields and TIPS yields with maturity 3, 5, 8, 10, 15 and 20 years are based on zero-coupon yield curves fitted at the Federal Reserve Board, see Gürkaynak, Sack and Wright (2007) and Gürkaynak, Sack and Wright (2010) for details.[1]

In Table 1 we report the percentage of variance of nominal yields and of jointly nominal and TIPS yields explained by the first five principal components extracted, respectively, from nominal yields and jointly from nominal and TIPS yields. Results in Table 1 show that two factors fully explain the cross-section of nominal yields, but when considering nominal and TIPS yields jointly an additional factor should be included in the analysis. This indicates that TIPS yields are driven by a factor that is unspanned by nominal yields which accounts for the liquidity premium in the

[1]We exclude the short end of the nominal yield curve to avoid the possible non-linearities associated with short maturities reaching the zero lower bound in the last part of the sample. Results including 3- and 6-month T-bill yields from the Federal Reserve Boards H.15 release and the nominal yield with maturity 1 year from Gürkaynak et al. (2007) are very similar to the ones presented in this paper and available upon request.

Table 1: Variances explained by principal components

	Nominal	Nom+TIPS
PC1	0.941	0.902
PC2	0.996	0.955
PC3	1.000	0.995
PC4	1.000	0.998
PC5	1.000	0.999

Note: this table report the percentage of variance of nominal yields (first column) and nominal and TIPS yields jointly (second column) explained by the first four principal components extracted from nominal (first column) and nominal and TIPS (second column) yields.

TIPS market. Accordingly, in our analysis we use two factors to explain the cross-section of nominal yields, i.e. $r_X = 2$, and one factor to explain the liquidity premium in the TIPS market.

To compare our estimates of the TIPS liquidity premium, we construct a liquidity proxy from inflation swap rates. We use mid-quotes of inflation swap rates with maturity 3, 5, 8, 10, 13, 15 and 20 years from Datastream converted to continuously compounded basis. Following Haubrich et al. (2012), we compute real rates as the difference between equivalent maturity nominal Treasury yields and inflation swap rates. We then construct a liquidity proxy as the average, across maturities, of the difference between equivalent maturity TIPS yields and real rates constructed using the inflation swaps.

As possible conditioning variables for the counterfactual analysis, we consider the TED spread (defined as the spread between the three month LIBOR and the three month Tbill rates), the Chicago Board Options Exchange Volatility Index (VIX), the Cleveland Financial Stress Index, the corporate spread (defined as the spread between the Baa corporate and the ten year Treasury rates), the bid-ask spread on the three month Tbill and the noise measure of Hu, Pan and Wang (2013) which is a market-wide measure of illiquidity. Data for all variables is obtained from the FRED database, except for the illiquidity measure of Hu et al. (2013) that we obtained from the authors.[2]

4 Estimation

The joint model for nominal and TIPS yields in Equations (6)–(8) is a restricted dynamic factor model with autocorrelated idiosyncratic components. In order to cast the model in a state-space form, we augment the vector of state variables with the vector of idiosyncratic components ε_t and an additional state variable c_t restricted to one at every period (by fixing its initial value to one and the variance of its innovations to zero). We then rewrite the measurement equation as

$$\begin{pmatrix} y_t^N \\ y_t^T \end{pmatrix} = \begin{bmatrix} B^N & 0 & a^N & I_n & 0 \\ B^R & B^L & a^T & 0 & I_m \end{bmatrix} \begin{pmatrix} X_t \\ L_t \\ c_t \\ \varepsilon_t^N \\ \varepsilon_t^T \end{pmatrix} + \begin{pmatrix} v_t^N \\ v_t^T \end{pmatrix} \tag{9}$$

where $X_t = (X_{1,t}, X_{2,t})'$, $\left((v_t^N)', (v_t^T)'\right)' \sim N(0, \epsilon I_{n+m})$ and ϵ is a coefficient that we fix to 1^{-12}. In the same way, we write the state equation as

$$\begin{pmatrix} X_t \\ L_t \\ c_t \\ \varepsilon_t^N \\ \varepsilon_t^T \end{pmatrix} = \begin{bmatrix} \Phi_{XX} & \Phi_{XL} & 0 & 0 & 0 \\ \Phi_{LX} & \Phi_{LL} & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & A^N & 0 \\ 0 & 0 & 0 & 0 & A^T \end{bmatrix} \begin{pmatrix} X_{t-1} \\ L_{t-1} \\ c_{t-1} \\ \varepsilon_{t-1}^N \\ \varepsilon_{t-1}^T \end{pmatrix} + \begin{pmatrix} u_t^X \\ u_t^L \\ \nu_t \\ v_t^N \\ v_t^T \end{pmatrix} \tag{10}$$

with $\left((u_t^X)', (u_t^L)', \nu_t, (v_t^N)', (v_t^T)'\right)' \sim N\left(0, blkdiag(Q, \epsilon, R)\right)$ and $A = diag(A^N, A^T)$.

The model in (9)–(10) is a restricted state-space model for which maximum likelihood estimators of the parameters are not available in closed form. Conditionally on the factors, the model reduces

[2]The noise measure is available at http://www.mit.edu/ junpan/

to a set of linear regressions. As consequence, we compute Maximum Likelihood estimates using the Expectation Maximization (EM) algorithm introduced by Shumway and Stoffer (1982) and Watson and Engle (1983). This estimator is feasible when the number of variables is large, and robust to non Gaussianity and to the presence of weak cross-sectional correlation among the idiosyncratic terms, see Doz, Giannone and Reichlin (2012). In addition, as shown in Coroneo, Giannone and Modugno (Forthcoming), using the Kalman filter and the EM algorithm allows us to easily impose linear restrictions on the parameters. For more details see Appendix A.

We identify the TIPS liquidity premium shock in model (9)–(10) by imposing a recursive causal ordering of the state variables. In particular, we assume the following order L_t, X_1, X_2, which implies that the TIPS liquidity premium has a zero impact response to nominal yield curve shocks. We examine the dynamics of the complete system via impulse response functions and compute confidence bands for the impulse response functions by parametric wild bootstrap. For more details see Appendix B.

4.1 Counterfactual analysis

Let's now assume that at time t_0 a policy is implemented and we are interested in assessing the effect of this particular policy on the liquidity premium in the TIPS market. This can be done by comparing the realised path of the TIPS liquidity premium factor with a counterfactual TIPS liquidity factor that does not incorporate the policy.

The counterfactual TIPS liquidity premium factor is the forecast of the TIPS liquidity factor for $t \geq t_0$ conditional on past TIPS and nominal yields, and possibly past and future values of suitable conditioning variables. A conditioning variable is suitable for the construction of a counterfactual path for the liquidity premium if it is informative about the liquidity premium in the TIPS market and it is invariant to the policy. In our framework, the first condition is satisfied if the conditioning variable Granger causes the TIPS liquidity premium. The invariance condition instead is satisfied if the policy does not affect the conditioning variables, and the TIPS liquidity premium (that in principle can be affected by the policy) does not feedback into the conditioning variables, i.e. it does not Granger cause the conditioning variable.

We collect the set of zero mean suitable conditioning variables in the $w \times 1$ vector W_t and add them to the state equation (8), see Appendix A for the state-space representation. We then denote the counterfactual TIPS liquidity factor as

$$L^*_{t|T} \equiv E[L_t | y^N_1, \ldots, y^N_{t_0-1}, y^T_1, \ldots, y^T_{t_0-1}, W_1, \ldots, W_T],\ t \geq t_0, \tag{11}$$

and the associated mean squared error as

$$V^*_{t|T} = E[(L_t - L^*_{t|T})(L_t - L^*_{t|T})'],\ t \geq t_0. \tag{12}$$

In practice, we are interested in extracting the TIPS liquidity factor for $t \geq t_0$ from a dataset of TIPS, nominal yields and conditioning variables, where the TIPS and nominal yields are unobserved from t_0. Both the counterfactual TIPS liquidity factor in (11) and its accuracy in (12) can be easily computed in our framework regardless of the dimensionality of the conditioning variables, thanks to the use of the state-space representation and Kalman filtering. This because we can use a modified state-space model where the dimensionality of the observation vector varies over time, see Durbin and Koopman (2012). In practice, after t_0 only the rows that refer to the conditioning variables will enter into the measurement equation.

We construct the $(1 - \alpha)$ confidence interval for the counterfactual TIPS liquidity premium factor as

$$CI(L^*_{t|T})_{1-\alpha} = \left(L^*_{t|T} - \Phi^{-1}(1-\alpha/2)\sqrt{V^*_{t|T}},\ L^*_{t|T} + \Phi^{-1}(1-\alpha/2)\sqrt{V^*_{t|T}}\right),\ t \geq t_0 \tag{13}$$

where $\Phi^{-1}(1 - \alpha/2)$ denotes the $(1 - \alpha/2)$ quantile of the standard normal distribution.

Table 2: Variance explained by the latent factors

	Nominal Yields			TIPS Yields			
Mat	X_1	X_2	Total	X_1	X_2	L	Total
3	0.850	0.146	0.996	0.722	0.005	0.229	0.956
5	0.947	0.053	1.000	0.810	0.001	0.179	0.991
8	0.999	0.000	0.999	0.841	0.017	0.141	1.000
10	0.991	0.009	1.000	0.840	0.032	0.125	1.000
15	0.945	0.048	0.993	0.809	0.078	0.098	0.988
20	0.901	0.058	0.960	0.744	0.135	0.088	0.969

Note: this table reports the percentage of variance of nominal yields (left panel) and of TIPS yields (right panel) explained by the estimated latent factors of the model in (9)-(10).

5 Estimation Results

Table 2 reports the percentage of variance of nominal and TIPS yields explained by the estimated latent factors of the joint model for nominal and TIPS yields in (9)-(10). The table shows that the model has a good fit for both nominal and TIPS yields, with at least 96% of the variance of yields explained by the latent factors. The table also shows that the first latent factor explains the bulk of the variation in both nominal and TIPS yields, while the second yield curve factor explains up to 14% of the variance of nominal and TIPS yields.

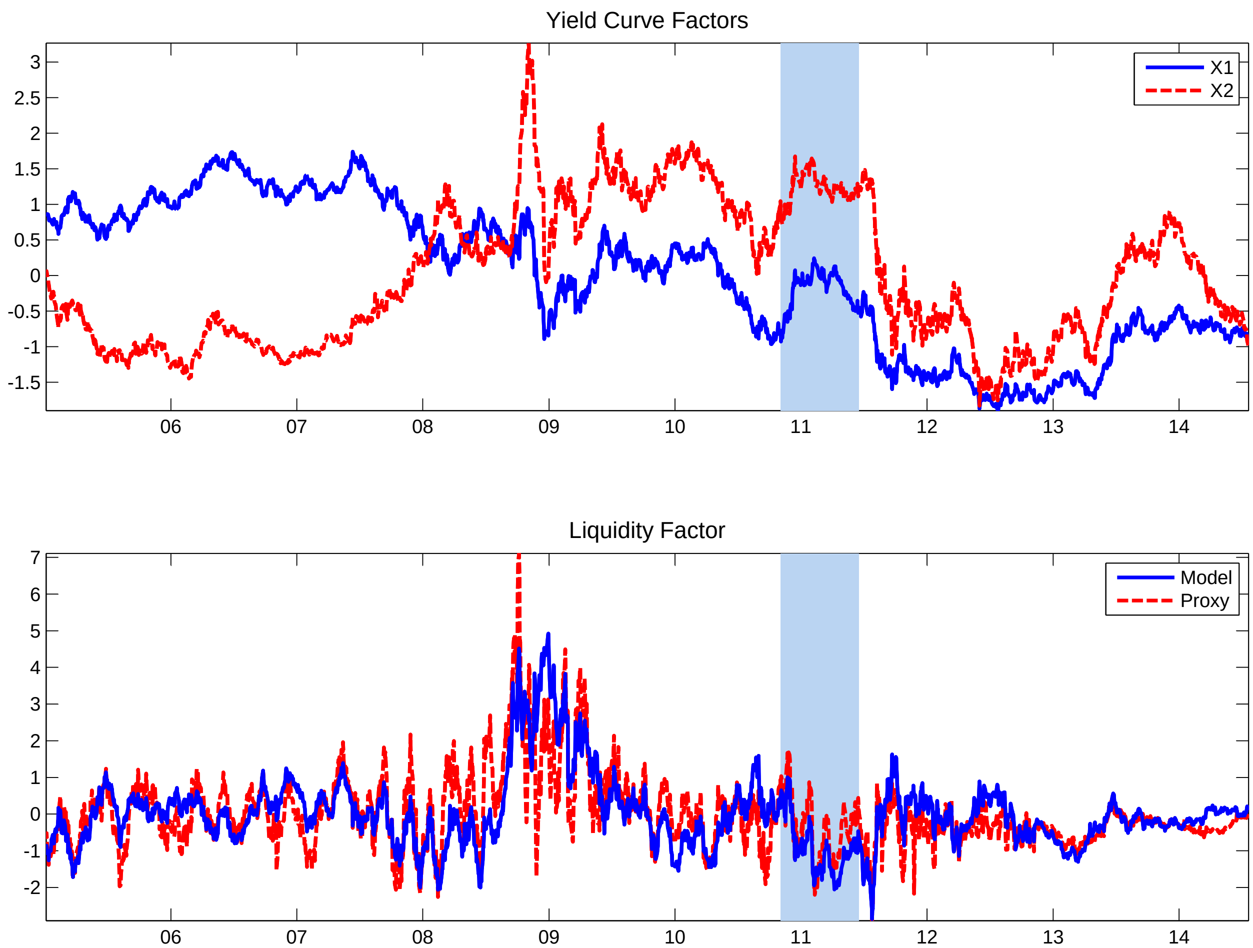
The TIPS liquidity factor by construction does not affect nominal yields but has substantial explanatory power for TIPS yields. It explains up to 23% of the variance of TIPS yields and its explanatory power is higher for shorter maturities, implying that investors require higher compensation for holding shorter term TIPS rather than longer term ones. This might be due to the fact that growth of the TIPS markets has not occurred uniformly, see Shen (2006). For example, the Treasury has issued 10-year TIPS every year since the TIPS program began in 1997. On the contrary, the 5-year TIPS, were issued in 1997 and 1998, but then not again until 2005. An additional explanation could be due to the presence of different types of investors in different segments of the TIPS yield curve. In particular, investors in the long end of the TIPS yield curve, e.g. pension funds, are more likely to use a buy and hold strategy and, thus, do not require a liquidity premium in order to invest in TIPS since they will rarely need to turn over their positions.

Figure 1 reports the estimated yield curve factors (top panel) and the TIPS liquidity factor (bottom panel). The first yield curve factor has a decreasing pattern in our sample due to a general decline in interest rates in this period. The second yield curve factor is more volatile than the first and is higher in the middle of the sample. The bottom plot of Figure 1 reports the TIPS liquidity factor and a proxy for the average liquidity in the TIPS market, constructed as the standardized average across maturities of the difference between TIPS yields and real rates computed using inflation swaps and nominal yields of the same maturity (for more details see Section 3). The figure shows that the TIPS liquidity factor is highly correlated with this empirical proxy. The pairwise correlation coefficient is 75%. We can also notice that the estimated TIPS liquidity factor is more persistent than the proxy for the average liquidity in the TIPS market constructed using inflation swaps. This may be due to the fact that inflation swaps are also subject to liquidity frictions, see Fleming and Sporn (2013), and therefore the liquidity proxy constructed using inflation swaps measures the liquidity premium in both TIPS and inflation swaps, see Christensen and Gillan (2012). Figure 1 also shows that during the subprime crisis, the TIPS liquidity premium became more volatile and, in September 2008, following the Lehman Brothers collapse, the TIPS liquidity factor increased substantially indicating a flight to liquidity in the US Treasury market. The TIPS liquidity premium factor remained at this higher level until mid-2009, when it returned to the pre-2008 level.

We examine the dynamics of the complete nominal-TIPS yield system via impulse response functions, which we show in Figures 2–4, along with the 90 percent confidence intervals. We consider three groups of impulse responses in turn: state responses, nominal yields responses and TIPS yields responses.

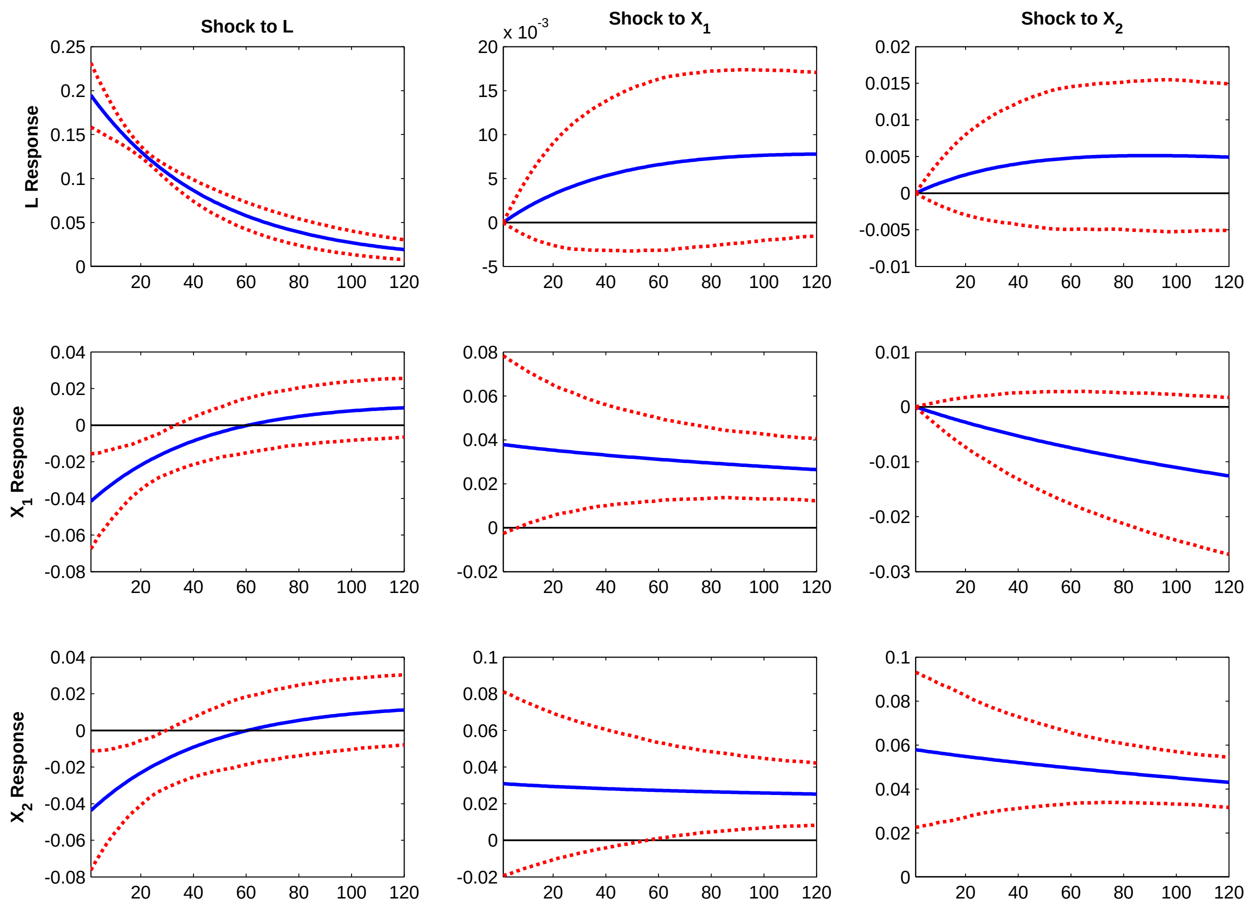
Responses of the latent state variables to shocks in the yield curve factors and to the TIPS liquidity factor are reported in Figure 2. A TIPS liquidity premium shock has a long lasting own effects for about 5 months and a negative effect on the nominal yield curve factors. An unanticipated increase of one standard deviation of the TIPS liquidity premium decreases both the level and the

Figure 1: Estimated yield curve and TIPS liquidity factor



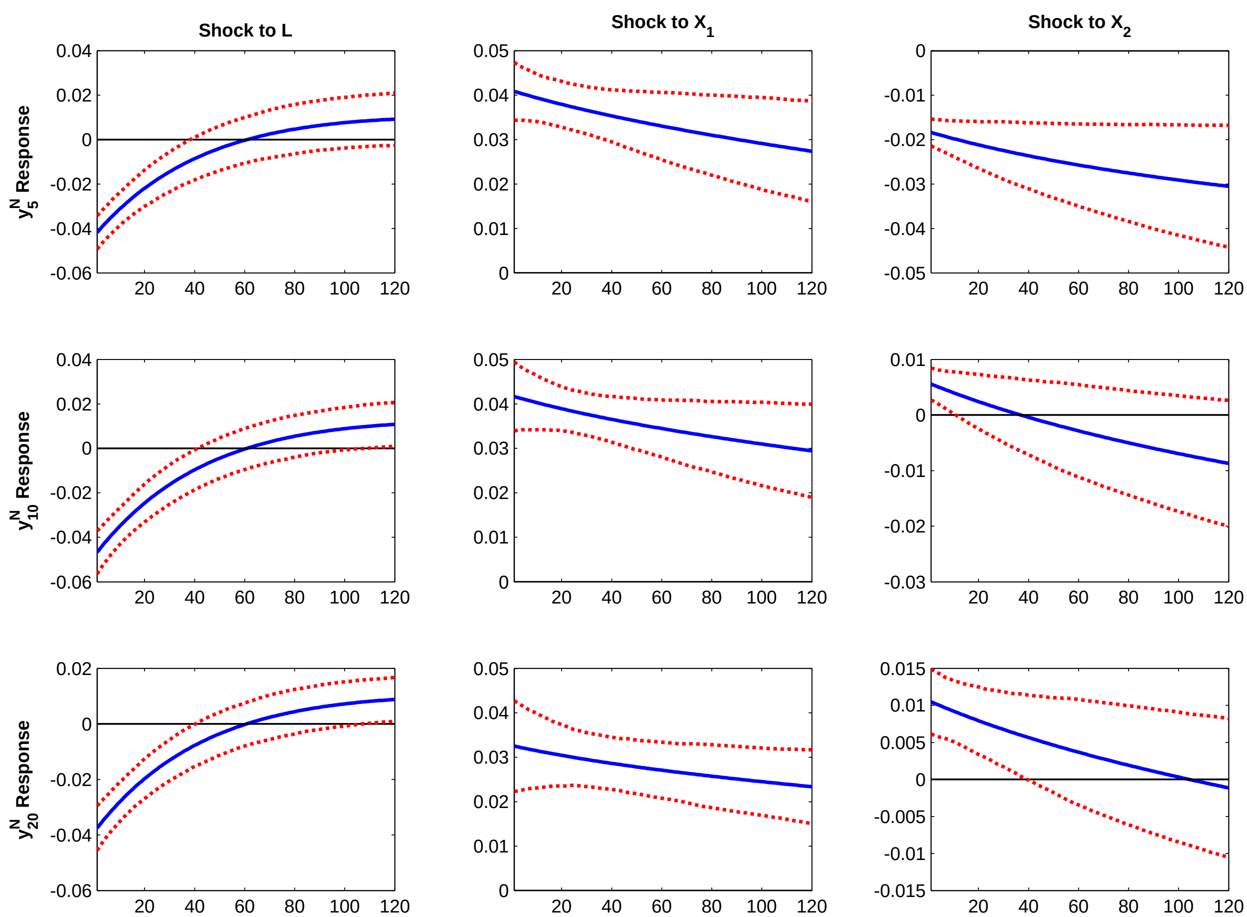
The figure displays the estimated latent factors from model (9)-(10). The top panel displays the estimated yield curve factors X_1 and X_2. The bottom panel displays the estimated TIPS liquidity factor L (continuous blue line) and a proxy for the TIPS liquidity factor constructed using inflation swaps (red dashed line). The blue shaded areas indicate the QE2 operation period.

Figure 2: Impulse-Response Functions of State Variables



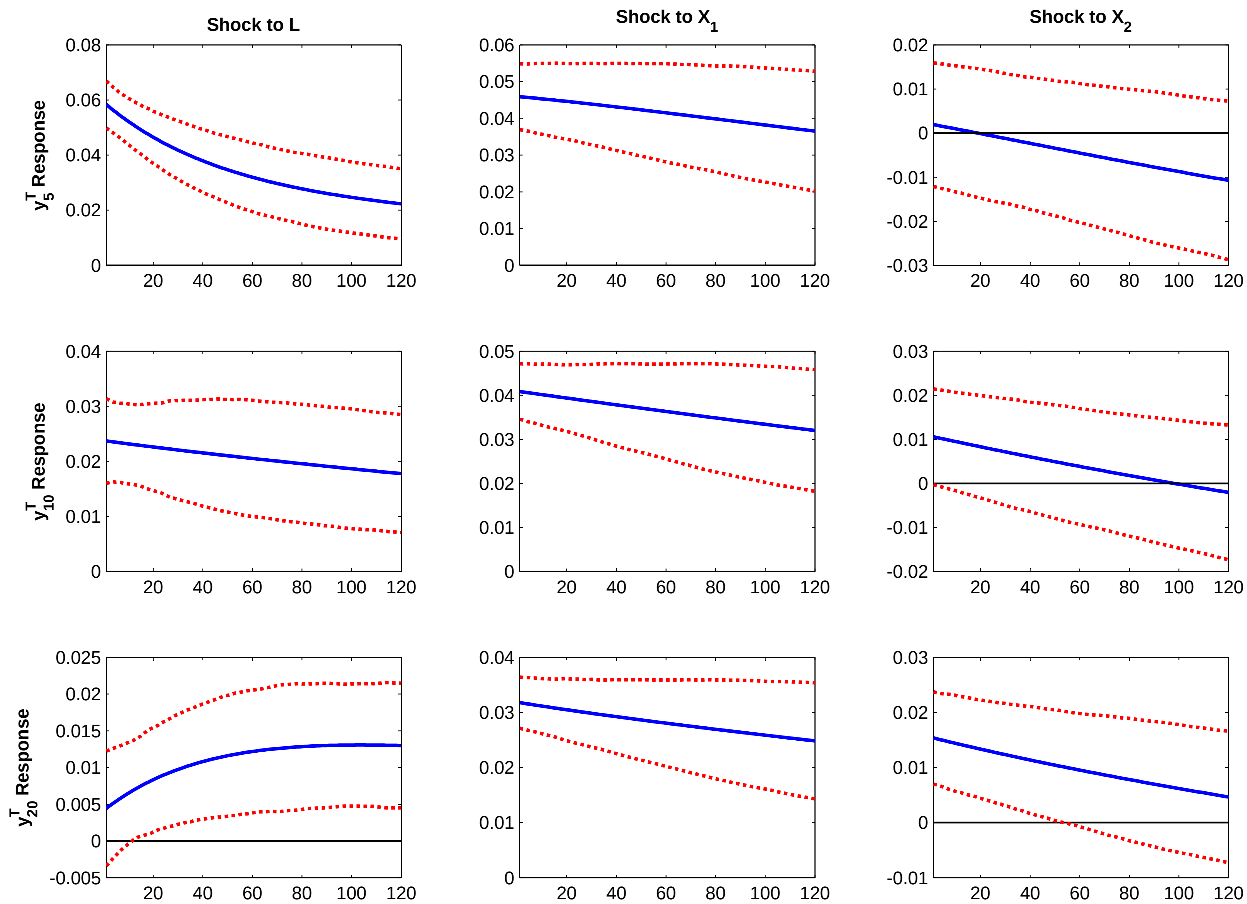
The figure displays the impulse response functions of the state variables and the associated 90% confidence bands constructed as detailed in Section 4 and Appendix B.

Figure 3: Impulse-Response Functions of Nominal Yields



The figure displays the impulse response functions of selected nominal yields and the associated 90% confidence bands constructed as detailed in Section 4 and Appendix B.

Figure 4: Impulse-Response Functions of TIPS Yields



The figure displays the impulse response functions of selected TIPS yields and the associated 90% confidence bands constructed as detailed in Section 4 and Appendix B.

slope of the yield curve by 0.04% on impact, and this effect lasts for about two months. This implies that a TIPS liquidity premium shock determines a flight to liquidity that increases the demand for the more liquid nominal bonds. As for the yield curve shocks, only the own effects are significant, in line with the findings in Diebold, Rudebusch and Aruoba (2006).

Figure 3 reports the responses of nominal yields to shocks to the TIPS liquidity premium and yield curve factors. A one standard deviation TIPS liquidity premium shock decreases nominal yields of all maturities by 0.04% and the effect lasts for about 2 months. A shock in the first yield curve factor increases nominal yields of all maturities on impact by 0.04%, with a long lasting effect. Finally, a shock to the second yield curve factor tilts the nominal yield curve of interest rates by decreasing yields with 5 years to maturity, increasing yields with 20 years to maturity and leaving unchanged nominal yields with 10 years to maturity.

Responses of TIPS yields to shocks to the TIPS liquidity premium and yield curve factors are reported in Figure 4. An unanticipated TIPS liquidity premium shock increases on impact the TIPS yield with maturity 5 years by 0.06% and the TIPS yield with maturity 10 years by 0.02%, while the impact effect on the TIPS yield with maturity 20 years is not significant. This is due to the fact that shorter term TIPS yields have a larger liquidity premium component, as shown in Table 2. A shock to the first yield curve factor increases all TIPS yields, with a larger effect on shorter term yields. Finally, a shock to the second yield curve factor has a significant effect only on the 20 year TIPS yield.

6 Quantitative Easing

Following the 2007 financial crisis, the Federal Reserve conducted massive asset purchases know as quantitative easing (QE) to lower long-term interest rates and spur economic growth.

On November 25, 2009 the Federal Open Market Committee (FOMC) announced the first quantitative easing program (QE1) which would involve purchases in government-sponsored enterprises (GSEs) debt and in mortgage-backed securities (MBS). On March 18, 2009 the FOMC announced that the QE1 program would involve additional purchases in GSEs and MBS. It was also announced that the program would involve purchases of $300 billion in long-term Treasury securities. The Treasury purchases ended on October 29, 2009 and involved $6.1 billion in TIPS purchases.

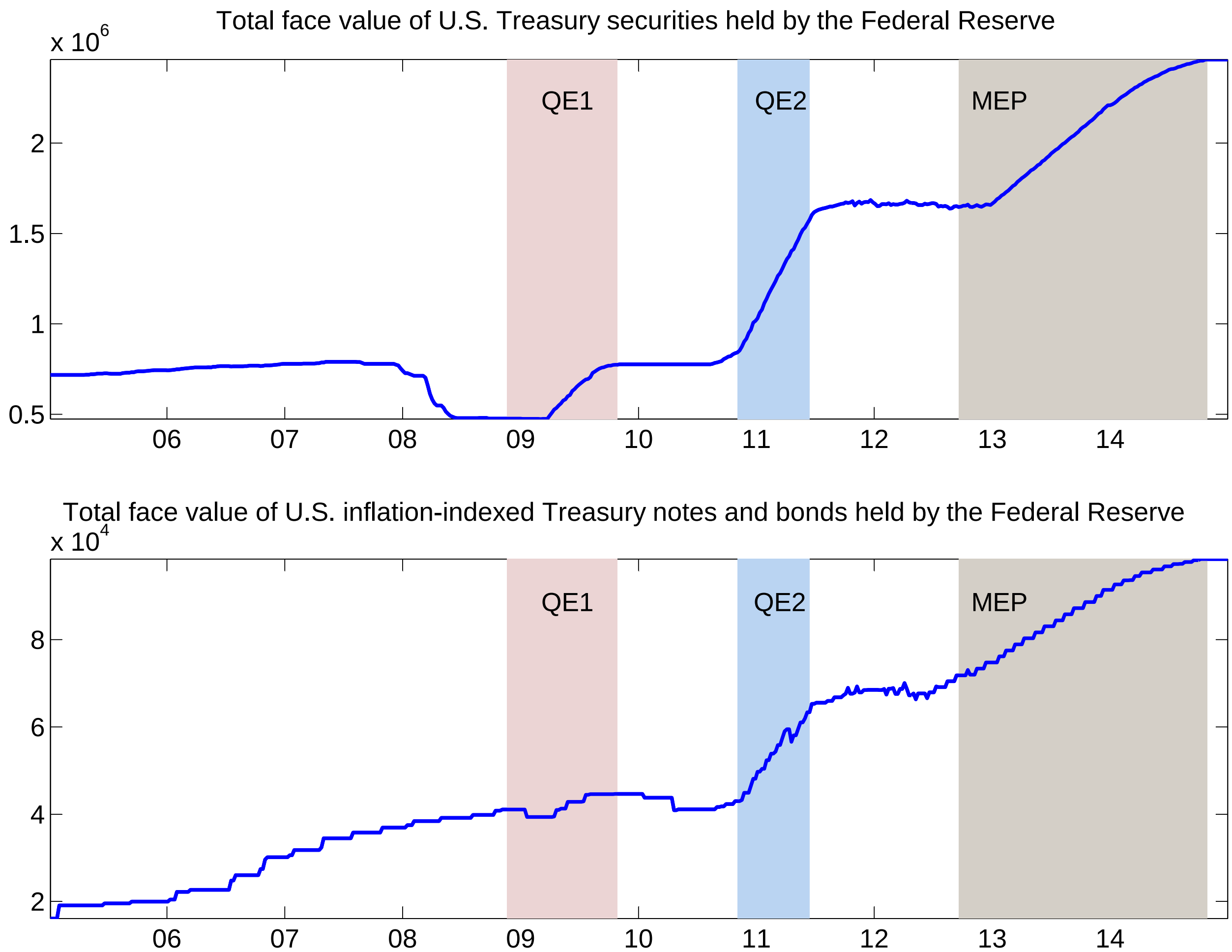
The second quantitative easing program (QE2) was announced on November 3, 2010 with the target of expanding the Federal Reserve's balance sheet by $600 billions through Treasury security purchases over an eight-month period. The gross purchases of Treasury securities from November 3, 2010 until June 30, 2011 amounted to nearly $750 billion, of which about $26 billion were TIPS purchases.

On September 21, 2011 the FOMC announced the third QE program, know as maturity extension program (MEP), which would involve Fed purchases of $400 billion in long-term Treasuries and equivalent sales in short-term Treasuries. On June 20, 2012 the FOMC announced that purchases of long-term bonds and the sales of short-term bonds would continue through 2012 and would involve a total of $600 billion in purchases and sales of securities. On December 12, 2012 the Fed announced that it would continue to purchase $45 billion in long-term Treasuries per month but without the sale of short-term Treasuries to sterilize purchases. The MEP involved TIPS purchases for a total of $27.1 billion, all in TIPS with more than 6 years to maturity. The TIPS sales within the MEP totaled $13.4 billion and only included TIPS with less than 3.25 years to maturity.

In Figure 5 we report the Federal Reserve's outright holdings of Treasury securities and TIPS. The figure shows that the Federal Reserve's outright holdings of both nominal Treasuries and TIPS sharply increased during the QE2 program. This because the Fed purchases of Treasuries within the QE2 program have been larger and concentrated in a shorter time spam with respect to the QE1 and the MEP programs.

Such massive purchases of Treasuries may had reduced the liquidity premia required by investors to buy TIPS, as the Federal Reserve's purchases may have made it less costly for investors to sell TIPS. However, this effect of the QE2 program on the TIPS liquidity premia depends on the Federal Reserve's flow of purchases and, therefore, we expect it to be limited to the duration of the QE2

Figure 5: Federal Reserve's outright holdings of Treasuries



The figure displays the total face value of the Federal Reserve's outright holdings of Treasury securities (top graph) and inflation-indexed Treasury notes and bonds (bottom plot). The shaded areas indicates the QE1, QE2 and the MEP operation periods. Data are weekly.

Table 3: QE2 TIPS purchase

	Dates	Amount (Mill.)	Average Maturity
0	03-Nov-10		
1	23-Nov-10	$1,821	9.43
2	08-Dec-10	$1,778	8.88
3	21-Dec-10	$1,725	16.09
4	04-Jan-11	$1,729	16.98
5	18-Jan-11	$1,812	14.64
6	01-Feb-11	$1,831	13.58
7	14-Feb-11	$1,589	14.16
8	04-Mar-11	$1,589	11.37
9	18-Mar-11	$1,653	17.77
10	29-Mar-11	$1,640	18.29
11	20-Apr-11	$1,729	23.17
12	04-May-11	$1,679	13.62
13	16-May-11	$1,660	20.49
14	07-Jun-11	$1,589	14.3
15	17-Jun-11	$2,129	5.98
	Average	$1,730	14.58

Note: this table reports the QE2 TIPS purchase operations dates along with the amount (in millions) and the (weighted) average maturity.

program. On the other hand, the FED's TIPS purchases have reduced the stock of TIPS available to investors and this may have instead increased the liquidity premium in the TIPS market.

Table 3 contains the exact dates of the TIPS purchases along with the amount and the average maturity. As a preliminary assessment of the effect of the QE2 program on the liquidity in the TIPS market, we report in Table 4 the changes in the estimated TIPS liquidity factor around the days of the QE2 announcement (Nov. 3, 2010) and operations (from Nov. 23, 2010 to Jun. 17, 2011) for different window sizes (from one day change to five days change). The table shows that on the day of the QE2 program announcement the estimated TIPS liquidity factor declined. In addition, on eleven out of fifteen TIPS operation dates of the QE2 program, the estimated TIPS liquidity factor declined either the same day or the following day. The average and median of the changes of the liquidity factor on the QE2 dates are negative, indicating that the program may

Table 4: Cumulative changes in the estimated TIPS liquidity factor around QE2 events

		1	2	3	4	5
0	03-Nov-10	-0.262	0.082	0.172	0.108	-0.231
1	23-Nov-10	0.191	-0.306	0.163	0.146	0.120
2	08-Dec-10	-0.272	-0.006	-0.420	-0.287	-0.864
3	21-Dec-10	-0.081	-0.193	-0.297	-0.092	-0.163
4	04-Jan-11	0.168	-0.199	-0.234	0.057	0.099
5	18-Jan-11	0.069	0.298	0.083	0.317	0.314
6	01-Feb-11	-0.235	-0.457	-0.856	-1.141	-1.255
7	14-Feb-11	0.223	0.087	0.037	0.119	0.022
8	04-Mar-11	0.284	0.310	0.199	0.505	0.728
9	18-Mar-11	-0.042	0.021	-0.020	-0.126	-0.291
10	29-Mar-11	-0.053	-0.101	-0.174	-0.227	-0.069
11	20-Apr-11	-0.137	-0.144	0.180	0.145	0.261
12	04-May-11	0.146	0.337	0.294	0.241	0.092
13	16-May-11	-0.079	0.044	-0.137	-0.121	-0.088
14	07-Jun-11	0.043	-0.039	-0.305	-0.163	-0.066
15	17-Jun-11	-0.096	-0.214	-0.264	-0.475	-0.438
	Mean	-0.008	-0.030	-0.099	-0.062	-0.114
	Median	-0.047	-0.022	-0.078	-0.017	-0.068

Note: this table reports the cumulative changes in the estimated TIPS liquidity factor around the days of the QE2 announcement (Nov. 3, 2010) and operations (from Nov. 23, 2010 to Jun. 17, 2011) for different window sizes (from one day change to five days change). The changes in the estimated TIPS liquidity factor are computed from the day before the event, i.e. the two day change for the QE2 announcement is the difference in the estimated TIPS liquidity factor between November 4, 2010 and November 2, 2010.

have lowered the liquidity premium required by market participants in order to invest in TIPS. To formally asses the impact of the QE2 program on the TIPS liquidity premium factor, in the next section we perform a counterfactual analysis.

6.1 Counterfactual Results

Our objective is to assess the effect of the QE2 program on the liquidity premium in the TIPS market. We do this by comparing the realised path of the TIPS liquidity premium factor with a counterfactual TIPS liquidity premium factor that does not incorporate the QE2 program.

As explained in Section 4.1, conditioning variables can be used in the constructions of the

Table 5: Granger causality tests

Null: the variable does not Granger cause L

	TED	VIX	CFSI	N	CS	BA	$\widehat{X}_1$	$\widehat{X}_2$
Fstat	2.375	4.331	2.295	11.262	6.266	0.005	2.199	0.804
pval	(0.12)	(0.04)	(0.13)	(0.00)	(0.01)	(0.94)	(0.14)	(0.37)

Null: L does not Granger cause the variable

	TED	VIX	CFSI	N	CS	BA	$\widehat{X}_1$	$\widehat{X}_2$
Fstat	0.001	0.297	0.071	0.430	1.170	6.313	24.599	9.490
pval	(0.98)	(0.59)	(0.79)	(0.51)	(0.28)	(0.01)	(0.00)	(0.00)

Note: this table report likelihood ratio test statistics and p-values. All variance-covariance matrix are robust to autocorrelation and heteroskedasticity. All statistics refer to a univariate VAR(1) of the listed variable and the estimated TIPS liquidity factor L. TED refers to the TED spread (spread between the three month LIBOR and the three month Tbill rates), VIX refers to the Chicago Board Options Exchange Volatility Index, CFSI refers to the Cleveland Financial Stress Index, N refers to the noise measure of Hu et al. (2013), CS refers to the corporate spread (spread between the Baa corporate and the ten year Treasury rates), BA denotes the bid-ask spread on the three month Tbill, $\widehat{X}_1$ and $\widehat{X}_2$ are the estimated yield curve factors from (9)–(10).

counterfactual TIPS liquidity premium, as long as they Granger cause the TIPS liquidity premium, they are not Granger caused by the TIPS liquidity premium and they are not affected by the policy.

As for the first two conditions, in Table 5 we report Granger causality tests for a set of potential conditioning variables that include the TED spread, the VIX index, the Cleveland Financial Stress Index, the noise measure of Hu et al. (2013), the corporate spread, the bid-ask spread on the three month Tbill and the yield curve factors. Results in Table 5 indicate that only the noise measure of Hu et al. (2013) and the corporate spread have significant predictive ability for the TIPS liquidity premium at 1% significance level and are not predicted by the TIPS liquidity premium. On the other hand, variables related to the yield curve of nominal Treasuries, i.e. the bid-ask spread on the three month Tbill and the yield curve factors, do not have any predictive ability for the TIPS liquidity premium factor. On the contrary, they are Granger caused by the TIPS liquidity premium. This indicates that changes in the TIPS liquidity premium affect nominal Treasuries.

The noise measure of Hu et al. (2013) is a market-wide illiquidity measure that exploits the connection between the amount of arbitrage capital in the market and observed noise in U.S.

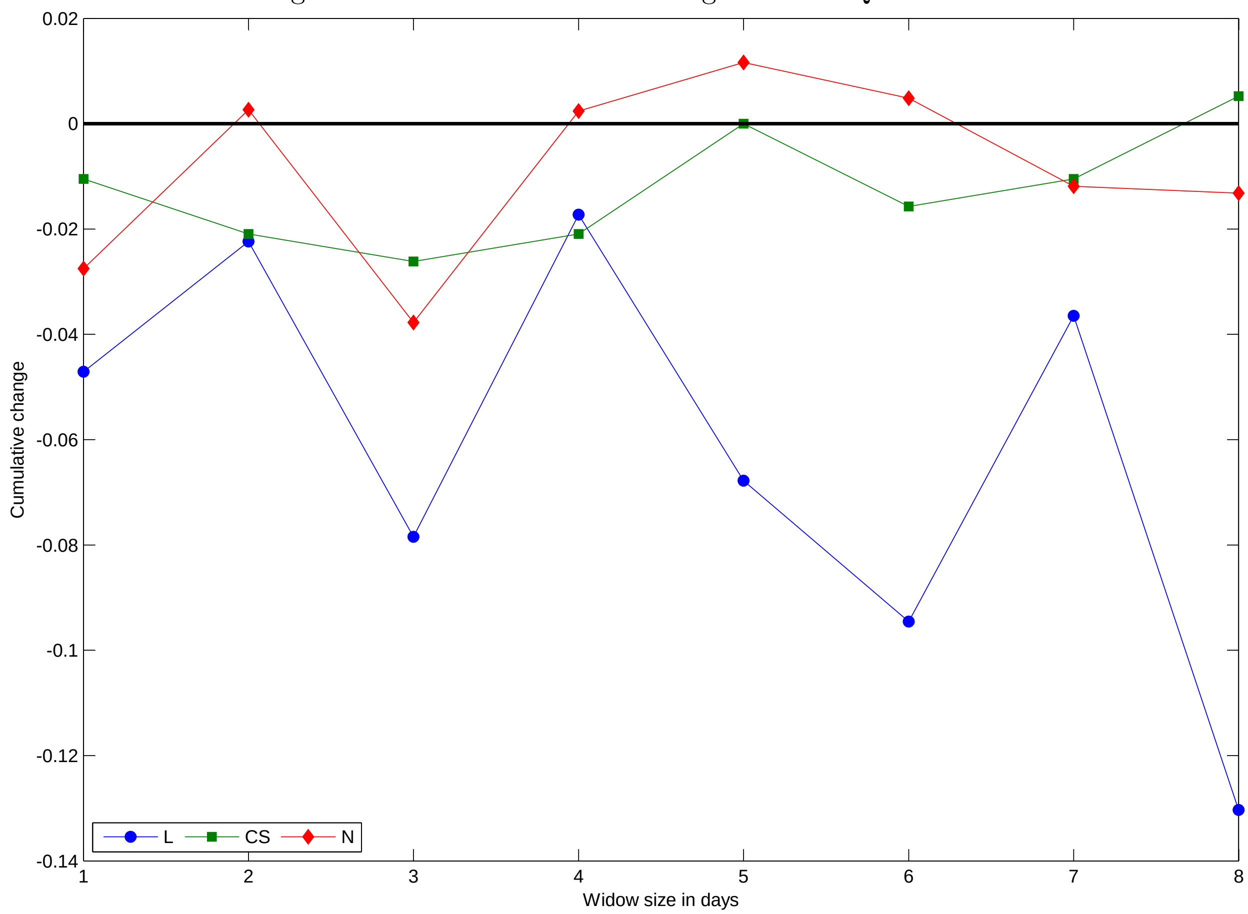
Treasury bonds. Hu et al. (2013) show that this measure captures episodes of liquidity crises of different origins across financial markets. Corporate bond spreads measure default risk premium and liquidity premium in corporate bonds, see Longstaff, Mithal and Neis (2005). Therefore, results in Table 5 indicate that the TIPS liquidity premium is Granger caused by measure of financial stress but, given the size of the TIPS market, events in this market have limited ability to spread across financial markets.

The last condition that a conditioning variable should satisfy in order to be included in a counterfactual exercise is that it should not be affected by the policy. In Figure 6 we report the median responses of the estimated TIPS liquidity premium, the standardized corporate spread and the standardized noise measure of Hu et al. (2013) around the dates of the QE2 events, for different window sizes. The figure indicates that both the corporate spread and the noise measure were not directly affected by the QE2 operations, as opposed to the TIPS liquidity premium that instead had large declines for any window size. We therefore conclude that both the noise measure and the corporate spread are suitable conditioning variables for the construction of the counterfactual TIPS liquidity premium factor.

We construct the counterfactual TIPS liquidity premium factor by estimating model parameters in (6)-(8) using observations up to November, 2 2010, i.e. the day before the announcement of the QE2 purchases. This implies that the counterfactual keeps historical pre-QE2 relations among the variables. We then assume that nominal and TIPS yields are only observed until November, 2 2010, and that conditioning variables are always observed. The counterfactual TIPS liquidity premium and the corresponding accuracy are then computed, respectively, as in (11) and (12), where $t_0 =$ November, 3 2010.

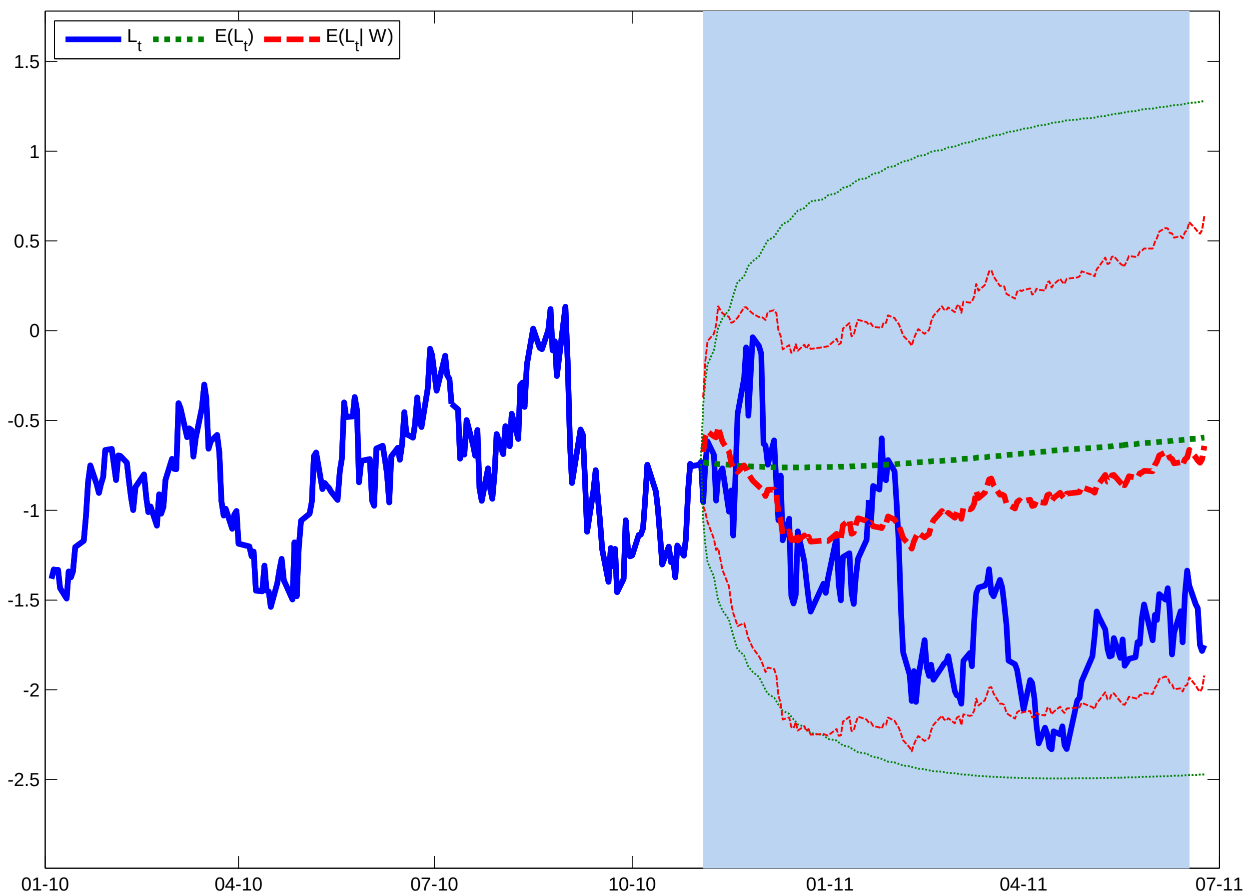
We perform two counterfactual exercises. In the first, we do not use any conditioning variable, i.e. $W_t = \emptyset$. In the second, we use as conditioning variables the noise measure of Hu et al. (2013) and the corporate spread, i.e. $W_t = [N_t, CS_t]$. Results in Figure 7 show that the two counterfactual liquidity premia are on average higher than the realised TIPS liquidity premium. The figure also shows that using conditioning variables has two effects on the counterfactual. First, when using

Figure 6: Median cumulative changes around QE2 events



The figure displays the median cumulative changes in the estimated TIPS liquidity factor (L), the standardized corporate spread (CS) and the standardized noise measure of Hu et al. (2013) (N) around the days of the QE2 announcement and operations for different window sizes (from one day change to eight days change).

Figure 7: TIPS liquidity premium factor: realised vs counterfactuals



The figure displays the estimated TIPS liquidity premium (continuous blue line) and two counterfactuals in which nominal and TIPS yields are observed only until November, 2 2010, as defined in (11). The thick green dotted line is the counterfactual TIPS liquidity premium factor that does not use any conditioning information, i.e. $W = \emptyset$. The thick dashed red line refers to the counterfactual TIPS liquidity premium factor that conditions on the noise measure of Hu et al. (2013) and the corporate spread. The thin lines delimitate the 95% confidence intervals for the counterfactuals with conditioning information (dashed) and without (dotted), computed as in (13). The blue shaded area indicates the QE2 operation period.

conditioning information, the counterfactual path for the TIPS liquidity factor gets on average closer to the realised liquidity premium. This indicates that part of the observed reduction of the TIPS liquidity premium in this period is due to a general reduction in illiquidity and risk premia in financial markets. Second, the accuracy of the counterfactual increases as more conditioning information is used. This because the conditioning variables provide additional information.

As for the comparison of the realised TIPS liquidity premium with the counterfactuals, Figure 7 shows that the realised TIPS liquidity premium is within the 95% confidence bands of the two counterfactuals most of the times. The only exception is in April 2011, when the realised TIPS liquidity factor is significantly lower than the counterfactual constructed using the illiquidity measure of Hu et al. (2013) and the corporate spread. However, this effect is only temporary and the realised TIPS liquidity factor reverts back within the 95% confidence bands in May 2011. We therefore conclude that the QE2 program had only a marginal effect on the liquidity premium in the TIPS market.

7 Conclusion

In this paper, we identify the liquidity premium in the TIPS market as the common component in TIPS yields that is unspanned by nominal yields. Using a joint factor model representation for nominal and TIPS yields, we extract the liquidity premium in the TIPS market by combining quasi-maximum likelihood and Kalman filtering. Our estimation results confirm that the liquidity premium is an important component of TIPS yields and that this component sharply increased during the recent financial crisis.

We use our setup to perform a counterfactual analysis of the liquidity premium in the TIPS market during the QE2 program. We construct a counterfactual path for the TIPS liquidity premium factor that does not incorporate the QE2 program but that conditions on suitable conditioning information. We define suitable conditioning variables for a counterfactual as variables that are invariant to the policy but informative about the variable on which we want to construct the counterfactual. Our empirical results indicate that a measure of market-wide illiquidity and the corporate spread are suitable conditioning variables for the construction of a counterfactual TIPS liquidity premium.

The counterfactual exercises show that using suitable conditioning variables improves the quality of the counterfactual. Nonetheless, we only find mild evidence for an effect of the QE2 program on the liquidity premium in the TIPS market.

A Estimation

The joint model for nominal yields (y_t^N), TIPS yields (y_t^T) and conditioning variables (W_t) can be written in compact notation as

$$\begin{aligned} z_t &= B^* F_t^* + v_t^*, \quad v_t^* \sim N(0, R^*) \\ F_t^* &= \Phi^* F_{t-1}^* + u_t^*, \quad u_t^* \sim N(0, Q^*) \end{aligned}$$

where

- $z_t = \begin{pmatrix} y_t^N \\ y_t^T \\ W_t \end{pmatrix}$, $B^* = \begin{bmatrix} B^N & 0 & 0 & a^N & I_n & 0 \\ B^R & B^L & 0 & a^T & 0 & I_m \\ 0 & 0 & I_w & 0 & 0 & 0 \end{bmatrix}$, $F_t^* = \begin{pmatrix} X_t \\ L_t \\ W_t \\ c_t \\ \varepsilon_t^N \\ \varepsilon_t^T \end{pmatrix}$, $R^* = \epsilon I_{n+m+w}$;

- $\Phi^* = \begin{bmatrix} \Phi & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & A \end{bmatrix}$, $u_t^* = \begin{bmatrix} u_t \\ \nu_t \\ v_t \end{bmatrix}$, $Q^* = \begin{bmatrix} Q & 0 & 0 \\ 0 & \epsilon & 0 \\ 0 & 0 & R \end{bmatrix}$

- ϵ is a coefficient that we fix to 1^{-12}.

- If $W_t = \emptyset$ we have a model without conditioning variables, as in (9)- (10)

We can write the restrictions on the factor loadings B^* and on the transition matrix Φ^* as

$$H_1 \ \text{vec}(B^*) = q_1, \qquad H_2 \ \text{vec}(\Phi^*) = q_2, \tag{A.1}$$

where H_1 and H_2 are selection matrices, and q_1 and q_2 contain the restrictions.

We assume that $F_1^* \sim N(\pi_1, V_1)$, and define $z = [z_1, \ldots, z_T]$ and $F^* = [F_1^*, \ldots, F_T^*]$. Then denoting the parameters by $\theta = \{B^*, \Phi^*, Q^*, \pi_1, V_1\}$, we write the joint loglikelihood of z_t and F_t, for $t = 1, \dots, T$, as

$$\begin{aligned} L(z, F^*; \theta) &= -\sum_{t=1}^{T} \left(\frac{1}{2} \left[z_t - B^* F_t^* \right]' (R^*)^{-1} \left[z_t - B^* F_t^* \right] \right) + \\ &\quad -\frac{T}{2} \log |R^*| - \sum_{t=2}^{T} \left(\frac{1}{2} [F_t^* - \Phi^* F_{t-1}^*]' (Q^*)^{-1} [F_t^* - \Phi^* F_{t-1}^*] \right) + \\ &\quad -\frac{T-1}{2} \log |Q^*| + \frac{1}{2} [F_1^* - \pi_1]' V_1^{-1} [F_1^* - \pi_1] + \\ &\quad -\frac{1}{2} \log |V_1| - \frac{T(p+k)}{2} \log 2\pi + \lambda_1' \left(H_1 \operatorname{vec}(B^*) - q_1 \right) + \\ &\quad +\lambda_2' \left(H_2 \operatorname{vec}(\Phi^*) - q_2 \right) \end{aligned}$$

where λ_1 and λ_2 contain the lagrangian multipliers associate with the constraints in (A.1).

The EM algorithm allows to obtain maximum likelihood estimates of the parameters and the latent factors by alternating Kalman filter extraction of the factors to the maximization of the likelihood. In practice, at the j-th iteration the algorithm we perform two steps:

1. In the Expectation-step, we compute the expected log-likelihood conditional on the data and the estimates from the previous iteration

   $$\mathcal{L}(\theta) = E[L(z, F^*; \theta^{(j-1)})|z]$$

   which depends on three expectations

   $$\begin{aligned} \hat{F}_t^* &\equiv E[F_t^*; \theta^{(j-1)}|z] \\ P_t &\equiv E[F_t^* (F_t^*)'; \theta^{(j-1)}|z] \\ P_{t,t-1} &\equiv E[F_t^* (F_{t-1}^*)'; \theta^{(j-1)}|z] \end{aligned}$$

   These expectations can be computed, for given parameters of the model, using the Kalman filter.

2. In the Maximization-step, we update the parameters maximizing the expected log-likelihood

with respect to the parameters θ:

$$\theta^{(j)} = \arg\max_{\theta} \mathcal{L}(\theta)$$

Given that the restrictions in (A.1) are linear. This step can be implemented taking the corresponding partial derivative of the expected log likelihood, setting to zero, and solving.

In order to start the algorithm, we initialize the yield curve factors with the first two normalized the principal components extracted from nominal yields. We then project the TIPS yields on these initial yield curve factors and use the first normalized principal component of the residuals of this regression to initialize the liquidity factor. Initial values for all parameters are then computed by OLS using the initial guesses of yield and liquidity factors.

Notice that the TIPS liquidity premium factor L_t is uniquely identified by the zero restrictions in the factor loadings. On the contrary, the yield curve factors X_1 and X_2 are only identified up to a rotation. To uniquely identify the yield curve factors we impose that the nominal yield with the shortest maturity has a positive factor loading on X_1 and a negative factor loading on X_2. This can be easily imposed by rotating the principal components in the initialization of the EM algorithm.

B Impulse-response functions

The joint model for nominal and TIPS yields in (6)-(8) can be written in compact notation as

$$y_t = a + BF_t + \varepsilon_t \tag{B.1}$$

$$\varepsilon_t = A\varepsilon_{t-1} + v_t, \quad v_t \sim N(0, R) \tag{B.2}$$

$$F_t = \Phi F_{t-1} + u_t, \quad u_t \sim N(0, Q) \tag{B.3}$$

where R is diagonal and Q is potentially non-diagonal.

In order to find the impulse response functions (IRFs), we need at first to write the VAR(1) in (B.3) in moving average form. Assuming that Φ satisfies the conditions for covariance stationarity, we can write the moving average representation of (B.3) as

$$F_t = \sum_{j=0}^{\infty} \Phi^j u_{t-j} \tag{B.4}$$

We use a Cholesky decomposition to obtain a lower-triangular matrix Σ that satisfies $Q = \Sigma\Sigma'$ and define the structural shocks as $\eta_t = \Sigma^{-1} u_t$.

The response of F_t to a one standard deviation shock to η^i_{t-j} is

$$IRF(F_t, \eta^i_{t-j}) = \frac{\partial F_t}{\partial \eta^i_{t-j}} = \Phi^j (\Sigma)_i \tag{B.5}$$

where $(\Sigma)_i$ is the i-th column of Σ. Substituting (B.4) in (B.1), we can compute the response of the observable variables y_t to a one standard deviation shock to η^i_{t-j} as

$$IRF(y_t, \eta^i_{t-j}) = \frac{\partial y_t}{\partial \eta^i_{t-j}} = B\Phi^j (\Sigma)_i \tag{B.6}$$

We compute confidence bands for the IRFs by parametric wild bootstrap. We proceed as follows. We estimate the model in (B.1)-(B.3) as detailed in Appendix A and save the idiosyncratic innovations and the state innovations. We then perform wild bootstrap of the state innovations and simulate the state variables. In the same way, we perform wild bootstrap of the idiosyncratic innovations and simulate the idiosyncratic components. We then obtain a sample of artificial yields by adding the simulated idiosyncratic components to the simulated state variables multiplied by the estimated factor loadings. We generate a 1,000 simulated samples of yields and for each simulated sample we estimate the model in (B.1)-(B.3) and compute the boostrapped IRFs in (B.5) and in (B.6). We then compute the $1 - \alpha$ confidence bands for the estimated IRFs by taking the $\alpha/2$ and the $1 - \alpha/2$ quantiles of the empirical distribution of each IRF.

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Tips from TIPS: the informational content of Treasury Inflation-Protected Security prices

Stefania D'Amico, Don H. Kim, and Min Wei

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Tips from TIPS: the informational content of Treasury Inflation-Protected Security prices*

Stefania D'Amico[†], Don H. Kim[‡], and Min Wei[§]

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†Division of Monetary Affairs, Federal Reserve Board of Governors, m1sxd02@frb.gov, +1-202-452-2567.

‡School of Business, Yonsei Unversity, donhkim@yonsei.ac.kr, +82-2-2123-2502.

§Division of Monetary Affairs, Federal Reserve Board of Governors, Min.Wei@frb.gov, +1-202-736-5619.

Abstract

TIPS breakeven inflation rate, defined as the difference between nominal and TIPS yields of comparable maturities, is potentially useful as a real-time measure of market inflation expectations. In this paper, we provide evidence that a fairly large TIPS liquidity premium existed until recently, using a multifactor no-arbitrage term structure model estimated with nominal and TIPS yields, inflation and survey forecasts of interest rates. Ignoring the TIPS liquidity premiums leads to counterintuitive implications for inflation expectations and inflation risk premium, and produces large pricing errors for TIPS. In contrast, models incorporating a TIPS liquidity factor generate much better fit for these variables and reveal a TIPS liquidity premium that was until recently quite large ($\sim 1\%$) but has come down in recent years, consistent with the common perception that TIPS market grew and liquidity conditions improved. Our results indicate that after taking proper account of the liquidity conditions in the TIPS market, the movement in TIPS breakeven inflation rate can provide useful information for identifying real yields, expected inflation and inflation risk premium.

1 Introduction

This paper presents a joint study of yields on nominal Treasury securities and those on Treasury Inflation-Protected Securities (TIPS) in a no-arbitrage asset pricing framework. Since its inception in 1997, the market for TIPS has grown substantially and now comprises about 8% of the outstanding Treasury debt market. More than a decade's TIPS data thus accumulated is a rich source of information to academic researchers and market participants alike. Because TIPS are securities whose coupon and principal payments are indexed to the price level, information about yields on these "real bonds" has direct implications for asset pricing models, many of which are written in terms of real consumption. Meanwhile, real-time TIPS data has attracted much attention from policy makers and market participants as a source of information about the state of the economy. In particular, the differential between yields on nominal Treasury securities and on TIPS of comparable maturities, often called the "breakeven inflation rate" (BEI) or "inflation compensation", has been used by policy makers and market participants as a proxy for market's inflation expectation. For example, the minutes of FOMC meetings often take note of changes in TIPS yields since the previous meeting,[1] and explicit references to TIPS breakeven rates in speeches by Fed officials are common.[2] Similarly, financial press frequently cite TIPS breakeven rates when discussing inflation expectations.

However, two difficulties arise in such interpretation of the TIPS breakeven inflation. First, TIPS breakeven inflation contains the inflation risk premium, which is the extra compensation investors in nominal bonds demand for bearing inflation risks. Second, TIPS has only been introduced recently and during its existence has been a less liquid instrument compared to nominal Treasury securities. The additional "liquidity premium" TIPS investors require for holding such instruments will drive up TIPS yields and depress the TIPS breakeven inflation. While the inflation risk premium has been studied by many researchers,[3] the liquidity pre-

[1] For example, the minutes of the June 2006 FOMC meeting includes the following sentence: "Yields on inflation-indexed Treasury securities increased by more than those on nominal securities, and the resulting decline in inflation compensation retraced a substantial share of the rise that had occurred over the preceding intermeeting period."

[2] Fed Vice Chairman Kohn (2006)'s speech on October 4, 2006, for example, includes the following remark: "In financial markets, the spread of nominal over indexed yields has also retreated substantially at the near end of the yield curve."

[3] See Pennacchi (1991), Buraschi and Jiltsov (2005), Ang, Bekaert, and Wei (2008) and Chernov and Mueller (2007), among others.

mium embedded in TIPS breakeven inflation has to our knowledge never been examined in the asset pricing literature.

The goal of this paper is to document the existence of liquidity premium in TIPS yields and to quantitatively characterize its behavior. To this end, we estimate and contrast several models for real and nominal yields, where the liquidity premium is either ignored or modeled as following different processes. All models we use are from the affine-Gaussian no-arbitrage term structure family and allow a rich dynamics in both the inflation risk premium and in nominal and real term premia.

Our main findings can be summarized as follows. First, a general 3-factor affine term structure model that ignores the liquidity premium generates large pricing errors for TIPS as well as counterfactual implications for inflation expectations and inflation risk premiums. In comparison, after incorporating an additional liquidity factor, the three 4-factor models that we estimate lead to notably smaller TIPS pricing errors, generate reasonable inflation risk premiums, and produce model-implied inflation expectations that agree well with survey inflation forecasts. Second, the liquidity premium estimates from all 4-factor models share the feature that it was large (1-2%) in the early years but declined in recent years, consistent with the notion that TIPS market liquidity conditions have improved over time and that TIPS pricing has possibly become more "efficient". In particular, around 80% of the variations in our estimates of TIPS liquidity premiums can be explained by variables related to the liquidity conditions in the TIPS market. Third, our best model for TIPS liquidity premiums has three parts, including a deterministic trend that captures the gradual but steady decline in TIPS liquidity premiums from the early years, a TIPS-specific factor that is independent of the nominal bond factors, as well as a component that is correlated with the rest of the economy. Finally, a variance decomposition shows that TIPS liquidity premiums explain more than 40% of variations in TIPS breakeven inflation, while that percentage declines to about one quarter in the long run.

The results in this paper shows that one needs to be careful in using the TIPS breakeven inflation rate as a proxy for inflation expectation, since an economically significant TIPS liquidity premium, on top of the inflation risk premium, could drive a large wedge between the TIPS breakeven inflation and inflation expectation. This problem seems to be especially severe in the early years of the TIPS market.

The remainder of this paper is organized as follows. In Section 2, we provide evidence that TIPS yields and TIPS breakeven inflation contain an additional factor, likely reflecting the illiquidity of TIPS, beyond those driving the nominal interest rates. Section 3 spells out the details of the no-arbitrage models we use, including the specification of the additional liquidity factor, and Section 4 explains the empirical methodology. Section 5 presents the main empirical results based on one model assuming zero TIPS liquidity premium and three models in which the TIPS liquidity premium is assumed to follow different specifications. Section 6 provides further discussions on the model estimates of the TIPS liquidity premiums and shows that they are indeed linked to the liquidity conditions in the TIPS markets. Section 7 provides some variance decomposition results for TIPS yields, TIPS breakeven inflation and nominal yields. Finally, Section 8 concludes.

2 A TIPS Liquidity Factor: Simple Analysis

In this section we present some simple analysis suggesting there exists a factor that is important for explaining the variations in TIPS yields but not as crucial for modeling nominal interest rates. We further argue that this factor is related to the illiquidity of the TIPS market. This serves as the motivation for introducing a TIPS-specific factor when we model nominal and TIPS yields jointly in later sections.

Simple Regression Analysis

In our first analysis, we regress the 10-year TIPS breakeven inflation rate, defined as the spread between the 10-year nominal yield and the 10-year TIPS yield, on 3-month, 2-year and 10-year nominal yields plus a constant:[4]

$$BEI_{t,10}^{\mathcal{T}} = \alpha + \beta_1 y_{t,0.25}^N + \beta_2 y_{t,2}^N + \beta_3 y_{t,10}^N + e_t. \tag{1}$$

Standard finance theory suggests that nominal yield of any maturity can be decomposed into the underlying real yield, inflation expectation and the inflation risk premium:

$$y_{t,\tau}^N = y_{t,\tau}^R + I_{t,\tau} + \wp_{t,\tau},$$

where $y_{t,\tau}^N$ and $y_{t,\tau}^R$ are the τ-period nominal and real yields, respectively, $I_{t,\tau}$ is the expected inflation over the next τ periods and $\wp_{t,\tau}$ is the inflation risk premium. If TIPS yields are a

[4] We thank Greg Duffee for this suggestion. Results using three different nominal yields or using the first principal components of nominal yields are similar. Nominal and TIPS yields are from fitted Svensson yield curves maintained by the staff at the Federal Reserve Board of Governors.

good measure of the underlying real yields, the TIPS breakeven inflation rate is simply the sum of expected inflation and inflation risk premiums, which are also parts of the nominal yields. Therefore, a regression of TIPS breakeven inflation onto nominal yield curve factors in this case can be expected to result in a high R^2. On the other hand, variations in TIPS yields that are unrelated to those in the nominal yields could lead to a low R^2 in such a regression. The results from running Regression (1) over the full sample of Jan. 6, 1999 to Mar. 14, 2007 are reported in Panel A of Table 1. The R^2 from this regression is a mere 32%, suggesting that a large portion of variations in the 10-year breakeven inflation cannot be explained by factors underlying the nominal interest rate variations. We have also examined this regression in first-differences, and obtained an R^2 of about 60%. This is much lower than the R^2's from a comparable regression of the first-difference of a nominal yield onto the first-differences of other nominal yields, which typically give an R^2 in excess of 95%.

Principal Components Analysis

Next, we conduct a principal component analysis (PCA) of the cross section of the nominal and TIPS yields. It is well known that, in the case of nominal yields, three factors explain most of the nominal yield curve movements. This is confirmed in Panel B of Table 1, which shows that more than 97% of the variations in weekly changes of 3- and 6-month and 1-, 2-, 4-, 7- and 10-year nominal yields can be explained by the first three principal components. However, once we add the 5-, 7- and 10-year TIPS yields, at least four factors are needed to explain the same amount of variance. Panel C of Table 1 reports the correlations between the first four PCA factors extracted from nominal yields alone and the first four PCA factors extracted from nominal and TIPS yields combined. It is interesting to note that, once we add TIPS yields to the analysis, the first, the second and the fourth factors largely retain their interpretations as the level, slope and curvature of the nominal yields curve, as can be seen from their high correlation with the first, the second and the third nominal factors, respectively. However, the third PCA factor extracted from nominal and TIPS yields combined is not highly correlated with any of the nominal PCA factors. The results shown here and the simple regression analysis shown above have an interesting parallel with the literature on the unspanned stochastic volatility (USV) effect: using a simple regression analysis, Collin-Dufresne and Goldstein (2002) argued that bond derivatives contain a factor that is not spanned by the yield curve factors, and Heidari and Wu (2003) reported evidence for unspanned stochastic volatility using a

PCA analysis.[5]

A Case for TIPS Liquidity Premium

A promising interpretation of the TIPS-specific factor we found above is that it reflects a "liquidity premium": investors would demand a compensation for holding a relative new and illiquid instrument like TIPS, especially in the early years.

Indeed, several measures related to TIPS market liquidity conditions, as well as anecdotal reports, indicate that the liquidity in TIPS market was much poorer than that of nominal securities, and that TIPS market liquidity improved over time, although this improvement was not a smooth, steady process. The top panel of Figure 1 shows the gross TIPS issuance over the period 1997-2007. The TIPS issuance dipped slightly in 2000-2001 before rising substantially in 2004. According to Sack and Elsasser (2004), there were talks around 2001 that the Treasury might discontinue the TIPS due to the relatively weak demand for TIPS. TIPS outstanding, shown in the bottom panel of Figure 1, began to grow at a faster pace from 2004 onward and now exceeds 400 billion dollars. Figure 2 tells a similar story from the demand side: TIPS transaction volumes grew by sixfold during our sample period and TIPS mutual funds also experienced significant growth.[6] In view of this institutional history, it is not unreasonable to suppose that TIPS contained a significant liquidity premium at least in its early years and that the liquidity premium have edged lower over time.

[Insert Figure 1 about here.]

[Insert Figure 2 about here.]

A liquidity premium in TIPS can help resolve a seeming inconsistency between survey inflation forecasts (10-year SPF survey and Michigan long-term survey) and the 10-year TIPS breakeven inflation, all of which are plotted in Figure 3. Recall that the true breakeven inflation, defined as the yield differential between nominal and real bonds of comparable maturities and liquidity features, is the sum of expected inflation and the inflation risk premium, and can be considered as a good measure of the former if the second term is relatively small and does not vary too much over time. However, Figure 3 shows that this is not the case: the

[5] Note, however, that the presence of USV is still debated. See, e.g., Joslin (2008) and Jacobs and Karoui (2009).

[6] Data on TIPS mutual fund is from the Investment Company Institute.

TIPS breakeven inflation lied below both measures of survey inflation forecasts almost all the time before 2004.[7] [8] [9] Such disparity cannot be attributed solely to the existence of inflation risk premium, as such an explanation would require the inflation risk premium to be mostly negative in the 1999-2007 period and highly volatile, which stands in contrast with most studies in the literature that find inflation risk premiums to be positive on average and relatively smooth.[10]

On the other hand, a positive TIPS liquidity premium would push the TIPS-based breakeven inflation below the true breakeven inflation and, if the TIPS liquidity premium exceeds the inflation risk premium in absolute terms, even lower than survey inflation forecasts. Furthermore, part of the volatility of the TIPS breakeven inflation rate may be due to the volatility of the TIPS liquidity premium.

In order to study these issues quantitatively, we need a framework for identifying and measuring the relevant components, including the TIPS liquidity premium, inflation expectations, and inflation risk premium. For this purpose, we use the no-arbitrage term structure modeling framework, to which we now turn.

[Insert Table 1 about here.]

[Insert Figure 3 about here.]

[7] This result is not specific to the use of survey inflation as a proxy for inflation expectations. Other measures of inflation expectation based on time-series models also tend to be above the TIPS breakeven inflation in early years.

[8] Similar points are made by Shen and Corning (2001) and Shen (2006).

[9] This is in contrast to the U.K. experience. The U.K. inflation-linked gilts were first issued in early 1980s, when inflation risk premiums were presumably still quite high after the recent experience of double-digit inflation. For example, Risa (2001) estimates the inflation risk premiums to be above 2% until late 1980s. The high inflation risk premiums evidently more than offset any potential liquidity premiums, resulting in a 10-year U.K. breakeven inflation that lay consistently above survey inflation forecasts throughout the 1980s (see Shen and Corning (2001)).

[10] See Campbell and Shiller (1996), Foresi, Penati, and Pennacchi (1997), Veronesi and Yared (1999), Buraschi and Jiltsov (2005), Ang, Bekaert, and Wei (2008), among others. Hördahl and Tristani (2009) provides a nice overview of some recent development.

3 A Joint Model of Nominal and TIPS yields

This section details the no-arbitrage framework that we use to model nominal and TIPS yields jointly. The no-arbitrage approach has the benefit of avoiding the tight assumptions that go into structural, utility-based models while still allowing term structure variations to be modeled in a dynamically consistent manner by requiring the cross section of yields to satisfy the no-arbitrage restrictions.

3.1 State Variable Dynamics and the Nominal Pricing Kernel

We assume that real yields, expected inflation and nominal yields are driven by a vector of three latent variables, $x_t = [x_{1t}, x_{2t}, x_{3t}]'$, which follows a multivariate Gaussian process,

$$dx_t = \mathcal{K}(\mu - x_t)dt + \Sigma dB_t, \tag{2}$$

where B_t is an n-dimensional vector of standard Brownian motion, μ is a 3×1 constant vector, and $\mathcal{K}, \Sigma$ are 3×3 constant matrices.

The nominal short rate is specified as

$$r^N(x_t) = \rho_0^N + \rho_1^{N'} x_t, \tag{3}$$

where ρ_0^N is a constant and ρ_1^N is a 3×1 vector.

The nominal pricing kernel takes the form

$$dM_t^N / M_t^N = -r^N(x_t)dt - \lambda^N(x_t)' dB_t, \tag{4}$$

where the vector of nominal prices of risk is given by

$$\lambda^N(x_t) = \lambda_0^N + \Lambda^N x_t, \tag{5}$$

in which λ_0^N is a 3×1 vector and Λ^N is a 3×3 matrix. Note that the nominal term structure in this paper falls into the “essentially affine” $A_0(3)$ category as described in Duffee (2002).

3.2 Inflation and the Real Pricing Kernel

The price level processes takes the form:

$$d \log Q_t = \pi(x_t)dt + \sigma_q' dB_t + \sigma_q^{\perp} dB_t^{\perp}. \tag{6}$$

where the instantaneous expected inflation, $\pi(x_t)$, is also an affine function of the state variables in the form of

$$\pi(x_t) = \rho_0^\pi + \rho_1^{\pi'} x_t, \tag{7}$$

and the unexpected inflation, $\sigma_q' dB_t + \sigma_q^\perp dB_t^\perp$, is allowed to load both on shocks that move the nominal interest rates and expected inflation, dB_t, and on an orthogonal shock $dB_t^\perp$ with $dB_t dB_t^\perp = 0$. The orthogonal shock is included to capture short-run inflation variations that may not be spanned by yield curve movements.

A real bond can be thought of as a nominal asset paying realized inflation upon maturity. Therefore, the real and the nominal pricing kernels are linked by the no-arbitrage relation

$$M_t^R = M_t^N Q_t. \tag{8}$$

Applying Ito's lemma to Equation (8) and using Equations (3) to (7), the real pricing kernel can be derived as following the process

$$dM_t^R / M_t^R = dM_t^N / M_t^N + dQ_t / Q_t + (dM_t^N / M_t^N) \cdot (dQ_t / Q_t) \tag{9}$$

$$= -r^R(x_t) dt - \lambda^R(x_t)' dB_t - (\cdot) dB_t^\perp \tag{10}$$

where the real short rate is given by

$$r^R(x_t) = \rho_0^R + \rho_1^{R'} x_t, \tag{11}$$

and the vector of real prices of risk is given by

$$\lambda^R(x_t) = \lambda_0^R + \Lambda^R x_t, \tag{12}$$

in which the coefficients are linked to their nominal counterparts by

$$\rho_0^R = \rho_0^N - \rho_0^\pi - \frac{1}{2}(\sigma_q' \sigma_q + \sigma_q^{\perp 2}) + \lambda_0^{N'} \sigma_q \tag{13}$$

$$\rho_1^R = \rho_1^N - \rho_1^\pi + \Lambda^{N'} \sigma_q \tag{14}$$

$$\lambda_0^R = \lambda_0^N - \sigma_q \tag{15}$$

$$\Lambda^R = \Lambda^N. \tag{16}$$

3.3 Nominal and Real Bond Prices

By the definition of nominal and real pricing kernels, the time-t prices of τ-period nominal and real bonds, $P_{t,\tau}^N$ and $P_{t,\tau}^R$, are given by

$$P_{t,\tau}^i = E_t(M_{t+\tau}^i) / M_t^i, \quad i = N, R. \tag{17}$$

The bond prices can be also expressed in terms of a risk-neutral expectation as

$$P^i_{t,\tau} = E^Q_t\left(\exp\left(-\int_t^{t+\tau} r^i_s\, ds\right)\right), \quad i = N, R. \tag{18}$$

where the superscript Q denotes the risk-neutral measure.

Following the standard literature,[11] it is straightforward to derive a closed-form solution for the bond prices:

$$P^i_{t,\tau} = \exp\left(A^i_\tau + B^{i\prime}_\tau x_t\right), \quad i = N, R, \tag{19}$$

where

$$\frac{dA^i_\tau}{d\tau} = -\rho^i_0 + B^{i\prime}_\tau\left(\mathcal{K}\mu - \Sigma\lambda^i_0\right) + \frac{1}{2}B^{i\prime}_\tau\Sigma\Sigma' B^i_\tau \tag{20}$$

$$\frac{dB^i_\tau}{d\tau} = -\rho^i_1 - \left(\mathcal{K} + \Sigma\Lambda^i\right)' B^i_\tau \tag{21}$$

with initial conditions $A^i_0 = 0$ and $B^i_0 = 0_{3\times 1}$.

Nominal and real yields therefore both take the affine form,

$$y^i_{t,\tau} = a^i_\tau + b^{i\prime}_\tau x_t, \quad i = N, R, \tag{22}$$

where the factor loadings a^i and b^i are given by

$$a^i_\tau = -A^i_\tau/\tau, \;\; b^i_\tau = -B^i_\tau/\tau, \tag{23}$$

3.4 Inflation Expectations and Inflation Risk Premiums

In this model, inflation expectations also take an affine form,

$$I_{t,\tau} \triangleq E_t(\log(Q_{t+\tau}/Q_t))/\tau = a^I_\tau + b^{I\prime}_\tau x_t, \tag{24}$$

where the factor loadings a^I and b^I are given by

$$\begin{aligned} a^I_\tau &= \rho^\pi_0 + (1/\tau)\rho^{\pi\prime}_1 \int_0^\tau ds(I - e^{-\mathcal{K}s})\mu \\ b^I_\tau &= (1/\tau)\int_0^\tau ds\, e^{-\mathcal{K}'s}\rho^\pi_1, \end{aligned}$$

From equations (22)-(24), it can be seen that both the breakeven inflation rate, defined as the difference between zero coupon nominal and real yields of identical maturities, and the

[11] See Duffie and Kan (1996) and Dai and Singleton (2000), among others.

inflation risk premium, defined as the difference between the breakeven inflation rate and the expected log inflation over the same horizon, are affine in the state variables:

$$BEI_{t,\tau} \triangleq y^N_{t,\tau} - y^R_{t,\tau} = a^N_\tau - a^R_\tau + (b^N_\tau - b^R_\tau)' x_t. \tag{25}$$

and

$$\wp_{t,\tau} \triangleq y^N_{t,\tau} - y^R_{t,\tau} - I_{t,\tau} = a^N_\tau - a^R_\tau - a^I_\tau + (b^N_\tau - b^R_\tau - b^I_\tau)' x_t. \tag{26}$$

(27)

Using Equation (8) we can write the price of a τ-period nominal bond as

$$P^N_{t,\tau} = E_t(M^R_{t+\tau} Q^{-1}_{t+\tau})/(M^R_t Q^{-1}_t). \tag{28}$$

It is then straightforward to show that the inflation risk premium $\wp_{t,\tau}$ consists of a covariance term, $c_{t,\tau}$, and a Jensen's inequality term, $J_{t,\tau}$:

$$\wp_{t,\tau} = c_{t,\tau} + J_{t,\tau}, \tag{29}$$

where

$$\begin{aligned} c_{t,\tau} &\equiv -(1/\tau)\log[1 + cov_t(M^R_{t+\tau}/M^R_t, Q_t/Q_{t+\tau})/(E_t(M^R_{t+\tau}/M^R_t)E_t(Q_t/Q_{t+\tau}))] \\ J_{t,\tau} &\equiv -(1/\tau)[\log(E_t(Q_t/Q_{t+\tau})) - E_t(\log(Q_t/Q_{t+\tau}))]. \end{aligned}$$

In practice, the Jensen's inequality term is fairly small, and the inflation risk premium is mainly determined by the covariance between the real pricing kernel and inflation,[12] and can assume either a positive or a negative sign depending on how the two terms covaries over time.

3.5 A Four-Factor Model of TIPS Yields

Given the evidence presented in Section 2 on the existence of a TIPS-specific factor, we allow the TIPS yield to deviate from the true underlying real yield. The spread between the TIPS yields and the true real yield,

$$L_{t,\tau} = y^{\mathcal{T}}_{t,\tau} - y^R_{t,\tau}, \tag{30}$$

[12] An alternative definition of inflation risk premium used in the literature is $\hat{\wp}_{t,\tau} = y^N_{t,\tau} - \left(y^R_{t,\tau} - \frac{1}{\tau}\ln E_t\left(Q_t/Q_{t+\tau}\right)\right)$ (See Buraschi and Jiltsov (2005)). The two definitions differ by the Jensen's inequality term $J_{t,\tau}$.

mainly captures the liquidity premium TIPS investors demand for holding a less liquid instrument, but could also reflect other factors that can potentially drive a wedge between the TIPS yield and the true real yield.[13] Since the relative illiquidity of TIPS would lower TIPS prices and raise TIPS yields, we would in general expect $L_{t,\tau}$ to be positive.

We model $L_{t,\tau}$ as containing a stochastic component and a deterministic component. To model the stochastic part, we assume that the investors discount TIPS cash flows by adjusting the true instantaneous real short rate with a positive liquidity spread, resulting in a TIPS yield that exceeds the true real yield by

$$L^s_{t,\tau} = -(1/\tau)\log E^Q_t\left(\exp\left(-\int_t^{t+\tau}(r^R_s + l_s)ds\right)\right) - y^R_t, \tag{31}$$

where $L^s_{t,\tau}$ denotes the stochastic part of the TIPS liquidity premium, l_t is the instantaneous liquidity spread, and the superscript Q represents expectation taken under the risk-neutral measure.[14] This is analogous to the corporate bond pricing literature,[15] where defaultable bonds are priced by discounting future cash flows using a default- and liquidity-adjusted short rate. Note that, without the instantaneous liquidity spread l in Equation (31), the TIPS yield becomes identical to the true real yield y^R and the stochastic part of the TIPS liquidity premium becomes zeros (see Equation (18)).

The instantaneous liquidity spread l_t is given by

$$l_t \;\; = \;\; \gamma' x_t + \tilde{\gamma}\tilde{x}_t, \tag{32}$$

where γ is a 3×1 constant matrix, $\tilde{\gamma}$ is a constant and $\tilde{x}_t$ follows the Vasicek (1977) process and is independent of all other state variables contained in x_t:

$$d\tilde{x}_t = \tilde{\kappa}(\tilde{\mu} - \tilde{x}_t)dt + \tilde{\sigma}dW_t, \tag{33}$$

in which $dW_t dB_t = 0_{3\times1}$. A non-zero γ allows the liquidity premium to be correlated with the state of economy. We assume that the independent liquidity factor $\tilde{x}_t$ carries a market price of risk of

$$\tilde{\lambda}_t = \tilde{\lambda}_0 + \tilde{\lambda}_1\tilde{x}_t. \tag{34}$$

[13] Such factors include indexation lags and seasonal and short-run variations in headline CPI prices.

[14] Although our treatment is motivated by the liquidity consideration, our model of TIPS yields could be also viewed more generally as a model in which TIPS yields of all maturities are affected by a common TIPS-specific factor.

[15] See Duffie and Singleton (1999), Longstaff, Mithal, and Neis (2005), Driessen (2005).

Appendix B shows that the stochastic part of the TIPS liquidity premium takes the affine form

$$L^s_{t,\tau} = \left[\tilde{a}_\tau + (a^{\mathcal{T}}_\tau - a^R_\tau)\right] + \left[\begin{array}{cc} (b^{\mathcal{T}}_\tau - b^R_\tau)' & \tilde{b}_\tau \end{array}\right] \left[\begin{array}{c} x_t \\ \tilde{x}_t \end{array}\right] \tag{35}$$

Note that although we focus on a one-factor specification for the liquidity factor $\tilde{x}_t$, it is straightforward to extend the model to incorporate multiple liquidity factors.

To accommodate potential nonstationarities associated with the inception of the TIPS market, we also allow for a maturity-independent downward-trending deterministic component in the liquidity premium, which takes the form

$$L^d_t = (c_1/2)\left[1 - \tanh\left(c_2\left(t - c_3\right)\right)\right], \tag{36}$$

where c_1 controls the initial level of TIPS liquidity premium, c_2 controls the speed that the liquidity premium comes down over time, and c_3 controls the time when the decline is the steepest. The backwards S-shaped hyperbolic tangent function is designed to yield a liquidity premium that was high when the TIPS was first introduced but decreases over time and asymptotes towards zero. This is meant to capture the depressed demand in a fledgling market as well as its gradual adjustment towards the equilibrium.

The total liquidity premium on a τ-year TIPS in our "full model" is then the sum of the two components:

$$L_{t,\tau} = L^d_t + L^s_{t,\tau}. \tag{37}$$

with the TIPS yields given by

$$y^{\mathcal{T}}_{t,\tau} = y^R_{t,\tau} + L_{t,\tau}. \tag{38}$$

We shall refer to this model as Model L-IId. In the empirical part, we also estimate three restricted versions of the full model. The model with the least restrictions, which we shall call Model L-II, sets c_1 and hence the deterministic part of the liquidity premium to zero. The next restricted model, which we shall term Model L-I, further sets $\gamma = 0_{3\times1}$ in Equation (32), so that the liquidity premiums on TIPS are not correlated with the nominal term structure factors. This results in a model similar to those in Driessen (2005) and Longstaff, Mithal, and Neis (2005), which model the liquidity premium in corporate bonds as a one-factor process that is independent of the credit and interest rate factors. Finally, the most restricted model, which we shall call Model NL, simply equate TIPS yields with the true real yields, i.e.,

$$y^{\mathcal{T}}_{t,\tau} = y^R_{t,\tau}. \tag{39}$$

This is the model studied by Chen, Liu, and Cheng (2005), although their specification differ from ours along other dimensions.

3.6 Discussions and Related Literature

Besides its tractability, the affine-Gaussian bond pricing framework used here allows for a flexible correlation structure between the factors. As inflation risk premiums arise from the correlation between the real pricing kernel and inflation, it is important to allow for a general correlation structure. On the other hand, the affine-Gaussian setup does not capture the *time-varying* inflation uncertainty and therefore cannot further decompose inflation risk premiums into the part due to time-varying inflation risks and time-varying prices of inflation risk. Nonetheless, the affine-Gaussian model could still provide a reasonable estimate of inflation risk premium, similar to the way it generates reasonable measures of term premia despite its inability to capture time-varying interest rate volatilities. We view the general affine-Gaussian model as an important benchmark to be investigated before more sophisticated models can be explored.

Some of the models studied in the earlier literature, such as Pennacchi (1991) and Campbell and Viceira (2001), can be viewed as a special case of this model. For example, Pennacchi (1991)'s model corresponds to a two-factor version of our model with constant market price of risk. Campbell and Viceira (2001) is also a special case of this model, but their real term structure has a lower dimension than the nominal term structure (nominal yields are described by 2 factors and real yields are described by 1 factor). In this paper, we let the real term structure have as many factors as the nominal term structure; if the real term structure is truly lower-dimensional than nominal term structure, we let the data decide on that. A related point is that in a reduced-form setup like ours, one cannot make a distinction between *real* and *nominal* factors, as correlation effects in the general model make such a distinction meaningless.

To our knowledge, this is the first paper to model liquidity premium in TIPS in a no-arbitrage framework. There is a large literature studying the pricing implications of indexed bonds using data from other countries with longer histories of issuing inflation linked securities,[16] There have also been studies of US real yields and inflation risk premia that use

[16] See Woodward (1990), Barr and Campbell (1997), Evans (1998), Remolona, Wickens, and Gong (1998) and Risa (2001) for the UK, Kandel, Ofer, and Sarig (1996) for Isreal and Hördahl and Tristani (2007) for the Euro

realized inflation[17] or survey inflation forecasts[18] without incorporating information from indexed bonds. Due to the short data history, studies using U.S. inflation-linked assets, including TIPS or inflation swaps, are fairly recent and relatively few.[19] In addition, most of these studies take TIPS at their face value, and typically find a real yield that seems too high as well as inflation risk premium estimates that are insignificant or negative in the early sample when TIPS was first introduced. In contrast, this paper shows that there is a persistent liquidity premium component in TIPS prices, which, if not properly taken account of, will bias the results.

4 Empirical Methodology

4.1 Identification and Summary of Models

We only impose restrictions that are necessary for achieving identification so as to allow a maximally flexible correlation structure between the factors, which has shown to be critical in fitting the rich behavior in risk premiums that we observe in the data.[20] In particular, we employ the following normalization:

$$\mu = 0_{3\times1}, \;\; \Sigma = \begin{bmatrix} 0.01 & 0 & 0 \\ \Sigma_{21} & 0.01 & 0 \\ \Sigma_{31} & \Sigma_{32} & 0.01 \end{bmatrix}, \;\; \mathcal{K} = \begin{bmatrix} \mathcal{K}_{11} & 0 & 0 \\ 0 & \mathcal{K}_{22} & 0 \\ 0 & 0 & \mathcal{K}_{33} \end{bmatrix}, \;\; \tilde{\sigma} = 0.01. \tag{40}$$

and leave all other parameters unrestricted. It can be shown that any specification of the affine Gaussian model that has a $\mathcal{K}$ matrix with all-real eigenvalues can be transformed to this form.[21]

area.

[17] See, e.g., Ang, Bekaert, and Wei (2008).

[18] See, e.g., Pennacchi (1991), Foresi, Penati, and Pennacchi (1997) and Brennan, Wang, and Xia (2004).

[19] To our knowledge, this paper and a contemporaneous study by Chen, Liu, and Cheng (2005) are the first two to study TIPS in a no-arbitrage framework. Other papers analyzing TIPS or inflation swaps include Chernov and Mueller (2007), Adrian and Wu (2008), Haubrich, Pennacchi, and Ritchken (2008), Christensen, Lopez, and Rudebusch (2008), Grishchenko and Huang (2008).

[20] See Duffie and Kan (1996) and Dai and Singleton (2000).

[21] With normalization (40), the specification we estimate in this paper can be shown to be equivalent to that of Sangvinatsos and Wachter (2005). The main difference between their paper and ours is empirical: they use a much longer sample, which would be desirable if the relationship between inflation and interest rates can be assumed to be stable.

To summarize, we estimate four models that differ in how TIPS liquidity premium is modeled, including one model that equates TIPS yields with true real yields and assumes zero liquidity premium on TIPS (Model NL), a model with an independent liquidity factor (Model L-I), a model allowing the TIPS liquidity premium to be correlated with other state variables (Model L-II), and the most general model (Model L-IId) in which TIPS liquidity premiums also contain a deterministic trend. Table 2 summarizes the models and the parameter restrictions. Two things are worth noting here: First, as shown in Section 3.5, Models NL, L-I and L-II can all be considered as special cases of Model L-IId. Second, Model NL has a 3-factor representation of TIPS yields, while in all other models TIPS yields have a 4-factor specification.

[Insert Table 2 about here.]

4.2 Data

We use 3- and 6-month, 1-, 2-, 4-, 7-, and 10-year nominal yields and CPI-U data from January 1990 to March 2007. In contrast, our TIPS yields are restricted by data availability and cover a shorter period from January 1999 to March 2007, with the earlier period without TIPS data (1990-1998) treated as missing observations. Both nominal and TIPS yields, shown in Figure 4, are based on zero-coupon yield curves fitted at the Federal Reserve Board[22] and are sampled at the weekly frequency, while CPI-U inflation is available monthly and assumed to be observed on the last Wednesday of the current month.[23] As discussed in more details in Appendix A, shorter-maturity TIPS yields are affected to a larger degree by the problem of indexation lags. In addition, no more than one TIPS with a maturity of below 5 years existed before 2002, hence near-maturity zero-coupon TIPS yields cannot be reliably estimated during that period. We therefore only use 5-, 7-, and 10-year TIPS yields in our estimation. Because the models we estimate do not accommodate seasonalities, we use seasonally-adjusted CPI inflation in the estimation. TIPS are indexed to non-seasonally-adjusted CPI; however, our use of seasonally-adjusted CPI is not expected to matter much for the relatively long maturities

[22] Nominal yields are based on the Svensson (1994) curve specification for the entire sample; TIPS yields are based on the Nelson and Siegel (1987) curve specification prior to January 2004 and the Svensson (1995) curve specification thereafter. See Gürkaynak, Sack, and Wright (2007, 2009) for more details.

[23] Here we abstract from the real-time data issue by assuming that investors correctly infer the current inflation rate in a timely fashion.

that we examine.

The sample period 1990-2007 was chosen as a compromise between having more data in order to improve the efficiency of estimation, and having a more homogeneous sample so as to avoid possible structural breaks[24] in the relation between term structure variables and inflation. This sample period roughly spans Greenspan's tenure and a little bit of Bernanke's as well.

Results from Kim and Orphanides (2006) suggest that the standard technique of estimating our models using only nominal and TIPS yields and inflation data for a relative short sample period of 1990-2007 will almost surely run into small sample problems: variables like $\mathcal{K}$ and Λ^N may not be reliably estimated, and the estimated model typically generates a path of expected future short rate over the next 5 to 10 years that is too smooth compared to survey-based measures of market expectations.[25] Therefore, we supplement the aforementioned data with survey forecasts of 3-month T-bill yields to help stabilize the estimation and to better pin down some of the model parameters. Note that survey *inflation* forecast data are *not* used in the estimation, as we would like to get a measure of inflation expectations from yields data, independently of other sources of information about inflation expectation.

To be specific, we use the 6-month- and 12-month-ahead forecasts of the 3-month T-bill yield from Blue Chip Financial Forecasts, which are available monthly, and allow the size of the measurement errors to be determined within the estimation. We also use long-range forecast of 3-month T-bill yield over the next 5 to 10 years from the same survey, which are available twice a year, with the standard deviation of its measurement error fixed at a fairly large value of 0.75% at an annual rate. This is done to prevent the long-horizon survey forecasts from having unduly strong influence on the estimation, and can be viewed as similar to a quasi-informative prior in a Bayesian estimation.

We denote the short-horizon survey forecasts by $f_{t,6m}$ and $f_{t,12m}$ and the long-range forecast by $f_{t,long}$. The standard deviation of their measurement errors are denoted denoted $\delta_{f,6m}, \delta_{f,12m}$ and $\delta_{f,long}$, respectively. These survey-based forecasts are taken as noisy measures of corresponding true market expectations. More specifically, we have that for the short-

[24] The 1979-83 episode of Fed's experiment with reserve targeting is a well known example.

[25] Results for our models based on the conventional estimation method are available upon request.

term survey forecasts,

$$f_{t,\tau} = E_t(y^N_{t+\tau,3m}) + \epsilon^f_{t,\tau}, \qquad \epsilon^f_{t,\tau} \sim N(0, \delta^2_{f,\tau}), \tag{41}$$

for $\tau = 6m$ or $12m$, and for long-range forecasts,

$$f_{t,long} = E_t\left(\frac{1}{5}\int_{5y}^{10y} y^N_{t+\tau,3m} d\tau\right) + \epsilon^f_{t,long}, \qquad \epsilon^f_{t,long} \sim N(0, 0.0075^2), \tag{42}$$

where the corresponding model forecasts, $E_t(y^N_{t+\tau,3m})$, can be solved from Equations (2) and (22) and can be shown to be

$$E_t(y^N_{t+\tau,3m}) = a^f_\tau + b^{f\prime}_\tau x_t, \tag{43}$$

where the factor loadings a^f_τ, b^f_τ are given by

$$a^f_\tau = a^N_{3m} + b^{N\prime}_{3m}\left(I_{3\times 3} - e^{-\kappa\tau}\right) \tag{44}$$

$$b^f_\tau = e^{-\kappa'\tau} b^N_{3m} \tag{45}$$

[Insert Figure 4 about here.]

4.3 Estimation Methodology

We rewrite the model in a state-space form and estimate it by the Kalman filter. Denote by $\mathrm{x}_t = [q_t, x'_t, \tilde{x}_t]'$ the augmented state vector including the log price level, $q_t \equiv \log(Q_t)$, and the TIPS liquidity factor, $\tilde{x}_t$. The state equation is derived as Euler discretization of equations (2), (6) and (33) and can be written in a matrix form as

$$\mathrm{x_t = G_h + \Gamma_h x_{t-h} + \eta^x_t}. \tag{46}$$

where

$$G_h = \begin{bmatrix} \rho^\pi_0 h \\ \mathcal{K}\mu h \\ \tilde{\kappa}\tilde{\mu} h \end{bmatrix}, \ \Gamma_h = \begin{bmatrix} 1 & \rho^{\pi\prime}_1 h & 0 \\ 0 & I_{3\times 3} - \mathcal{K}h & 0 \\ 0 & 0 & 1 - \tilde{\kappa}h \end{bmatrix} \text{ and } \eta^{\mathrm{x}}_t = \begin{bmatrix} \sigma'_q \eta_t + \sigma^\perp_q \eta^\perp_t \\ \Sigma\eta_t \\ \tilde{\sigma}\tilde{\eta}_t \end{bmatrix}$$

in which η_t, $\eta^\perp_t$, and $\tilde{\eta}_t$ are independent of each other, and have the distribution

$$\eta_t \sim N(0, hI_{n\times n}), \ \ \eta^\perp_t \sim N(0, h), \ \ \tilde{\eta}_t \sim N(0, h). \tag{47}$$

We specify the set of nominal yields as $Y_t^N = \{y_{t,\tau_i}^N\}_{i=1}^7$, and the set of TIPS yields as $Y_t^{\mathcal{T}} = \{y_{t,\tau_i}^{\mathcal{T}}\}_{i=1}^3$, and collect in y_t all data used in the estimation, including the log price level q_t, all nominal yields Y_t^N, all TIPS yields $Y_t^{\mathcal{T}}$, and 6 month-ahead, 12 month-ahead, and long-horizon forecasts of future 3-month nominal yield:

$$\mathrm{y}_t = [q_t, Y_t^N, Y_t^{\mathcal{T}}, f_{t,6m}, f_{t,12m}, f_{t,long}]'. \tag{48}$$

We assume that all nominal and TIPS yields and survey forecasts of nominal short rate are observed with error. The observation equation therefore takes the form

$$\mathrm{y}_t = A + B\mathrm{x}_t + \mathrm{e}_t \tag{49}$$

where

$$A = \begin{bmatrix} 0 \\ A^N \\ \tilde{a} + A^{\mathcal{T}} \\ a_{6m}^f \\ a_{12m}^f \\ a_{long}^f \end{bmatrix}, \quad B = \begin{bmatrix} 1 & 0 & 0 \\ 0 & B^{N\prime} & 0 \\ 0 & B^{\mathcal{T}\prime} & \tilde{b}' \\ 0 & b_{6m}^{f\prime} & 0 \\ 0 & b_{12m}^{f\prime} & 0 \\ 0 & b_{long}^{f\prime} & 0 \end{bmatrix}, \quad \mathrm{e}_t = \begin{bmatrix} 0 \\ e_t^N \\ e_t^{\mathcal{T}} \\ e_{t,6m}^f \\ e_{t,12m}^f \\ e_{t,long}^f \end{bmatrix}, \tag{50}$$

in which A^i and B^i, $i = N, \mathcal{T}$ collect the nominal and TIPS yield loadings on x_t, respectively, in obvious ways, and $\tilde{a}$ and $\tilde{b}$ collects the TIPS yield loadings on the independent liquidity factor $\tilde{x}_t$. We assume a simple i.i.d. structure for the measurement errors so that

$$e_{t,\tau_i}^N \sim N(0, \delta_{N,\tau_i}^2), \quad e_{t,\tau_i}^{\mathcal{T}} \sim N(0, \delta_{\mathcal{T},\tau_i'}^2), \quad e_{t,\tau_i}^f \sim N(0, \delta_{f,\tau_i}^2) \tag{51}$$

Based on the state equation (46) and the observation equation (49), it is straightforward to implement the Kalman-filter and perform the maximum likelihood estimation. The details are given in Appendix C. Two aspects are worth noting here: first, the log price level q_t is nonstationary, so we use a diffuse prior for q_t when initializing the Kalman filter. Second, inflation, survey forecast and TIPS yields are not available for all dates, which introduces missing data in the observation equation and are handled in the standard way by allowing the dimensions of the matrices A and B in Equation (49) to be time-dependent (see, for example, Harvey (1989, sec. 3.4.7)).

Note that all four versions of our models can be accommodated in the above setup. To implement Model NL without the liquidity premium, one simply set $\tilde{\gamma} = 0$ and $\gamma = 0_{3\times 1}$, and fix $\tilde{\mu}$, $\tilde{\kappa}$, $\tilde{\lambda}_0$ and $\tilde{\lambda}_1$ at arbitrary values as those variables do not enter the likelihood function of Model NL. To implement Model L-I with the independent liquidity factor only, one would fix $\gamma = 0_{3\times 1}$.

To facilitate the estimation and also to make the results easily replicable, we follow the following steps in estimating all our models:

1. We first perform a "pre"-estimation where a set of preliminary estimates of the parameters governing the nominal term structure is obtained using nominal yields and survey forecasts of 3-month T-bill yield alone.
2. Based on these estimates and data on nominal yields, we can obtain a preliminary estimate of the state variables, x_t.
3. A regression of the monthly inflation onto estimates of x_t obtained in the second step gives a preliminary set of estimates of the parameters governing the inflation dynamics.
4. Finally, these preliminary estimates are used as starting values in the full, one-step estimation of all model parameters.

5 Empirical Results

In this Section, we discuss and compare the empirical performance of the various Models. As we shall see, there are notable differences between the model equating TIPS yields with the true real yields (Model NL) and the models that allow the two sets of yields to differ by a liquidity premium component (Models L-I, L-II and L-IId).

5.1 Parameter Estimates and Overall Fit

Parameter Estimates

Table 3 reports the parameter estimates for all four models. Four things are worth noting here: First, estimates of parameters governing the nominal term structure are almost identical across the three models; under our set-up, these parameters seem to be fairly robustly estimated. In particular, all estimations uncover a very persistent factor with a half life of about

13 years. Note also that all four models exhibit a similar fit to nominal yields and survey forecasts of nominal short-term interest rates. For example, the nominal yield fitting errors ($\delta_{N,\tau}$) are fairly small in all four models: except for the 3-month yield which has δ_N of about 10 basis points, other maturity yields have δ_N of 5 basis points or less.

Second, there are notable differences in the estimates of parameters governing the expected inflation process. In particular, the loading of the instantaneous inflation on the second and the most persistent factor is negligible in the model without a TIPS liquidity factor (Model NL) but becomes positive and significant in the three models with a TIPS liquidity factor (Models L-I, L-II and L-IId). As a result, the monthly autocorrelation of one-year-ahead inflation expectation is about 0.9 in Model NL but above 0.99 in all other models. As we will see later, the lack of persistence in the inflation expectation process prevents Model NL from generating meaningful variations in longer-term inflation expectations as we observe in the data.

Third, parameter estimates for the TIPS liquidity factor process are significant in both Models L-I and L-II and assume similar values. The estimated market price of liquidity risk carries the expected negative sign, as one would generally expect any deterioration of liquidity conditions to occur during bad economic times. In Models L-II and L-IId, the loading of the instantaneous TIPS liquidity premium on each of the three state variables, γ, is estimated to be indistinguishable from zero; however, a Wald test shows that they are jointly significant.

Finally, the fit to TIPS yields are significantly better in models with a TIPS liquidity factor, as can be seen from the smaller estimates of the standard deviations of TIPS measurement errors. For example, for the 10-year TIPS, the fitting errors from the L-I and L-II models are 6 basis points, while the fitting error from Model NL is 35 basis points. The fitting errors are found to have a substantial serial correlation. For example, in the case of the 5-year TIPS, we obtain a weekly AR(1) coefficient of 0.96, 0.91, and 0.91 for Model NL, L-I model, and L-II model, respectively. The finding of serial correlation in term structure fitting errors are however a fairly common phenomenon, and have been noted by Chen and Scott (1993) and others.

[Insert Table 3 about here.]

Overall Fit

Panel A of Table 4 reports some test statistics that compare the overall fit of the three models. We first report two information criteria commonly used for model selection, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Both information criteria are minimized by the most general model, Model L-IId.

We also report results from likelihood ratio (LR) tests of the three restricted models, Models NL, L-I and L-II, against their more general counterparts, Model L-I, L-II and L-IId, respectively. Compared to Model L-I, Model NL imposes the restriction $\tilde{\gamma} = 0$. The standard likelihood ratio test does not apply here because the nuisance parameters, $\tilde{\kappa}$, $\tilde{\mu}$, $\tilde{\lambda}_0$ and $\tilde{\lambda}_1$, are not identified under the null (Model NL) and appear only under the alternative (Model L-I).[26] Here we follow Garcia and Perron (1996) and calculate a conservative upper bound for the significance of the likelihood ratio test statistic as suggested by Davies (1987). In particular, denote by θ the vector of nuisance parameters of size s, and define the likelihood ratio statistic as a function of θ:

$$LR(\theta) = 2\left[\log L_1(\theta) - \log L_0\right],$$

where $L_1(\theta)$ is the likelihood value of the alternative model for any admissible values of the nuisance parameters $\theta \in \Omega$, and L_0 is the maximized likelihood value of the null model. For an estimated LR value of M, Davies (1987) derives an upper bound for its significance as

$$\Pr\left[\sup_{\theta\in\Omega} LR(\theta) > M\right] < \Pr\left[LR(\theta) > M\right] + VM^{\frac{1}{2}(s-1)} \exp^{-(M/2)} \frac{2^{-s/2}}{\Gamma(s/2)}$$

where $\Gamma(.)$ represents the Gamma function and V is defined as

$$V = \int_\Omega \left|\frac{\partial LR(\theta)}{\partial\theta}\right| d\theta.$$

Garcia and Perron (1996) further assumes that the likelihood ratio statistic has a single peak at $\widehat{\theta}$, which reduces V to $2M^{\frac{1}{2}}$. Apply this procedure to testing the null of Model NL against the alternative of Model L-I gives an estimate of the maximal p value of essentially zero, hence Model NL is overwhelmingly rejected in favor of Model L-I. With the LR statistic estimated as $-2\log\left[L(\mathrm{NL})/L(\mathrm{L{-}I})\right] = 4617.67$ with 1 degree of freedom, we feel confident that using alternative econometric procedures to deal with the nuisance parameter problem is unlikely to overturn the rejection.

The LR test of Model L-I against Model L-II, on the other hand, is fairly standard. Based on the likelihood estimates of the two models, we obtain a LR statistic of

$$-2\log\left[L(\mathrm{L{-}I})/L(\mathrm{L{-}II})\right] = 8.6,$$

[26] For discussions on testing with nuisance parameters, see, for example, Davies (1977, 1987, 2002) and Andrews and Ploberger (1994, 1995).

and are able to reject Model L-I in favor of Model L-II at the 5% level based on a χ^2_3 distribution.

Finally, Model L-II is rejected in favor of the full model, Model L-IId, based on the Davies (1987) procedure, with a large LR test value of 433.41.

[Insert Table 4 about here.]

5.2 Fitting TIPS Yields and TIPS Breakeven Inflation

The estimated standard deviations of TIPS measurement errors reported in the previous section suggest that Model NL has trouble fitting the TIPS yields. This section looks at the fit of TIPS yields and TIPS breakeven inflation across models in more details.

The three left (right) panels of Figures 5 plot the actual and the model-implied TIPS yields (TIPS breakeven inflation) based on Models NL, L-I and L-IId, respectively, together with the real yields (the true breakeven inflation) as implied by the three models.[27] By construction, the model-implied TIPS yields and the model-implied real yields coincide under Model NL.

The top left panel of Figures 5 shows that, according to Model NL, the downward path of 10-year TIPS yields from 1999 to 2004 is part of a broader decline in real yields since the early 1990's, with real yields estimated to have come down from a level as high as 7% in the early 90's to about 2% around 2003. During the same period, the 10-year nominal yield declined from around 9% to a little over 4%. Therefore, Model NL attributes the decline of 10-year nominal yield entirely to a lower real yield, leaving little room for lower inflation expectation or lower inflation risk premiums. While there is some empirical evidence suggesting that long-term inflation expectations may have edged down during this period,[28] it is hard to imagine economic mechanisms that would generate such a large decline in long-term real yields. Furthermore, although Model NL matches the general trend of TIPS yields during this period, it has problem fitting the time variations, frequently resulting in large fitting errors. In contrast, the decline in real yields as implied by Models L-I and L-IId, plotted in the middle

[27] Model-implied true breakevens are calculated as the difference between model-implied nominal yields and model-implied real yields of comparable maturities. Model-implied values are calculated using smoothed estimates of the state variables. Results for Model L-II are similar to those for Model L-IId and are not reported.

[28] See Kozicki and Tinsley (2006), for example.

and the bottom left panels, is less pronounced and more gradual. With the flexibility brought by the additional liquidity premium factor, these two models are also able to fit TIPS yields almost perfectly.

The problem with Model NL can be further seen by looking at the model-implied 10-year breakeven inflation, as shown in the upper right panel of Figures 5. The 10-year breakeven rate implied by Model NL, which by construction should equal the 10-year TIPS breakeven inflation, appears too smooth compared to its data counterpart and misses most of the short-run variations in the actual series. The poor fitting of the TIPS breakeven inflation rates highlights the difficulty that the 3-factor model has in fitting nominal and TIPS yields simultaneously.[29] In contrast, the 10-year breakeven inflation rates implied by Models L-I and L-IId, shown in the middle and bottom left panels, show substantial variations that roughly match those of the actual TIPS breakeven inflation rate. In particular, the model-implied and the TIPS-based breakeven inflation rates peak locally at the beginning of 2000, in the middle of 2001 and 2002, and so on, and the magnitude of their variation are also similar. In these two models, the gap between the model-implied and the TIPS-based breakeven inflation rates is the sum of TIPS liquidity premium and TIPS measurement errors.

To quantify the improvement in terms of the model fit, Panels B and C of Table 4 provide three goodness-of-fit statistics for TIPS yields at the 5-, 7- and 10-year maturities and TIPS breakeven inflation at the 7- and 10-year maturities, respectively. The first statistic, CORR, is simply the sample correlation between the fitted series and its data counterpart. Consistent with the visual impression from Figure 5, allowing a TIPS liquidity premium component improves the model fit for raw TIPS yields and even more so for TIPS breakeven inflation, with the correlation between model-implied 10-year TIPS breakeven and the data counterpart rising from 32% to over 90% once we move from Model NL to the other models. The next two statistics are based on one-step-ahead model prediction errors from the Kalman Filter, v_t, defined in Equation (C-15) in Appendix C, and are designed to capture how well each model can explain the data without resorting to large exogenous shocks or measurement errors. More specifically, the second statistic is the root mean squared prediction errors (RMSE), and the third statistic is the coefficient of determination (R^2), defined as the percentage of in-sample

[29] Given the flexible nature of latent-factor model used in this paper, it is possible that there may exist another local maximum of the likelihood function under which the TIPS yields are fitted better, producing a closer match between the model-implied and the TIPS-based breakeven inflation rates. However, such a fit would certainly come at the expense of other undesirable features of the model.

variations of each data series explained by the model:

$$R^2 = 1 - \frac{\sum_{t=2}^{T} v_t^2}{\sum_{t=2}^{T} (y_t - \overline{y})^2}, \tag{52}$$

where y_t is the observed series and $\overline{y}$ denotes its sample mean.[30] As we can see from Panels B and C of Table 4, based on these two metrics, the improvement moving from Model NL to models with a liquidity factor is notable even for TIPS yields. In other words, the seemingly reasonable fit of Model NL for raw TIPS yields is only achieved by assuming large exogenous shocks to the state variables. The fit of Model NL for TIPS breakevens is even worse, with a R^2 of -18.12% at the 10-year maturity. In comparison, all other models with a TIPS liquidity factor explain more than 88% of the time variations of TIPS breakevens at both maturities.

[Insert Figure 5 about here.]

5.3 Matching Survey Inflation Forecasts

It is conceivable that a model with more parameters like Model L-IId could generate smaller in-sample fitting errors for variables whose fit is explicitly optimized, but produce undesirable implications for variables not used in the estimation. To check this possibility, we examine the model fit for a variable that is not used in our estimation but is of enormous economic interest, the expected inflation. In particular, we examine how closely the model-implied inflation expectations mimic survey-based inflation forecasts. Ang, Bekaert, and Wei (2007) recently provide evidence that survey inflation forecasts outperforms various other measures of inflation expectations in predicting future inflation. In addition, survey inflation forecast has the benefit of being a real-time, model-free measure, and hence not subject to model estimation errors or look-ahead biases that could affect measures based on in-sample fitting of realized inflation.[31]

[30] Unlike in a regression setting, a negative value of R^2 could arise because the model expectation and the prediction errors are not guaranteed to be orthogonal in a small sample.

[31] Alternatively, we could compare the out-of-sample forecasting performance of various models. However, we doubt the usefulness of such an exercise for two reasons. First, the sample available for carrying out such an exercise is extremely limited due to the relatively short sample of TIPS. In addition, the large idiosyncratic fluctuations associated with commonly used price indices would lead to substantial sampling variability in any metric of forecast performance we use and further complicate the inference problem.

Panel D of Table 4 reports the three goodness-of-fit statistics, CORR, RMSE and R^2, for 1- and 10-year ahead inflation forecasts from the SPF. Among the models, Model NL generates inflation expectations that agree least well with survey inflation forecasts, producing large RMSEs and small R^2 statistics at both horizons. This poor fit is especially prominent at the 1-year horizon: the RMSE is large, the correlation between the model and survey forecast is essentially 0, and the R^2 is highly negative at -52%. In contrast, all other models, which have a liquidity factor, generate a reasonable fit with the survey forecasts at both horizons. The best fit is achieved by Models L-II and L-IId, both of which generate correlations above 80% and small RMSEs at both horizons and explain a large amount of sample variations in survey inflation forecasts. Models L-II and L-IId also improve notably upon Model L-I, suggesting that some cyclical variations in TIPS yields might not be due to movements in the real yields. Overall, Model L-IId does not seem to suffer from an overfitting problem. As we will see from later sections, this model also generate sensible implications for TIPS liquidity premiums and inflation risk premiums, further supporting our conclusion.

A visual comparison of the model-implied inflation expectations and survey forecasts can help us understand the results in Table 4. The left panels of Figure 6 plot the 1-year inflation expectation based on Models NL, L-I and L-IId, together with the survey forecast. It can be seen that the Model-NL-implied 1-year inflation expectation contains a large amount of short-run fluctuations that are not shared by its survey counterpart. It also fails to capture the downward trend in survey inflation forecasts during much of the sample period. In comparison, implied 1-year inflation expectation based on the other models show a visible downward trend, consistent with the survey evidence. It is interesting that although Models L-I and L-IId exhibit similar fit to TIPS yields and TIPS breakevens, as can be seen from Figure 5, they are more differentiable based on their implications for inflation expectations. In particular, while the 1-year inflation expectation implied by Model L-IId bears a high resemblance to the 1-year survey forecast, the same series implied by Model L-I appears to be much more variable than the survey counterpart.

It is also not surprising that Model NL produces a larger RMSEs for 10-year inflation expectations than the L-I and L-II models: the upper middle panel of Figure 6 shows that Model NL completely misses the downward trend in the 10-year survey inflation forecast since the early 1990s and implies a 10-year inflation expectations that moved little over the sample period. This is the flip side of the discussions in Section 5.2, where we see a Model-

NL-implied 10-year real rate that is too variable and is used by the model to explain the entire decline in nominal yields in the 1990s. Overall, the near-constancy of the long-term inflation expectation is the most problematic feature of Model NL. Models L-I and L-IId, on the other hand, produce 10-year inflation expectations that are clearly downward trending, though the model-implied values are a bit lower than the survey forecast in the early 1990s, as shown in the two lower panels in the middle column of Figure 6. As can be recalled from Figure 5, the long-term real yields in these models also display a downward trend, but a much weaker one compared to that in Model NL.

Finally, the three right panels of Figure 6 plot the model-implied inflation risk premiums at the 1- and 10-year horizons for the three models under consideration. One immediately notable feature is that Model-NL implies an inflation risk premium, shown in the upper right panel, that is negative and increasing over time in the 1990-2007 period. In contrast, as mentioned in Section 2, most of the existing studies not using TIPS find that average inflation risk premium has been positive historically. Furthermore, studies such as Clarida and Friedman (1984) indicate that the inflation risk premium likely was positive and substantial in the early 1980s and probably has come down since then. As can be seen from Figure 7, which plots the 10-year inflation risk premium estimates together with the 95% confidence bands for the three models, even after we take into account sampling uncertainties, long-term inflation risk premiums implied by Model NL remain negative over most of the sample period. In comparison, the two models that allow for a liquidity premium, Models L-I and L-IId, both generate 10-year inflation risk premiums that are positive and fluctuate in the 0 to 1% range over the same sample period. The short-term inflation risk premiums implied by these two models, on the other hand, are fairly small, consistent with our intuition.

[Insert Figure 6 about here.]

[Insert Figure 7 about here.]

5.4 Summary

In summary, we find that Model NL, which equates TIPS yields with true underlying real yields, fares poorly along a number of dimensions, including generating a poor fit with the TIPS data as well as unreasonable implications for inflation expectations and inflation risk premiums. This underscores the need to take into account a liquidity premium in modeling TIPS yields. In contrast, models that allows for a TIPS liquidity premium, Models L-I and L-II, improves upon Model NL in all three aspects and in particular produce long-term inflation expectations that agree quite well with survey forecasts.

Among models allowing a liquidity premium in TIPS yields, Models L-II and Model L-IId generate short-term inflation expectations that matches survey counterparts better than Model L-I, suggesting it is important to allow for a systematic component in TIPS liquidity premiums.

Finally, a likelihood ratio test rejects Models L-II in favor of our preferred model, Model L-IId, which features a deterministic trend in TIPS liquidity premium that is designed to capture the "newness effect" during the early years of TIPS. In the remainder of our analysis we'll be mainly focusing on this model.

6 TIPS Liquidity Premium

6.1 Model Estimates of TIPS Liquidity Premiums

Once we estimate the model parameters and the state variables, we can calculate the TIPS liquidity premiums at various maturities based on Equation (35). The top and the middle panels of Figure 8 plot the 5-, 7- and 10-year liquidity premiums implied by Models L-I and L-II, respectively, while the bottom panel shows the the deterministic and the stochastic components of the liquidity premiums based on Model L-IId.

Three things are worth noting from this graph: First, all three panels show that liquidity premiums exhibit substantial time variations at all maturities. The substantial variabilities at maturities as long as 10 years are in part due to the fact that the independent liquidity factor is estimated to be very persistent under the risk-neutral measure. As can be seen from Table 3, the risk-neutral persistence of the liquidity factor, $\tilde{\kappa}^* = \tilde{\kappa} + \tilde{\sigma}\tilde{\lambda}_1$, is estimated to be very small at around 0.1 in all models and is tightly estimated, with a standard error of about 0.006. In contrast, the persistence parameter under the physical measure, $\tilde{\kappa}$, is not as precisely estimated, with typical values of around 0.20 and typical standard errors of around 0.27.

Second, the term structure of TIPS liquidity premiums is relatively flat at all times under Model L-I, while under Model L-II, the term structure has a mild downward-sloping behavior during the 2001-2004 period. Technically, a market price of risk on the independent liquidity factor that is on average positive, as is the case in all three models here, would contribute to a downward-sloping term structure of TIPS liquidity premium.[32] This is in contrast to the standard one-factor interest rate models, where the market price of interest rate risk is typically found to be negative. Although the TIPS liquidity premiums in Models L-II and L-IId are also driven by the nominal bond factors, x_t, in addition to $\tilde{x}_t$, a variance decomposition indicates that the TIPS-specific factor $\tilde{x}_t$ drives most of the variations in TIPS liquidity premium. Nonetheless, as we've seen in Section 5, allowing the TIPS liquidity premiums to depend on nominal bond factors seems important in explaining the dynamics of TIPS yields.

Finally, all three models imply that the TIPS liquidity premiums were fairly high (1-2 %) when TIPS were first introduced, had been on a downward trajectory until around 2004, and have stayed at a relatively low level from 2005 onwards. The deterministic trend implied by Model L-IId came down from about 120 basis points in 1999 to below 10 basis points by the end of 2004. After removing the downward trend, the stochastic liquidity premiums appear more stationary and largely vary between -50 and 50 basis points.

[Insert Figure 8 about here.]

6.2 What Drives the TIPS Liquidity Premiums?

The behavior of the liquidity premiums we have seen in Figure 8 seems broadly consistent with the perception that TIPS market liquidity conditions have improved over time. In this section, we examine this issue more closely. One difficulty in this regard is the lack of precise, real-time measures of the TIPS market liquidity. One measure that has been used in the literature[33] is the 13-week moving average of weekly TIPS turnover, defined as the weekly average of

[32] For example, it is straightforward to show that under Model L-I, the slope of the TIPS liquidity premium curve is given by

$$\frac{\partial L_{t,\tau}}{\partial \tau}|_{\tau=0} = 0.5\tilde{\kappa}^*(\tilde{\mu}^* - \tilde{x}_t),$$

the unconditional mean of which is given by

$$0.5\tilde{\kappa}^*(\tilde{\mu}^* - \tilde{\mu}) = -0.5\tilde{\sigma}(\tilde{\lambda}_0 + \tilde{\lambda}_1\tilde{\mu}).$$

where the equality comes from Equation (B-6). Therefore, if the average market price of liquidity risk, $\tilde{\lambda}_0 + \tilde{\lambda}_1\tilde{\mu}$, is positive, the term structure of the liquidity premium will be on average downward-sloping.

[33] See Sack and Elsasser (2004).

daily TIPS transaction volumes divided by the TIPS outstanding at the end of the current month.[34] As can be seen in the top panel of Figure 3, the turnover in TIPS remained low up to mid 2002 and then rose substantially, suggesting an improvement in the liquidity conditions of the TIPS market in recent years.[35] The rise coincides roughly with the decline in our TIPS liquidity premium estimates. In particular, all our model-based TIPS liquidity premiums (Model L-I, L-II, L-IId) have correlations with this measure more negative than -73%.

However, the turnover may be affected by factors other than the liquidity conditions in the TIPS market. For example, there is a large empirical literature documenting a positive contemporaneous correlation between price volatility and trading volumes, independent of current market liquidity conditions.[36] In particular, as shown in the middle panel of Figure 9, interest rate volatilities declined markedly during the latter half of the sample period, which might have contributed to the drop in TIPS turnover after 2005. Indeed, evidence from TIPS bid-ask spreads, arguably a better measure of liquidity conditions in the TIPS market, indicates that the early improvement in TIPS liquidity may not have been largely reversed in the most recent sample period, as one might assume based on the rapid decline in TIPS turnover since 2005. For example, two informal surveys of the primary dealers conducted by the Federal Reserve Bank of New York in 2003 and 2007, shown in Table 5, find that the average bid-ask spreads on TIPS continue to narrow across all maturities during this period.[37] Unfortunately, a long history of this measure is unavailable.

[Insert Table 5 about here]

To quantify the effects of various factors on our estimates of TIPS liquidity premiums, we therefore regress the 5-, 7- and 10-year TIPS liquidity premiums from Model L-IId onto three explanatory variables, the first of which being the TIPS turnover ratio.

$$L_{t,\tau}^{L-IId} = \alpha + \beta_1 TURNOVER_t + \beta_2 IMPVOL_t + \beta_3 ASW_t^{nom} + \varepsilon_t^L, \;\; \tau = 5, 7, 10. \qquad (53)$$

[34] TIPS transaction volumes are reported by primary dealers in Government Securities Dealers Reports (FR-2004) collected by the Federal Reserve Bank of New York, and the amount of TIPS outstanding are based on Monthly Statement of the Public Debt issued by the Treasury.

[35] The decline in the liquidity premium during the 2003-2004 period may also be driven by the increased market attention to inflation risk amid a booming economy and rising oil prices.

[36] See Karpoff (1987) for a review of the empirical evidence.

[37] Results from the 2003 survey are quoted in Sack and Elsasser (2004).

The second explanatory variable, *IMPVOL*, is the implied volatility from options on 10-year Treasury note futures and is included to control for the positive contemporaneous correlation between price volatility and trading volumes. The last variable, *ASW*, represents the difference between the on-the-run and the off-the-run 10-year Treasuries par asset swap spreads and can be considered as a market-based measure of the liquidity premiums on the nominal Treasury market. In a fixed-income asset swap, one party exchanges the fixed-rate cash flows from the underlying security for a floating-rate cash flow where the floating rate is typically quoted as 6-month LIBOR plus a spread, the asset swap spread. Asset swap spreads varies over time and across securities according to the perceived default and liquidity risk of the underlying security. Because both nominal Treasury and TIPS are usually considered free of default risks, their asset swap spreads can be regarded as a good measure of the liquidity premiums in those assets. Consistent with their relative liquidity, we usually observe increasingly more negative spreads as we move across asset classes in the order of TIPS, off-the-run nominal Treasuries and on-the-run nominal Treasuries. For our purposes, an ideal measure of the relative illiquidity of TIPS compared to off-the-run nominal Treasuries would be the difference between the TIPS and the off-the-run nominal asset swap spreads.[38] Unfortunately TIPS asset swaps only started trading in 2006; we therefore use the difference between the off-the-run and the on-the-run 10-year nominal Treasuries as an approximation. The daily correlation between the two spreads is 0.90 over the period of March 16, 2006 to November 13, 2009.

Figure 9 plots all three explanatory variables; their correlations with TIPS liquidity premium estimates from Model LII-d and with each other are reported in Panel B of Table 6. The three variables are not highly correlated with each other, but all have large correlations with the liquidity premium estimates. The results from this regression are reported in Panel A of Table 6. The coefficients on all three variables are statistically significant and carry the expected sign. In particular, a lower TIPS turnover raises the TIPS liquidity premiums, but the effect will be smaller if the lower turnover is accompanied by a lower volatility.[39] Together these three variables explain about 80% of the variations in TIPS liquidity premium estimates at all maturities.[40] It remains an interesting topic for future research to see whether

[38] Such a measure is used in a recent study by Campbell, Shiller, and Viceira (2009) as they focus on a more recent sample of July 2007 to April 2009.

[39] Results using measures of realized volatilities are similar.

[40] We note, however, that this type of regression should be viewed only as a rough gauge of the relationship; quantities like turnover are not expected to have a simple linear relationship to the liquidity premium. For example, although the turnover for nominal Treasury securities have also risen substantially in our sample period,

our model-based measures of TIPS liquidity premiums correlate with other measures of TIPS market liquidity.[41]

[Insert Table 6 about here]

[Insert Figure 9 about here]

The results in Table 6 suggest one simple way to adjust the TIPS breakeven inflation for the liquidity effects. Consider the difference between the SPF forecast of average inflation over the next ten years, $SPF_{t,10}$, and the 10-year TIPS breakeven inflation, $BEI_{t,10}$, and regress it on the same three right-hand-side variables as in Equation (53):[42]

$$SPF_{t,10} - BEI^{\mathcal{T}}_{t,10} = \alpha + \beta_1 \textbf{\textit{TURNOVER}}_t + \beta_2 \textbf{\textit{IMPVOL}}_t + \beta_3 \textbf{\textit{ASW}}^{nom}_t + \varepsilon_t \qquad (54)$$

Assuming that the 10-year inflation risk premiums do not vary too much over time, the fitted values from this regression can be thought of as a rough gauge of the liquidity premium component in the difference between the TIPS breakeven inflation and the survey counterpart, the other components being inflation risk premiums and measurement errors. Using the coefficient estimates, one can generate a real-time estimate of TIPS liquidity premiums, which can be added to the observed TIPS breakeven inflation to produce a liquidity-adjusted series. The results from such an exercise are plotted in Figure 10, which shows the adjusted 10-year TIPS breakeven inflation together with the raw series as well as the model-implied true breakeven inflation. The adjusted BEI using this simple method is much closer to the true BEI based on our full model. It is much more variable than the true BEI, especially in the early years, although the difference has narrowed towards the end of our sample period.

that probably had a very small effect on the liquidity premium, as the turnover was already high and liquidity premiums were likely negligible for these securities.

[41] For example, Fleming and Krishnan (2009) develops several measures of liquidity conditions in the TIPS market using high-frequency trading data. However, their measures are only available for a very short period of time due to data availability.

[42] The Cleveland Fed used a similar regression to adjust TIPS BEI, in which they regress the BEI-survey forecast differential on the level and the squared level of nominal Treasury off-the-run premiums plus a constant. Our analysis suggests that such a regression might be biased as it misses the persistent downward trend in the TIPS liquidity premiums in the early years. The Cleveland Fed stopped updating this adjustment in October 2008 citing “the extreme rush to liquidity is affecting the accuracy of the estimates” (http://www.clevelandfed.org/research/data/tips/index.cfm).

While the qualitative behavior of TIPS liquidity premium thus seems reasonable, our estimates of L_t does seem large in comparison with that of the corporate bonds. Corporate bonds, including those with the highest credit rating (AAA/AA), tend to trade infrequently at once a day or less; TIPS, in comparison, trade more often than AAA/AA corporate bonds even during the early years when liquidity was the poorest. The bid-ask spread in TIPS has also been substantially smaller than those of corporate bonds. In this regard, our estimates of TIPS liquidity premium around 1.5% in the early years seems puzzlingly high, in comparison with investment-grade corporate bonds which typically trade at a liquidity premiums of about 50 basis points.[43] The high value of the TIPS liquidity premium in the early years may partly reflect a depressed demand for TIPS due to the newness of the security and the relative complexity of TIPS payoff structure. Furthermore, a popular belief that TIPS are tax-disadvantageous for taxable investors[44] may have further depressed the demand for TIPS.

7 Variance Decomposition

7.1 Decomposing TIPS Yields and TIPS Breakeven Inflation

In this section we examine how much variations in TIPS yields and TIPS breakeven inflation rate can be attributed to variations in TIPS liquidity premiums. Using Equations (2) and (30), we can decompose TIPS yields, $y^{\mathcal{T}}_{t,\tau}$, and TIPS breakven inflation, $BEI^{\mathcal{T}}_{t,\tau}$, into different components:

$$y^{\mathcal{T}}_{t,\tau} = y^{R}_{t,\tau} + L_{t,\tau}, \qquad BEI^{\mathcal{T}}_{t,\tau} = I_{t,\tau} + \wp_{t,\tau} - L_{t,\tau}, \tag{55}$$

where $y^{R}_{t,\tau}$ is the true underlying real yields, $L_{t,\tau}$ is the TIPS liquidity premiums, $I_{t,\tau}$ is the expected inflation over the next τ periods, and $\wp_{t,\tau}$ is the inflation risk premiums.

Table 7 reports the variance decomposition results based on Equation (55) and Model L-IId estimates, using either the unconditional (Panel A) or the instantaneous (Panel B) variance-covariance matrix of the state variables. A time series plot of the decomposition is shown in Figure 11.

[Insert Table 7 about here.]

[43] See Longstaff, Mithal, and Neis (2005), de Jong and Driessen (2006) for example.

[44] See, for example, the discussion in Hein and Mercer (2003).

For TIPS yields, real yields dominate TIPS liquidity premiums in accounting for the time variations both unconditionally and instantaneously. In comparison, TIPS liquidity premiums are more important in driving TIPS breakeven inflation, explaining about 23% of its unconditional variations at all three maturities, although expected inflation still accounts for the majority of time variations in TIPS breakeven inflation. The contribution of TIPS liquidity premiums is even larger instantaneously and explains about 43% of the short-run variations in TIPS breakeven inflation. The last observation suggests that one should be especially cautious in interpreting short-run variations in TIPS breakeven inflation solely in terms of changes in inflation expectation or inflation risk premiums.

7.2 Decomposing Nominal Yields

Although it is not the focus of the current paper, our models can also be used to separate nominal yields into real yields, expected inflation and inflation risk premiums:

$$y^N_{t,\tau} = y^R_{t,\tau} + I_{t,\tau} + \wp_{t,\tau}. \tag{56}$$

Figure 12 plots the 1- and 10-year nominal yields and their constituents, whereas Table 8 reports the variance decomposition results.

These results indicate that, at least during our sample period, real yield changes explain more than half of the variations in nominal yields at all maturities. Inflation expectation explains about 40% (20%) of the variations in the 1-quarter (10-year) nominal yield. Inflation risk premiums account for the remaining 10% of the nominal yield changes. This stands in contrast to previous studies using a longer sample period but not using TIPS yields, which typically find relatively smooth real yields but volatile inflation expectation or inflation risk premiums.[45] The limited evidence we have so far from TIPS seems to suggest that real yields may also vary considerably over time.

8 Conclusion

In this paper, we document that there exists a TIPS-specific factor that is important for explaining TIPS yield variations but not as crucial for explaining nominal interest rate movement, and

[45] See Ang, Bekaert, and Wei (2008, Figure 2) and Chernov and Mueller (2007, Figure 7) for example.

provide evidence that this factor might be reflecting a liquidity premium in TIPS yields.

We then develop a joint no-arbitrage term structure model of nominal and TIPS yields incorporating a rich specification of the TIPS liquidity premiums. The main findings can be summarized as the following. First, we find that our estimated liquidity premium was quite large ($\sim 1\%$) until about 2003 but has come down in recent years, consistent with the common perception that TIPS market liquidity has improved in recent years. Second, our TIPS liquidity premium estimates contain a persistent downward trend in its early years, that is best modeled as a deterministic trend reflecting gradual market acceptance of TIPS as a new debt instrument. Finally, we show that ignoring the liquidity premium components leads to a poor model fit of TIPS yields, TIPS breakeven inflation and survey inflation forecasts.

TIPS breakeven inflation has been increasingly gaining attention as a measure of investors' inflation expectations that is available in real-time and at high frequencies. However, our results raise caution in interpreting movement in TIPS breakeven inflation solely in terms of changing inflation expectations, as substantial liquidity premiums and inflation risk premiums could at times drive a large wedge between between the two. In an encouraging note, the reduced liquidity premium that we find for the most recent period (2005-2007) raises the possibility that, going forward, the TIPS yields may be a better gauge of the true real yields. However, given that TIPS is less liquid than nominal Treasury securities, we caution that TIPS liquidity premiums might rise again in times of financial market stress. A better understanding of the determinants of TIPS liquidity premiums and the sources of its variation remains an interesting topic for future research.

Appendix

A More on the TIPS Data

This appendix is devoted to a more detailed discussion of the TIPS data. Figure A1 shows the smoothed TIPS par yield curves on June 9, 2005 in the top panel and on June 9, 1999 in the bottom panel, together with the actual traded TIPS yields that were used to create the smoothed TIPS par-yield and zero-coupon curves. The smoothing is done by assuming that the zero-coupon TIPS yield curve follows the 4-parameter Nelson-Siegel (1987) functional form up to the end of 2003 and the 6-parameter Svensson (1994) functional form thereafter,[46] and minimizing the fitting error for the actual traded TIPS securities. The substantial increase in the number of points in the top panel reflects the growth of the TIPS market. Note that in 1999 there is essentially one data point on the curve between the 0 and 5 years maturity (corresponding to the 5-year TIPS issued in 1997), thus the TIPS term structure in the short-maturity region of 0-5 years cannot be determined reliably. With more points across the maturity spectrum in 2005, shorter maturity TIPS yields can be determined more reliably than in 1999.

[insert Figure A1 about here]

Still, the analysis of the short-maturity TIPS are complicated by the indexation lag and seasonality issues. Note that the TIPS payments are indexed to the CPI 2.5 months earlier, thus TIPS yields contain some amount of realized inflation, often referred to as the "carry effect". The yield that is more relevant to policy makers is the one that takes out this realized inflation – the so-called carry-adjusted yields, which can be heuristically represented as

$$y_{t,\tau}^{\mathcal{T},CA} = y_{t,\tau}^{\mathcal{T}} + (\delta/\tau)\pi_{t-\delta,t}, \tag{A-1}$$

where $\pi_{t-\delta,t} = \log(Q_t/Q_{t-\delta})/\delta$ denotes the inflation realized between time $t-\delta$ and t, with $\delta =$ 2.5 months.[47] Because the realized inflation $\pi_{t-\delta,t}$ can be quite volatile, the carry-unadjusted yield $y^{\mathcal{T}}$ and the carry-adjusted yield $y^{\mathcal{T},CA}$ can differ significantly, though the difference becomes smaller with increasing maturity, due to the δ/τ factor in Equation (A-1). Figure A2 shows the carry-adjusted and unadjusted TIPS yields for 5-year and 10-year maturities. It can be seen that indeed the 5-year carry-adjusted and unadjusted TIPS yields show greater discrepancies than the 10-year ones. This has been

[46] In comparison, the zero-coupon nominal yield curve is assumed to follow the 6-parameter Svensson (1994) functional form during the entire sample period. In the case of TIPS, however, there were not enough securities in the early years to pin down as many parameters. See Gurkaynak, Sack, and Wright (2007a, 2007b) for details.

[47] Note that equation (A-1) takes out realized inflation in the previous 2.5 months but makes no adjustment for the lack of inflation protection during the last 2.5 months prior to the maturity date.

particularly the case in 2005, during which large fluctuations in oil prices caused sharp short-term fluctuations in inflation. The expression (A-1) for the carry adjustment is only a schematic one. The actual carry-adjustment is further complicated by the fact that TIPS is indexed to the seasonally-unadjusted CPI, rather than the seasonally-adjusted CPI. While one could in principle explicitly model seasonality (and carry effects) within the dynamic model of inflation and term structure, such a procedure may be more prone to specification errors than the case in which these effects are corrected at the input stage.[48]

[insert Figure A2 about here]

As noted in the main text, since data reliability and indexation lags pose larger problems to shorter-maturity TIPS, in this paper we focus on long-maturity TIPS yield for which the effects of indexation lag and seasonality are less important. While the analysis of shorter-maturity TIPS yields is an important problem in itself, it deserves a fuller treatment elsewhere.[49] The 5-, 7- and 10-year carry-unadjusted TIPS yields used in this analysis can be viewed as the carry-corrected TIPS yield plus a measurement error, as suggested by Equation (A-1).

B Stochastic TIPS Liquidity Premium

Since $\tilde{x}_t$ is independent of the other state variables in x_t, the first term on the right-hand side of Equation (31) can be written as the sum of two components:

$$\begin{aligned} & -(1/\tau)\log E_t^Q\left(\exp\left(-\int_t^{t+\tau}(r_s^R + l_s)ds\right)\right) \\ = & -(1/\tau)\log E_t^Q(e^{-\int_t^{t+\tau}\tilde{\gamma}\tilde{x}_s ds}) - (1/\tau)\log E_t^Q(e^{-\int_t^{t+\tau}(\rho_0^R + (\rho_1^R+\gamma)' x_s)ds}) \end{aligned} \quad \text{(B-2)}$$

The first component can be solved to be

$$-(1/\tau)\log E_t^Q(e^{-\int_t^{t+\tau}\tilde{\gamma}\tilde{x}_s ds}) = \tilde{a}_\tau + \tilde{b}_\tau \tilde{x}_t \quad \text{(B-3)}$$

where $\tilde{a}$ and $\tilde{b}$ has the familiar form of factor loadings in a one-factor Vasicek model:

$$\tilde{a}_\tau = \tilde{\gamma}\left[(\tilde{\mu}^* - \frac{\tilde{\sigma}^2}{2\tilde{\kappa}^*})(1-\tilde{b}_\tau) + \frac{\tilde{\sigma}^2}{4\tilde{\kappa}^*}\tau\tilde{b}_\tau^2\right] \quad \text{(B-4)}$$

$$\tilde{b}_\tau = \tilde{\gamma}\frac{1-\exp(-\tilde{\kappa}^*\tau)}{\tilde{\kappa}^*\tau}, \quad \text{(B-5)}$$

[48] See Ghysels (1993) for a recent discussion of the Sims (1974)-Sargent (1978) debate that bears on this issue.

[49] Taking a proper account of the seasonality and carry effects is important to TIPS traders, but here in this paper we are concerned with more basic questions.

in which the risk-neutral $\tilde{\kappa}^*, \tilde{\mu}^*$ are given by

$$\tilde{\kappa}^* = \tilde{\kappa} + \tilde{\sigma}\tilde{\lambda}_1, \qquad \tilde{\mu}^* = (\tilde{\kappa}\tilde{\mu} - \tilde{\sigma}\tilde{\lambda}_0)/\tilde{\kappa}^*, \tag{B-6}$$

The second component can be shown to take the form

$$-(1/\tau)\log E_t^Q(e^{-\int_t^{t+\tau}(\rho_0^R+(\rho_1^R+\gamma)'x_s)ds}) = a_\tau^{\mathcal{T}} + b_\tau^{\mathcal{T}\prime} x_t \tag{B-7}$$

where $a^{\mathcal{T}}$, $b^{\mathcal{T}}$ are given by

$$a_\tau^{\mathcal{T}} = -A_\tau^{\mathcal{T}}/\tau, \tag{B-8}$$

$$b_\tau^{\mathcal{T}} = -B_\tau^{\mathcal{T}}/\tau, \tag{B-9}$$

where

$$\frac{dA_\tau^{\mathcal{T}}}{d\tau} = -\rho_0^R + B_\tau^{\mathcal{T}\prime}\left(\mathcal{K}\mu - \Sigma\lambda_0^R\right) + \frac{1}{2}B_\tau^{\mathcal{T}\prime}\Sigma\Sigma' B_\tau^{\mathcal{T}} \tag{B-10}$$

$$\frac{dB_\tau^{\mathcal{T}}}{d\tau} = -\left(\rho_1^R + \gamma\right) - \left(\mathcal{K} + \Sigma\Lambda^R\right)' B_\tau^{\mathcal{T}} \tag{B-11}$$

with initial conditions $A_0^{\mathcal{T}} = 0$ and $B_0^{\mathcal{T}} = 0_{n\times 1}$.

Taken together, we have that

$$\begin{aligned} L_{t,\tau}^s &= \left(\tilde{a} + a_\tau^{\mathcal{T}}\right) + \left[\begin{array}{cc} b_\tau^{\mathcal{T}\prime} & \tilde{b} \end{array}\right]\left[\begin{array}{c} x_t \\ \tilde{x}_t \end{array}\right] - y_t^R \\ &= \left[\tilde{a}_\tau + (a_\tau^{\mathcal{T}} - a_\tau^R)\right] + \left[\begin{array}{cc} (b_\tau^{\mathcal{T}} - b_\tau^R)' & \tilde{b}_\tau \end{array}\right]\left[\begin{array}{c} x_t \\ \tilde{x}_t \end{array}\right] \end{aligned} \tag{B-12}$$

where the second equality comes from Equation (23).

C Kalman Filter and Likelihood Function

We use the Kalman filter to compute optimal estimates of the unobservable state factors based on all available information. For example, given the initial guess for the state factors $\widehat{\mathrm{x}}_0$, it follows from the state equation (46) that the optimal estimate of the state factor x_t at time $t = h$ is given by

$$\widehat{\mathrm{x}}_{h,0} \triangleq E(\mathrm{x_h} \mid \Im_0) = \mathrm{G_h} + \Gamma_\mathrm{h}\widehat{\mathrm{x}}_0,$$

which implies that we carry the error of the initial guess to all subsequent estimations. More generally, we have

$$\widehat{\mathrm{x}}_{t,t-h} \triangleq E(\mathrm{x_t} \mid \Im_{\mathrm{t-h}}) = \mathrm{G_h} + \Gamma_\mathrm{h}\widehat{\mathrm{x}}_{\mathrm{t-h,t-h}}. \tag{C-13}$$

for any time period t.

The variance-covariance matrix of the estimation error can be derived as

$$\begin{aligned} Q_{t,t-h} &\triangleq E\left[\left(\mathrm{x_t}-\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)\left(\mathrm{x_t}-\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)'\right] \\ &= E\left\{\left[\Gamma_h\left(\mathrm{x_{t-h}}-\widehat{\mathrm{x}}_{\mathrm{t-h}}\right)+\eta_t^{\mathrm{x}}\right]\left[\Gamma_h\left(\mathrm{x_{t-h}}-\widehat{\mathrm{x}}_{\mathrm{t-h}}\right)+\eta_t^{\mathrm{x}}\right]'\right\} \\ &= \Gamma_h Q_{t-h,t-h}\Gamma_h' + \Omega_{t-h}^{\mathrm{x}}, \end{aligned} \tag{C-14}$$

where $\Omega_{t-h}^{\mathrm{x}} = E\left[\eta_t^{\mathrm{x}}\eta_t^{\mathrm{x}\prime}\right]$.

Given any forecast for $\mathrm{x_t}$, we can compute a forecast for the observable variables based on all time $t-h$ information:

$$\widehat{\mathrm{y}}_{t,t-h} \triangleq E\left[\mathrm{y_t} \mid \Im_{\mathrm{t-h}}\right] = A + B\widehat{\mathrm{x}}_{t,t-h},$$

the forecast error of which is given by

$$\mathrm{v_t} \triangleq \mathrm{y_t} - \widehat{\mathrm{y}}_{t,t-h} = B(\mathrm{x_t} - \widehat{\mathrm{x}}_{t,t-h}) + \mathrm{e_t}. \tag{C-15}$$

The conditional variance-covariance matrix of this estimation error can then be computed as

$$\begin{aligned} V_{t,t-h} &\triangleq E\left\{\left(\mathrm{y_t}-\widehat{\mathrm{y}}_{\mathrm{t,t-h}}\right)\left(\mathrm{y_t}-\widehat{\mathrm{y}}_{\mathrm{t,t-h}}\right)'\right\} \\ &= BQ_{t,t-h}B' + \Omega_t^e \end{aligned} \tag{C-16}$$

where

$$\Omega_t^e = E\left[\mathrm{e_t}\mathrm{e_t}'\right].$$

The next step is to update the equation for the state variables. Before doing this, we need to recover the distribution of $\mathrm{x_t} \mid \mathrm{y_t}$. The conditional covariance between the forecasting errors for state variables and that for observation variables takes the form of

$$\begin{aligned} V_{t,t-h}^{xy} &\triangleq E\left\{\left(\mathrm{y_t}-\widehat{\mathrm{y}}_{\mathrm{t,t-h}}\right)\left(\mathrm{x_t}-\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)'\right\} \\ &= BE\left[\left(\mathrm{x_t}-\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)\left(\mathrm{x_t}-\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)'\right] \\ &= BQ_{t,t-h} \end{aligned} \tag{C-17}$$

The conditional joint distribution for $\mathrm{y_t}$ and $\mathrm{x_t}$ is therefore

$$\begin{bmatrix} \mathrm{y_t} \\ \mathrm{x_t} \end{bmatrix} \mid \Im_{t-h} \sim N\left(\begin{bmatrix} a + F\widehat{\mathrm{x}}_{t,t-h} \\ \widehat{\mathrm{x}}_{t,t-h} \end{bmatrix}, \begin{bmatrix} BQ_{t,t-h}B' + \Omega_t^e & BQ_{t,t-h} \\ Q_{t,t-h}B' & Q_{t,t-h} \end{bmatrix}\right),$$

which implies that conditional on $\mathrm{y_t}$, $\mathrm{x_t}$ is also distributed normal:

$$\mathrm{x_t} \mid \mathrm{y_t} \sim N\left(\widehat{\mathrm{x}}_{t,t}\,, Q_{t,t}\right),$$

where

$$\widehat{\mathrm{x}}_{t,t} = \widehat{\mathrm{x}}_{t,t-h} + Q_{t,t-h}B'V_{t,t-h}^{-1}\left(\mathrm{y_t} - \widehat{\mathrm{y}}_{\mathrm{t,t-h}}\right) \tag{C-18}$$

$$Q_{t,t} = Q_{t,t-h} - Q_{t,t-h}B'V_{t,t-h}^{-1}BQ_{t,t-h}; \tag{C-19}$$

The variance-covariance matrix of the updated state vector, $Q_{t,t}$, will be smaller than the previous estimate, $Q_{t,t-h}$, due to the new information coming in through the observation of $\mathrm{y_t}$.

We estimate the parameters by maximizing the log-likelihood function

$$\sum_{t=h}^{Th} \log f\left(\mathrm{y_t}|\Im_{\mathrm{t-h}}\right) = -\frac{T}{2}\log(2\pi) - \frac{1}{2}\sum_{i=h}^{t}\log|V_i| - \frac{1}{2}\sum_{i=h}^{t}\left[\left(\mathrm{y_t} - \mathrm{A} - \mathrm{B}\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)' V_t^{-1}\left(\mathrm{y_t} - \mathrm{A} - \mathrm{B}\widehat{\mathrm{x}}_{\mathrm{t,t-h}}\right)\right]. \tag{C-20}$$

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Table 1: TIPS Liquidity Factor

Panel A: Regression Analysis

Coefficients				Adj.
Constant	3-month	2-year	10-year	R^2
		In Level		
3.4637	-0.4519	0.6516	-0.4384	32.3%
(0.1138)	(0.0345)	(0.0479)	(0.0346)	
		In Weekly Changes		
0.0032	0.0110	-0.0850	0.5687	59.0%
(0.0025)	(0.0334)	(0.0409)	(0.0366)	

Panel B: Variance Explained by Principal Components

PC	nominal yields only	nominal and TIPS yields
1st	75.17	71.11
2nd	93.25	87.26
3rd	97.44	94.72
4th	99.36	97.58

Panel C: Correlation of Principal Components

		nominal and TIPS yields			
		PC1	PC2	PC3	PC4
nominal	PC1	0.97	-0.21	-0.15	0.01
yields	PC2	0.12	0.86	-0.49	0.02
alone	PC3	0.04	0.08	0.20	0.97
	PC4	-0.01	-0.03	-0.06	0.01

Panel A regresses 10-year TIPS breakevens on 3-month, 2-year and 10-year nominal yields using weekly data from Jan. 6, 1999 to Mar. 14, 2007. Panel B report the cumulative percentage of total variance of weekly yield changes explained by the first four principal components, where the second and the third column report results for nominal yields alone and nominal and TIPS yields combined, respectively. The in-sample correlation between the two sets of principal components are reported in Panel C.

Table 2: Summary of Models

Model	Restrictions and Idenfications
Model NL	$\gamma = 0_{3\times 1}, \quad \tilde{\gamma} = 0, \quad c_1 = 0, \quad \tilde{\kappa}, \tilde{\mu}, \tilde{\lambda}_0, \tilde{\lambda}_1$, c_2 and c_3 unidentified
Model L-I	$\gamma = 0_{3\times 1}, \quad \tilde{\gamma}, \tilde{\kappa}, \tilde{\mu}, \tilde{\lambda}_0, \tilde{\lambda}_1$ unrestricted, $\quad c_1 = 0, \quad c_2$ and c_3 unidentified
Model L-II	$\gamma, \tilde{\gamma}, \tilde{\kappa}, \tilde{\mu}, \tilde{\lambda}_0, \tilde{\lambda}_1$ unrestricted, $\quad c_1 = 0, \quad c_2$ and c_3 unidentified
Model L-IId	$\gamma, \tilde{\gamma}, \tilde{\kappa}, \tilde{\mu}, \tilde{\lambda}_0, \tilde{\lambda}_1$, c_1, c_2 c_3 unrestricted

Table 3: Parameter Estimates

	Model NL		Model L-I		Model L-II		Model L-IId	
State Variables Dynamics								
$dx_t = \mathcal{K}(\mu - x_t)dt + \Sigma dB_t$								
$\mathcal{K}_{11}$	0.8587	(0.5206)	0.8676	(0.5227)	0.8573	(0.4948)	0.8374	(0.4606)
$\mathcal{K}_{22}$	0.0529	(0.0787)	0.0573	(0.0793)	0.0555	(0.0794)	0.0529	(0.0781)
$\mathcal{K}_{33}$	1.5219	(0.8048)	1.5321	(0.8040)	1.5394	(0.7729)	1.5672	(0.7574)
$100 \times \Sigma_{21}$	-0.3346	(0.3200)	-0.3098	(0.3105)	-0.3232	(0.3101)	-0.3175	(0.3101)
$100 \times \Sigma_{31}$	-4.5682	(9.1343)	-4.5353	(9.0421)	-4.4144	(8.1903)	-4.0846	(6.7681)
$100 \times \Sigma_{32}$	-0.5524	(0.2581)	-0.5449	(0.2522)	-0.5494	(0.2538)	-0.5362	(0.2469)
Nominal Pricing Kernel								
$dM_t^N/M_t^N = -r^N(x_t)dt - \lambda(x_t)'dB_t$,								
$r^N(x_t) = \rho_0^N + \rho_1^{N\prime} x_t, \quad \lambda(x_t) = \lambda_0^N + \Lambda^N x_t$								
ρ_0^N	0.0419	(0.0135)	0.0434	(0.0116)	0.0428	(0.0125)	0.0422	(0.0132)
$\rho_{1,1}^N$	2.8343	(5.2462)	2.8318	(5.2564)	2.7671	(4.7530)	2.5726	(3.9118)
$\rho_{1,2}^N$	0.4825	(0.1249)	0.4797	(0.1239)	0.4809	(0.1248)	0.4675	(0.1207)
$\rho_{1,3}^N$	0.6089	(0.0378)	0.6177	(0.0403)	0.6180	(0.0387)	0.6195	(0.0377)
$\lambda_{0,1}^N$	0.4362	(0.2228)	0.4107	(0.1807)	0.4147	(0.1946)	0.4236	(0.2449)
$\lambda_{0,2}^N$	-0.1818	(0.8732)	-0.2933	(0.7752)	-0.2447	(0.8142)	-0.2049	(0.8544)
$\lambda_{0,3}^N$	-0.0471	(3.3761)	-0.4308	(2.8805)	-0.2597	(3.1019)	-0.1136	(3.3049)
$[\Sigma\Lambda^N]_{11}$	-0.5330	(1.7491)	-0.5489	(1.7874)	-0.5288	(1.6390)	-0.4592	(1.3462)
$[\Sigma\Lambda^N]_{21}$	1.7508	(4.9179)	1.7894	(4.9932)	1.7104	(4.5060)	1.5341	(3.7315)
$[\Sigma\Lambda^N]_{31}$	3.7651	(15.9132)	3.8379	(16.1348)	3.6471	(14.3685)	3.1187	(11.0801)
$[\Sigma\Lambda^N]_{12}$	-0.0274	(0.2452)	-0.0277	(0.2406)	-0.0272	(0.2370)	-0.0419	(0.2252)
$[\Sigma\Lambda^N]_{22}$	-0.2865	(0.1339)	-0.2854	(0.1318)	-0.2849	(0.1330)	-0.2752	(0.1326)
$[\Sigma\Lambda^N]_{32}$	-0.6948	(0.8960)	-0.6677	(0.8587)	-0.6854	(0.8420)	-0.6296	(0.6714)
$[\Sigma\Lambda^N]_{13}$	-0.0717	(0.3145)	-0.0749	(0.3224)	-0.0725	(0.3155)	-0.0551	(0.3238)
$[\Sigma\Lambda^N]_{23}$	0.6171	(0.2355)	0.6329	(0.2429)	0.6303	(0.2397)	0.6314	(0.2404)
$[\Sigma\Lambda^N]_{33}$	0.6551	(2.1043)	0.6812	(2.1309)	0.6634	(1.9803)	0.5887	(1.7096)

Table 3 Continued

	Model NL		Model L-I		Model L-II		Model L-IId	
Log Price Level								
$d\log Q_t = \pi(x_t)dt + \sigma_q' dB_t + \sigma_q^{\perp} dB_t^{\perp},\ \pi(x_t) = \rho_0^{\pi} + \rho_1^{\pi'} x_t$								
ρ_0^{π}	0.0271	(0.0035)	0.0280	(0.0069)	0.0239	(0.0082)	0.0236	(0.0084)
$\rho_{1,1}^{\pi}$	-0.7843	(2.8227)	0.8836	(1.4332)	0.0746	(0.6436)	0.0729	(0.5890)
$\rho_{1,2}^{\pi}$	0.0766	(0.1062)	0.2563	(0.0707)	0.2575	(0.1262)	0.2443	(0.1248)
$\rho_{1,3}^{\pi}$	-0.5094	(0.3937)	0.1216	(0.1276)	-0.0165	(0.2079)	-0.0221	(0.2107)
$100 \times \sigma_{q,1}$	-0.1724	(0.0651)	-0.1176	(0.0720)	-0.1050	(0.0763)	-0.1076	(0.0757)
$100 \times \sigma_{q,2}$	-0.0231	(0.0803)	0.0597	(0.0750)	0.0651	(0.0757)	0.0506	(0.0750)
$100 \times \sigma_{q,3}$	-0.0016	(0.0656)	0.0354	(0.0594)	0.0306	(0.0611)	0.0358	(0.0609)
$100 \times \sigma_q^{\perp}$	0.7795	(0.0288)	0.7279	(0.0241)	0.7144	(0.0245)	0.7144	(0.0245)
TIPS Liquidity Premium								
$l_t = \tilde{\gamma}\tilde{x}_t + \gamma' x_t,\ d\tilde{x}_t = \tilde{\kappa}(\tilde{\mu} - \tilde{x}_t)dt + \tilde{\sigma} dW_t,\ \tilde{\lambda}_t = \tilde{\lambda}_0 + \tilde{\lambda}_1 \tilde{x}_t.$								
$\tilde{\gamma}$			0.6114	(0.0411)	0.6152	(0.0415)	1.2545	(0.0914)
$\tilde{\kappa}$			0.2083	(0.2655)	0.2206	(0.2630)	0.6037	(0.3973)
$\tilde{\mu}$			0.0218	(0.0113)	0.0157	(0.0115)	0.0003	(0.0105)
$\tilde{\lambda}_0$			0.3213	(0.6657)	0.2851	(0.5090)	-0.0263	(0.3356)
$\tilde{\sigma}\tilde{\lambda}_1$			-0.1091	(0.2652)	-0.1209	(0.2627)	-0.1472	(0.4020)
γ_1					-0.6765	(1.2459)	-2.9521	(5.7532)
γ_2					-0.0179	(0.1547)	0.2739	(0.1717)
γ_3					-0.0833	(0.2509)	-1.0137	(0.3285)
c_1							1.1871	(0.0310)
c_2							0.0014	(0.0001)
c_3							731467.911	(25.2593)

Table 3 Continued

	Model NL		Model L-I		Model L-II		Model L-IId	
Measurement Errors: Nominal Yields								
$100 \times \delta_{N,3m}$	0.1005	(0.0026)	0.1012	(0.0027)	0.1012	(0.0027)	0.1013	(0.0027)
$100 \times \delta_{N,6m}$	0.0231	(0.0016)	0.0221	(0.0016)	-0.0222	(0.0016)	-0.0224	(0.0017)
$100 \times \delta_{N,1y}$	0.0532	(0.0017)	0.0530	(0.0018)	0.0530	(0.0018)	0.0531	(0.0017)
$100 \times \delta_{N,2y}$	0.0000	(140.6008)	-0.0000	(59.2489)	-0.0000	(50.6589)	-0.0000	(27.7162)
$100 \times \delta_{N,4y}$	0.0293	(0.0012)	0.0294	(0.0012)	0.0294	(0.0013)	0.0294	(0.0012)
$100 \times \delta_{N,7y}$	0.0000	(120.1913)	0.0000	(0.9395)	0.0000	(44.6608)	-0.0000	(0.9058)
$100 \times \delta_{N,10y}$	0.0489	(0.0018)	0.0490	(0.0019)	0.0490	(0.0019)	0.0489	(0.0018)
Measurement Errors: TIPS Yields								
$100 \times \delta_{\mathcal{T},5y}$	0.4307	(0.0953)	0.0654	(0.0059)	0.0657	(0.0060)	-0.0000	(4.8466)
$100 \times \delta_{\mathcal{T},7y}$	0.3511	(0.0832)	-0.0021	(0.0414)	-0.0004	(0.2385)	-0.0428	(0.0035)
$100 \times \delta_{\mathcal{T},10y}$	0.3578	(0.0802)	0.0647	(0.0060)	-0.0643	(0.0059)	-0.0520	(0.0038)
Measurement Errors: Survey Forecasts of Nominal Short Rate								
$100 \times \delta_{f,6m}$	0.1760	(0.0135)	0.1758	(0.0134)	0.1758	(0.0134)	0.1758	(0.0134)
$100 \times \delta_{f,12m}$	0.2261	(0.0197)	0.2260	(0.0196)	0.2260	(0.0197)	0.2261	(0.0196)

This table reports parameter estimates and standard errors for all four models we estimate. Standard errors are calculated using the BHHH formula and are reported in parentheses.

Table 4: Specification Tests

		Model NL	Model L-I	Model L-II	Model L-IId
Panel A: Overall model fit					
No. of parameters		42	47	50	53
Log likelihood		53,663.65	55,972.49	55,976.70	56,193.41
AIC		-107,243.30	-111,850.97	-111,853.40	-112,280.81
BIC		-107,041.70	-111,625.37	-111,613.39	-112,026.41
LR p-value		0.00*	0.04	0.00*	
Panel B: Fitting TIPS yields					
5-year	CORR (in %)	93.14	99.41	99.42	99.53
	RMSE	0.43	0.13	0.13	0.11
	R^2 (in %)	83.93	98.61	98.62	99.06
7-year	CORR (in %)	92.99	99.45	99.46	99.50
	RMSE	0.36	0.10	0.10	0.10
	R^2 (in %)	85.96	98.91	98.92	98.93
10-year	CORR (in %)	92.52	99.19	99.20	99.42
	RMSE	0.37	0.12	0.11	0.10
	R^2 (in %)	80.90	98.18	98.21	98.76
Panel C: Fitting TIPS Breakeven Inflation					
7-year	CORR (in %)	51.61	97.21	97.24	97.35
	RMSE	0.35	0.09	0.09	0.10
	R^2 (in %)	23.44	94.47	94.54	94.21
10-year	CORR (in %)	32.08	94.76	94.80	95.11
	RMSE	0.35	0.11	0.11	0.10
	R^2 (in %)	-18.12	88.71	88.85	89.74
Panel D: Matching survey inflation forecasts					
1-year	CORR (in %)	2.07	62.94	88.65	88.08
	RMSE	0.78	0.58	0.33	0.34
	R^2 (in %)	-52.21	17.45	72.93	70.71
10-year	CORR (in %)	73.34	72.72	83.86	83.92
	RMSE	0.51	0.40	0.42	0.42
	R^2 (in %)	17.36	49.46	44.35	42.22

This table reports various diagnostic statistics for the four models estimated. Panel A reports the number of parameters, the log likelihood, the Akaike information criterion (AIC), the Bayesian information criterion (BIC) values, and the p-value from a Likelihood Ratio test of the current model against the more general Model to its right, where the p-values reported for Models NL and L-II are the Davie (1987) upper bounds. Panels B to D report three goodness-of-fit statistics for the 5-, 7- and 10-year TIPS yields, 7- and 10-year TIPS breakeven inflation and 1- and 10-year survey inflation forecasts, respetively, including the root mean squared fitted errors (RMSE), the correlation between the fitted series and the data counterpart (CORR), and the coefficient of determination (R^2) as defined in Equation (52).

Table 5: TIPS Bid-Ask Spreads Across Maturities (in ticks)

	Less than five years	Five to Ten Years	Above ten years
2003	1 to 2	2	4 to 16

	Two-year	Five-year	Ten-Year	Twenty-Year	Thirty-year
2007	1/2 to 1	1	1-2	4-6	6-10

This table reports the TIPS bid-ask spread at various maturities based on two informal survey conducted by the Federal Reserve Bank of New York in 2003 and 2007, respectively. One tick is 1/32s of a point where a point roughly equals one percent of the security's par value.

Table 6: What Drives the TIPS Liquidity Premiums

Panel A: Regression Analysis

	Coefficients				Adjusted
Maturity	Constant	Turnover	Imp Vol	ASW Spread	R^2
5-year	0.3074	-0.4309	0.1196	0.0258	79.52%
	(0.0771)	(0.0275)	(0.0095)	(0.0025)	
7-year	0.4139	-0.3752	0.0824	0.0253	80.95%
	(0.0641)	(0.0229)	(0.0079)	(0.0020)	
10-year	0.5076	-0.3337	0.0465	0.0251	82.30%
	(0.0541)	(0.0193)	(0.0067)	(0.0017)	

Panel B: In-Sample Correlations

	Liquidity Premiums			TIPS	10-Year
	5-year	7-year	10-year	Turnover	Imp Vol
TIPS Turnover	-0.7286	-0.7547	-0.7850		
10-year implied volatility	0.5515	0.5098	0.4449	-0.1314	
On/off ASW spread	0.7996	0.8189	0.8340	-0.6374	0.4742

Panel A regresses 5, 7- and 10-year TIPS liquidity premium estimates based on Model L-IId on TIPS turnover, implied volatility of 10-year nominal Treasury future options and the difference between the on-the-run and the off-the-run 10-year Treasuries par asset swap spreads using weekly data from either Jan. 6, 1999 to Mar. 14, 2007. Their in-sample pairwise correlations are reported in Panel B.

Table 7: Variance decomposition of TIPS Yields and TIPS BEI

Panel A: Unconditional Variance Decomposition

	TIPS yield		TIPS BEI		
Maturity	real yield	liq prem	inf exp	inf risk prem	liq prem
5-year	1.1717	-0.1717	0.5870	0.1890	0.2240
	(0.2836)	(0.2836)	(0.3050)	(0.2386)	(0.3170)
7-year	1.1819	-0.1819	0.5659	0.1994	0.2347
	(0.2690)	(0.2690)	(0.3065)	(0.2616)	(0.3131)
10-year	1.1910	-0.1910	0.5453	0.2090	0.2458
	(0.2581)	(0.2581)	(0.3192)	(0.2944)	(0.3095)

Panel B: Instantaneous Variance Decomposition

	TIPS yield		TIPS BEI		
Maturity	real yield	liq prem	inf exp	inf risk prem	liq prem
5-year	1.1596	-0.1596	0.5447	0.0167	0.4386
	(0.2963)	(0.2963)	(0.2473)	(0.2064)	(0.2639)
7-year	1.2285	-0.2285	0.5500	0.0239	0.4261
	(0.3040)	(0.3040)	(0.2710)	(0.2397)	(0.2597)
10-year	1.3024	-0.3024	0.5431	0.0348	0.4221
	(0.3073)	(0.3073)	(0.2984)	(0.2740)	(0.2556)

Note: This table reports the unconditional and the instantaneous variance decompositions of TIPS yields into real yields and TIPS liquidity premiums, and of nominal yields into expected inflation, the inflation risk premiums and the negative of TIPS liquidity premiums, all based on Model L-IId estimates. The variance decompositions of TIPS yields are calculated according to

$$1 = \frac{cov\left(y^{\mathcal{T}}_{t,\tau}, y^{R}_{t,\tau}\right)}{var\left(y^{\mathcal{T}}_{t,\tau}\right)} + \frac{cov\left(y^{\mathcal{T}}_{t,\tau}, L_{t,\tau}\right)}{var\left(y^{\mathcal{T}}_{t,\tau}\right)},$$

while the variance decompositions of the TIPS breakeven inflation are calculated according to

$$1 = \frac{cov\left(BEI^{\mathcal{T}}_{t,\tau}, I_{t,\tau}\right)}{var\left(BEI^{\mathcal{T}}_{t,\tau}\right)} + \frac{cov\left(BEI^{\mathcal{T}}_{t,\tau}, \wp^{I}_{t,\tau}\right)}{var\left(BEI^{\mathcal{T}}_{t,\tau}\right)} + \frac{cov\left(BEI^{\mathcal{T}}_{t,\tau}, -L_{t,\tau}\right)}{var\left(BEI^{\mathcal{T}}_{t,\tau}\right)},$$

where the results are based on either the unconditional variance-covariance matrix of the state variables (Panel A) or the instantaneous variance-covariance matrix of the state variables, $\Sigma\Sigma'$ (Panel B). Standard errors calculated using the delta method are reported in parentheses.

Table 8: Variance decomposition of Nominal Yields

Panel A: Unconditional Variance Decomposition

Maturity	real yield	inf exp	inf risk prem
1-quarter	0.5108	0.4156	0.0736
	(0.2541)	(0.2281)	(0.0927)
1-year	0.5715	0.3497	0.0787
	(0.1930)	(0.1843)	(0.0924)
5-year	0.6503	0.2609	0.0888
	(0.1486)	(0.1417)	(0.1146)
10-year	0.6715	0.2347	0.0938
	(0.1401)	(0.1429)	(0.1362)

Panel B: Instantaneous Variance Decomposition

Maturity	real yield	inf exp	inf risk prem
1-quarter	0.7719	0.2252	0.0029
	(0.1090)	(0.1009)	(0.0312)
1-year	0.7692	0.2172	0.0137
	(0.1082)	(0.0915)	(0.0365)
5-year	0.7132	0.2496	0.0372
	(0.1231)	(0.1154)	(0.0970)
10-year	0.6892	0.2494	0.0614
	(0.1331)	(0.1438)	(0.1345)

Note: This table reports the unconditional and the instantaneous variance decompositions of nominal yields into real yields, expected inflation, the inflation risk premiums, all based on Model L-IId estimates. The variance decomposition is calculated according to

$$1 = \frac{cov\left(y_{t,\tau}^{N}, y_{t,\tau}^{R}\right)}{var\left(y_{t,\tau}^{N}\right)} + \frac{cov\left(y_{t,\tau}^{N}, I_{t,\tau}\right)}{var\left(y_{t,\tau}^{N}\right)} + \frac{cov\left(y_{t,\tau}^{N}, \wp_{t,\tau}^{I}\right)}{var\left(y_{t,\tau}^{N}\right)},$$

where the results are based on either the unconditional variance-covariance matrix of the state variables (Panel A) or the instantaneous variance-covariance matrix of the state variables, $\Sigma\Sigma'$ (Panel B). Standard errors calculated using the delta method are reported in parentheses.

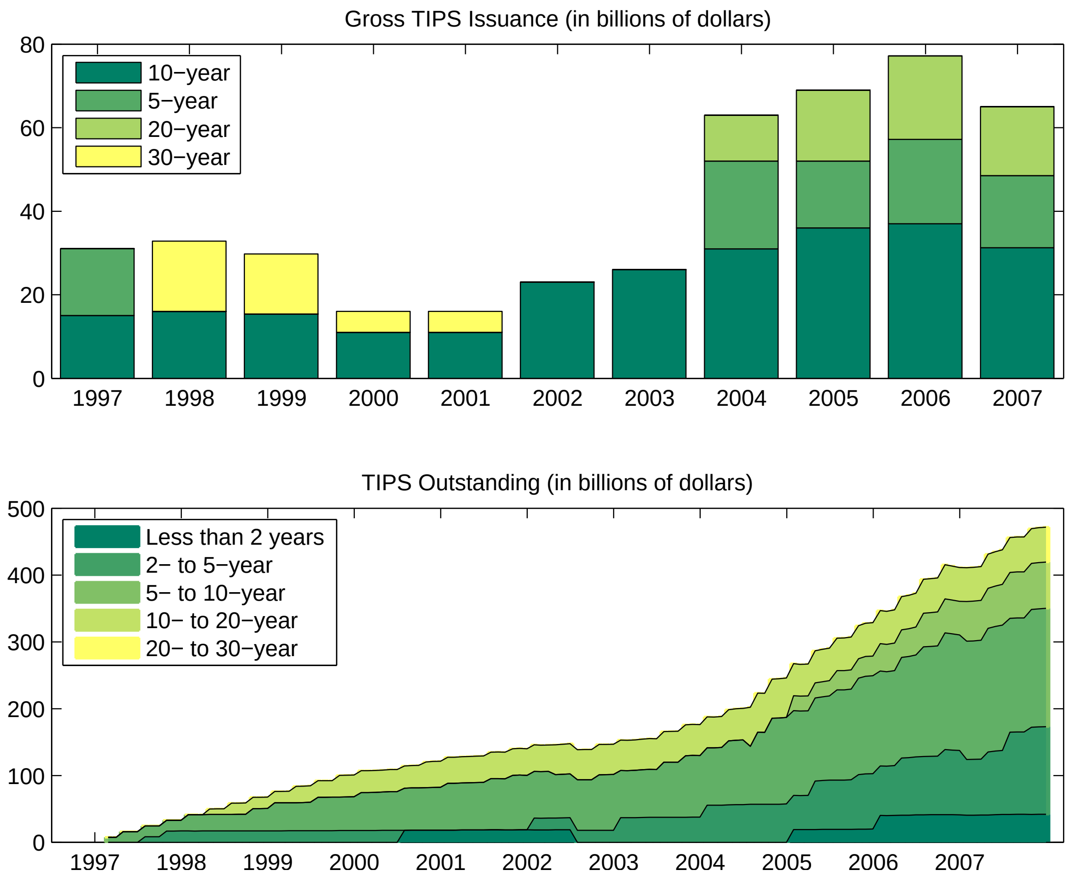


Figure 1: TIPS Issuance and Outstanding

The top panel plots gross TIPS issuance broken down by initial maturities of 10, 5, 20 and 30 years. The bottom panel plots TIPS outstanding broken down by remaining maturities, based on data reported in the Treasury's Monthly Statement of the Public Debt (MSPD).

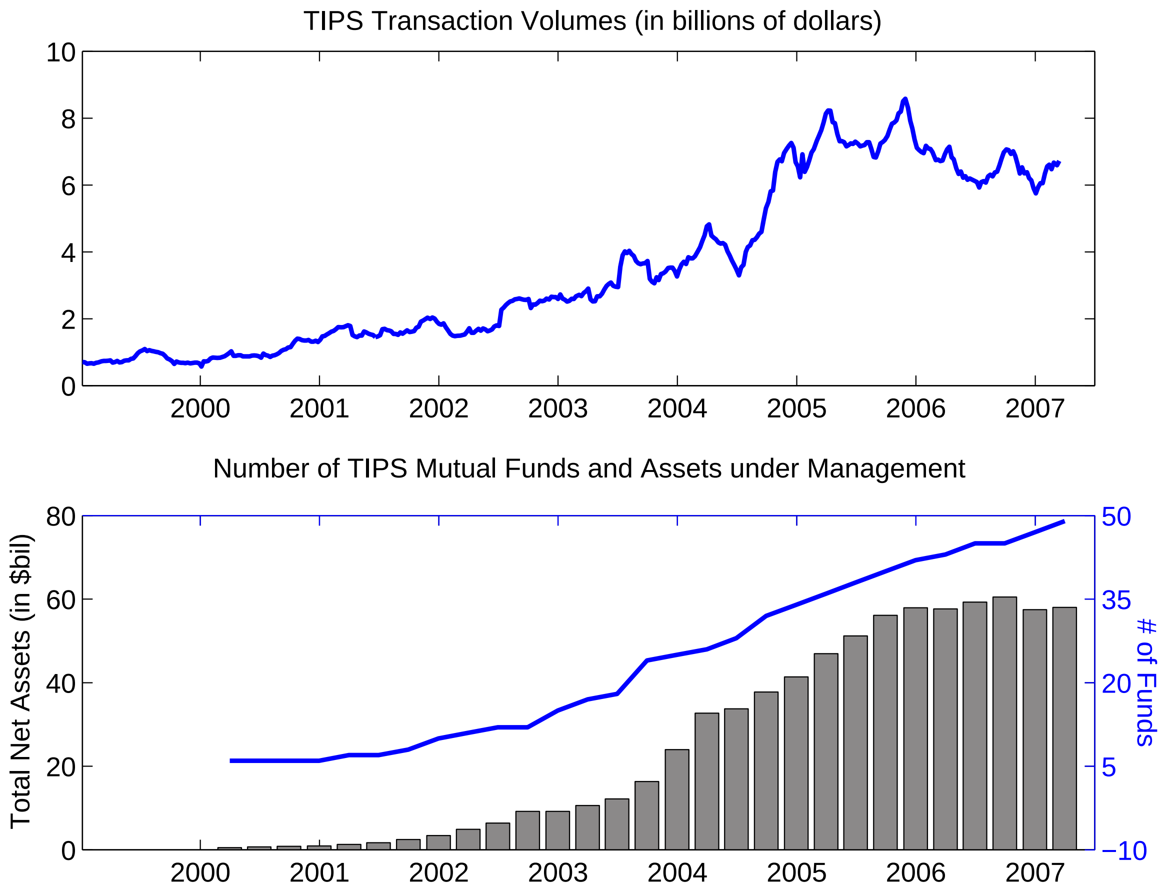


Figure 2: TIPS Transaction Volumes and TIPS Mutual Funds

Top top panel plots the weekly TIPS transaction volumes, defined as 13-week moving average of weekly averages of daily TIPS transaction volumes reported by primary dealers in Government Securities Dealers Reports (FR-2004). The bottom panels plots number of TIPS mutual funds (left axis) and the total net assets under management (left axis).)

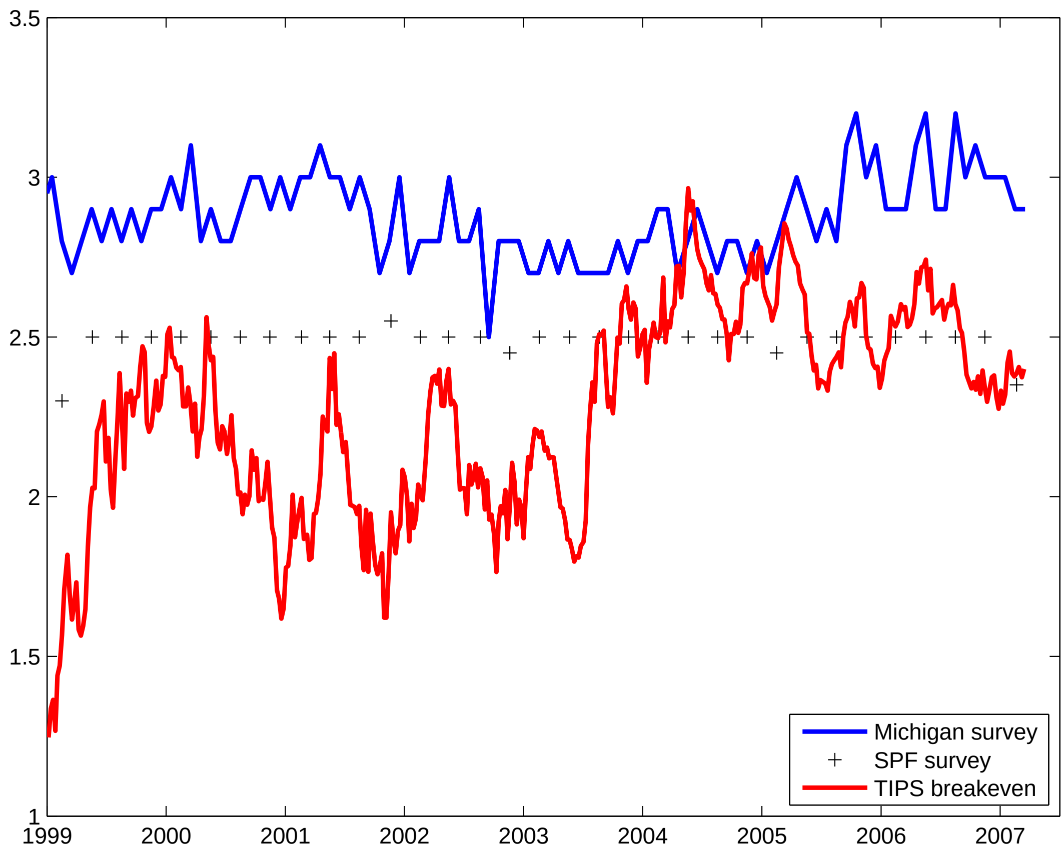


Figure 3: Survey Inflation Forecasts and TIPS Breakeven Inflation

This chart shows the 10-year TIPS breakeven inflation (red line), long-horizon Michigan inflation forecast (blue line), and 10-year SPF inflation forecast (black pluses).

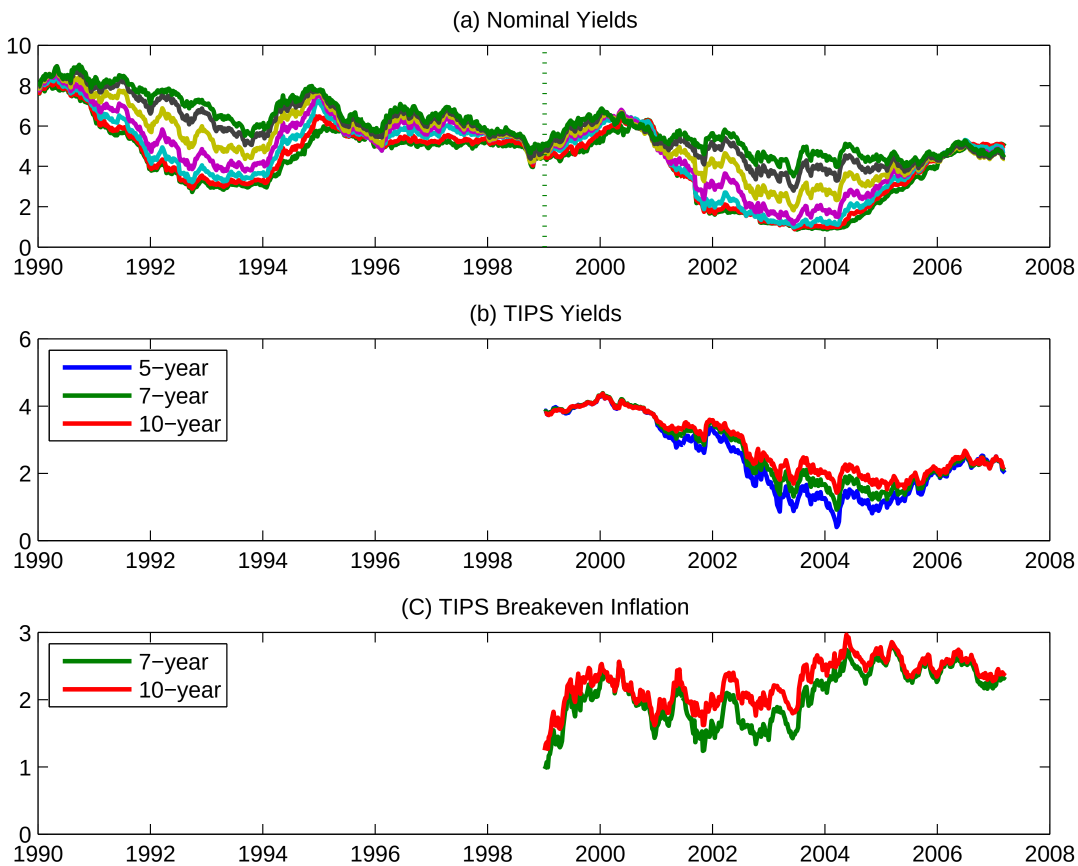


Figure 4: Nominal and TIPS Yields and TIPS Breakeven Inflation

Top top panel plots the 3- and 6-month, 1-, 2-, 4-, 7- and 10-year nominal yields. The middle panel plots the 5-, 7- and 10-year TIPS yields. The bottom panels plots the 5- and 7-year TIPS breakeven inflation.)

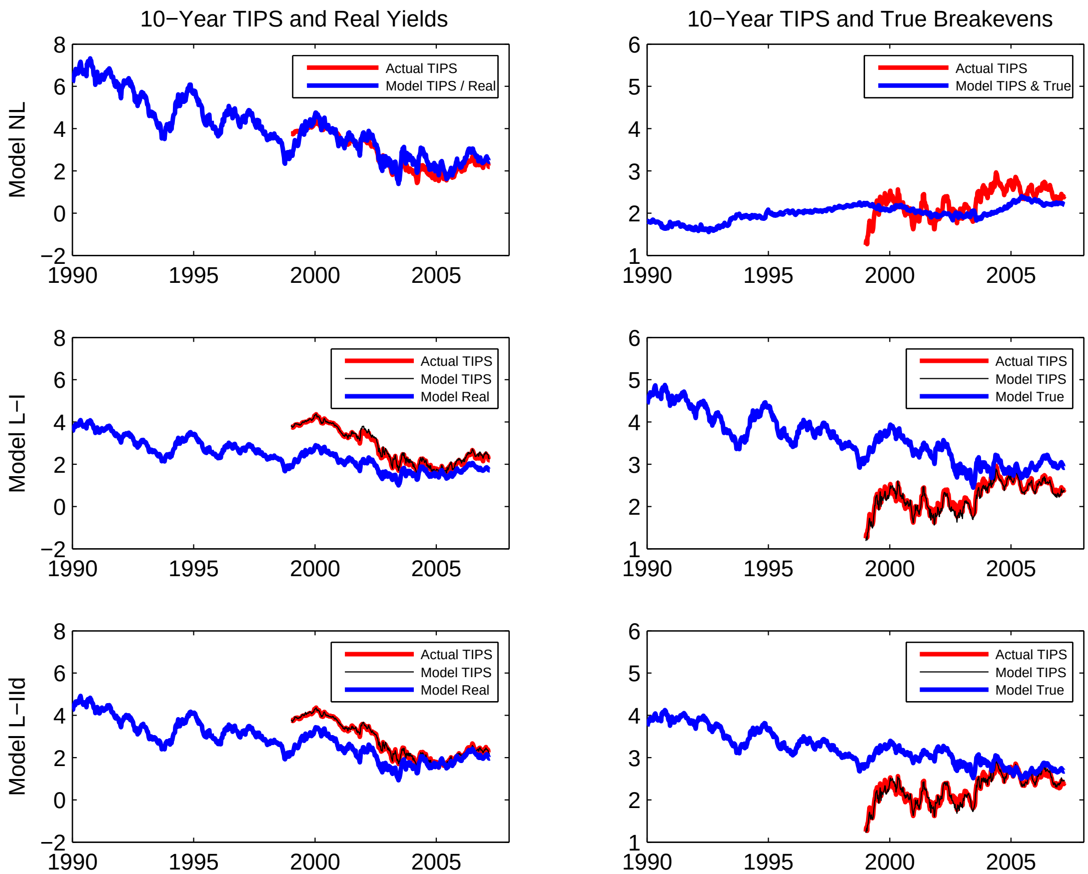
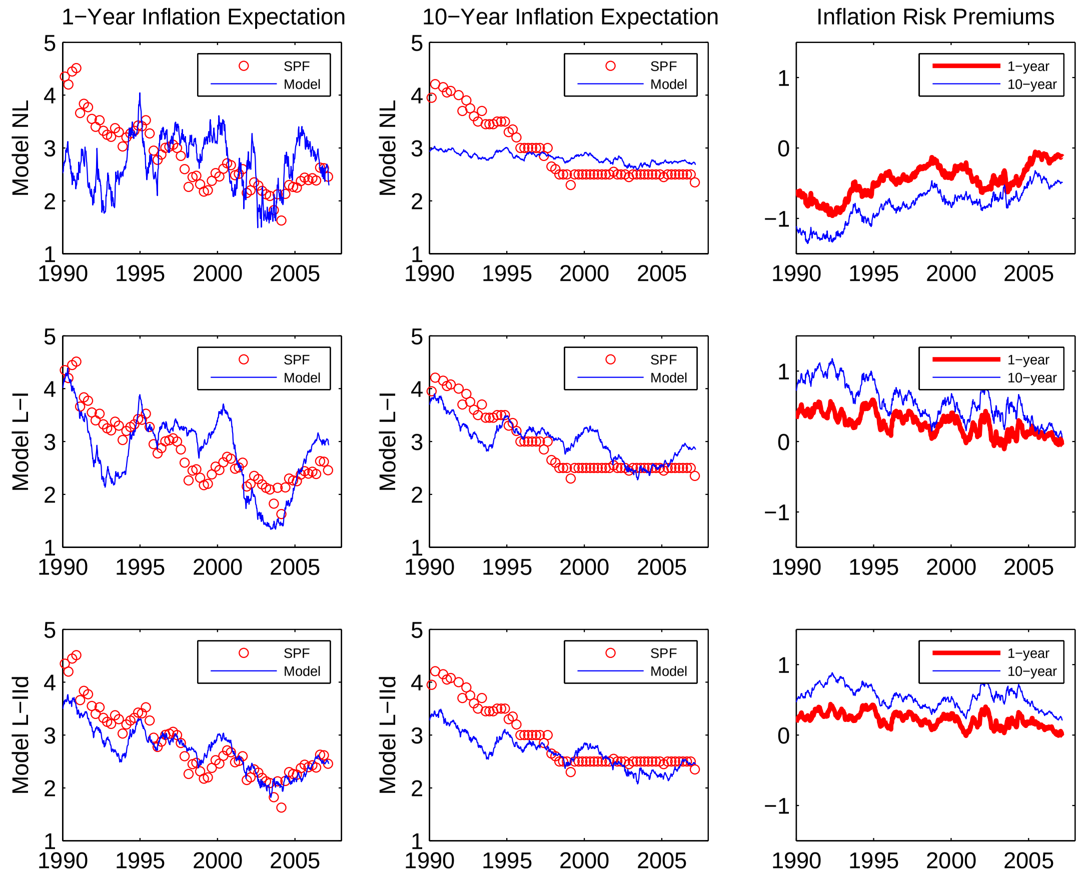


Figure 5: Actual and Model-Implied TIPS Yields and Breakevens

The panels on the left plot the 10-year actual TIPS yields (red), the 10-year model-implied TIPS yields (black) and the 10-year model-implied real yields (blue). The panels on the right plot the 10-year actual TIPS breakevens (red), the 10-year model-implied TIPS breakevens (black) and the 10-year model-implied true breakevens (blue). The model estimates are based on Model NL (upper panels), Model L-I (middle panels), and Model L-IId (lower panels), respectively.



The left and middle panels plot the 1- and 10-year model-implied inflation expectation, respectively, together with the survey counterparts from Survey of Professional Forecasters (SPF), while the right panels plot the 1- and 10-year model-implied inflation risk premiums. The model estimates are based on Model NL (upper panels), Model L-I (middle panels), and Model L-IId (lower panels), respectively.

Figure 6: Inflation Expectations and Inflation Risk Premiums

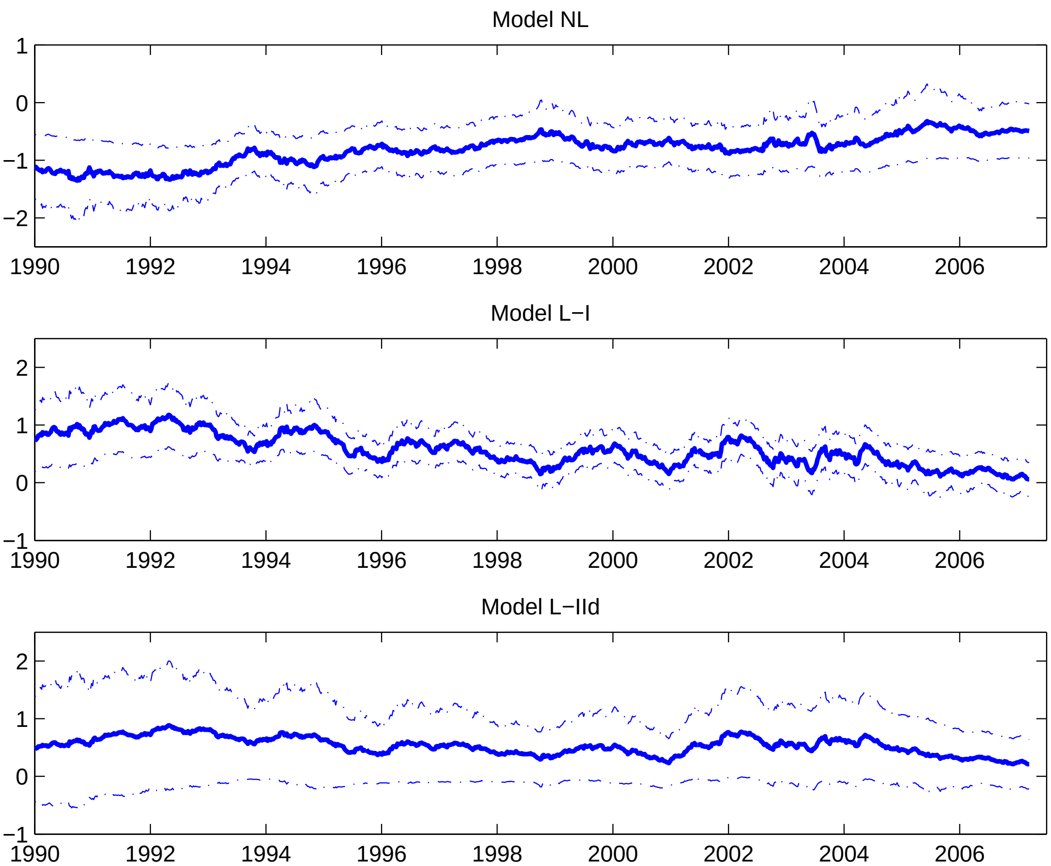


Figure 7: 10-year Inflation Risk Premium with Confidence Bands

The three panels plot the model-implied 10-year inflation risk premiums with 2 BHHH standard error bands based on Model NL (top panel), Model L-I (middle panel) and Model L-IId (bottom panel), respectively.

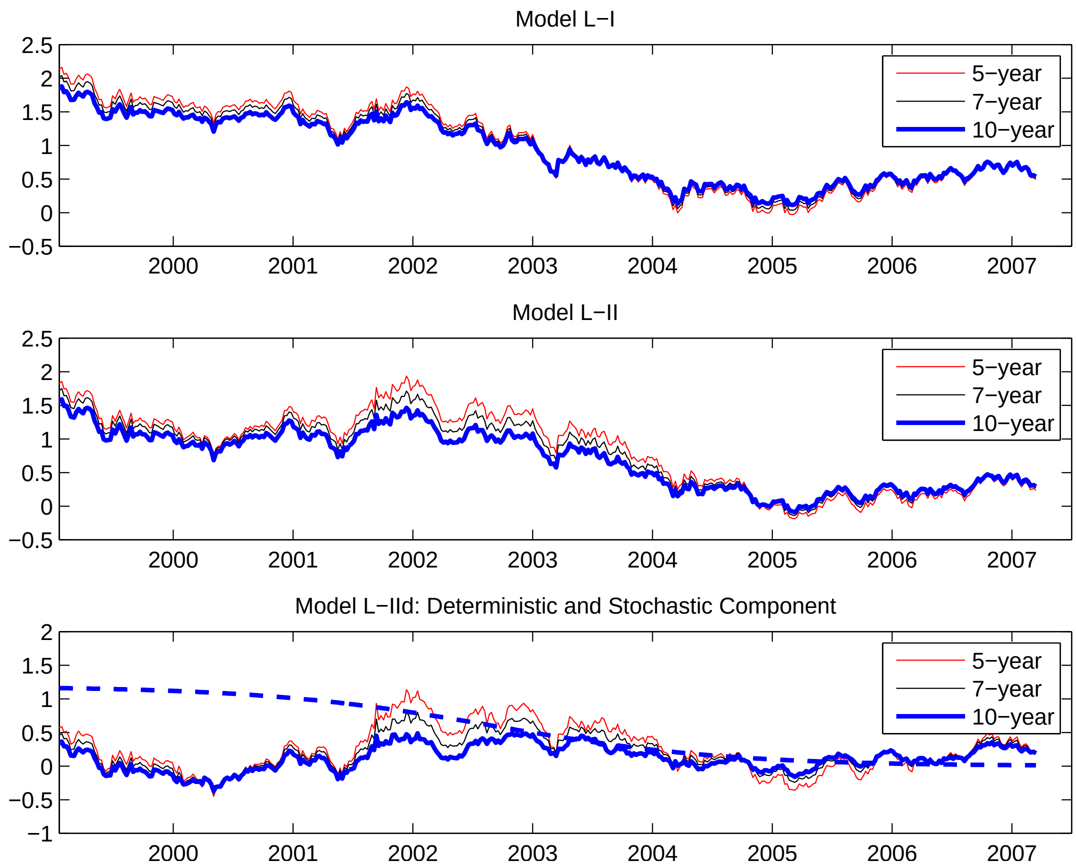


Figure 8: TIPS Liquidity Premiums

The top panel plot the 5-, 7- and 10-year TIPS liquidity premiums based on Model NL estimates. The bottom two panels plots the same series based on Model L-IId estimates, as well as a decomposition of these series into a deterministic component (dashed line in the middle panel) and a stochastic component (bottom panel).

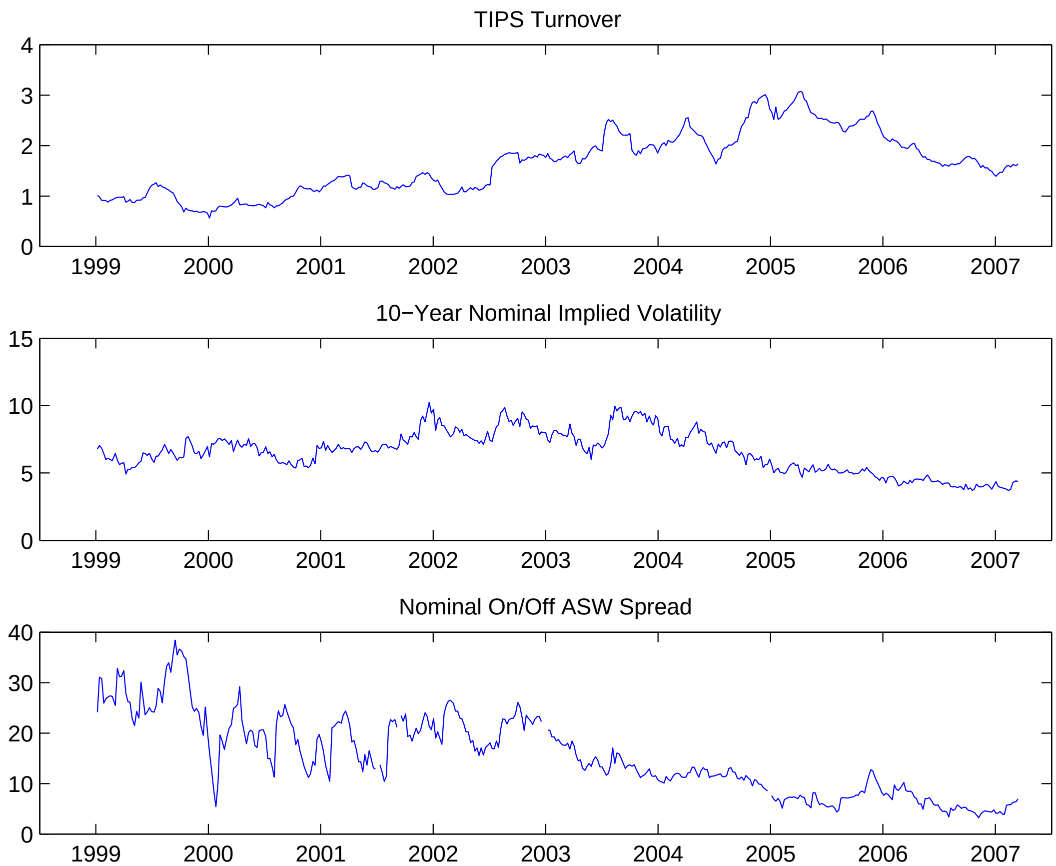


Figure 9: Measures Related to TIPS Liquidity

This chart plots various measures that potentially reflect liquidity conditions in the TIPS market, including the TIPS turnover ratio as defined in Section 6.2 (top panel), implied volatilities from options on the 10-year nominal Treasury note futures (middle panel) and the difference between the on-the-run and the off-the-run 10-year Treasuries par asset swap spreads (bottom panel).

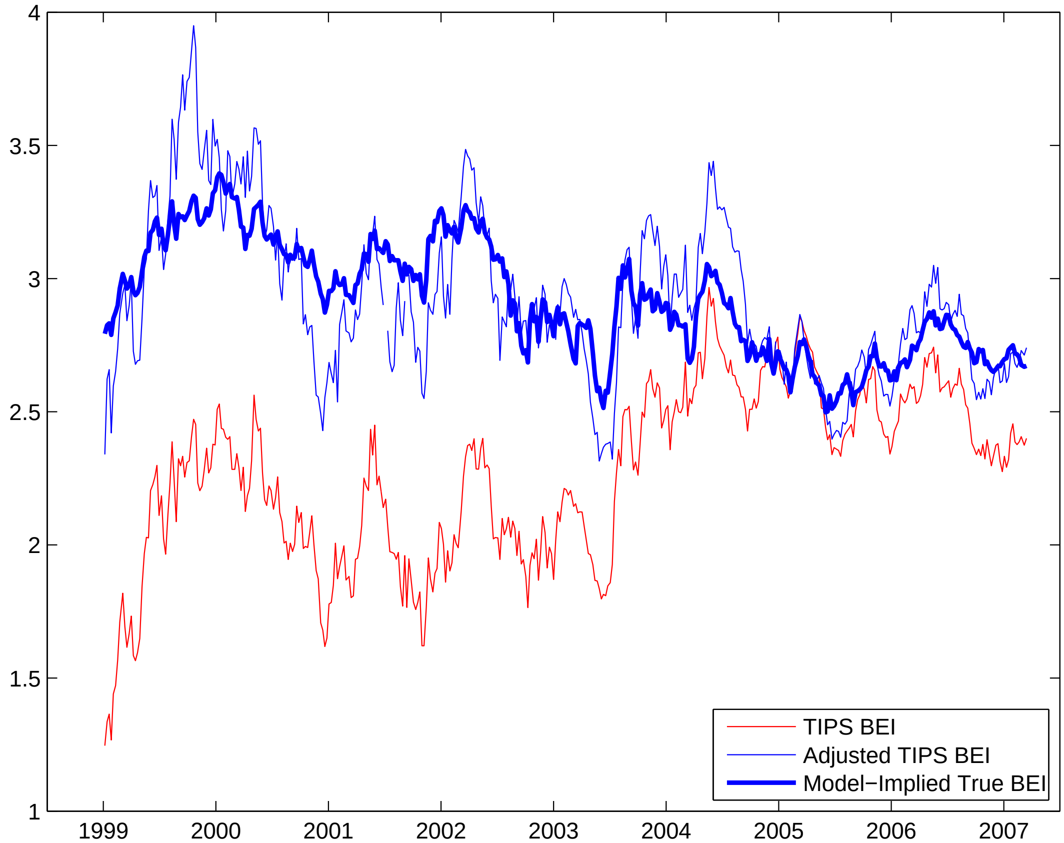


Figure 10: A Simple Liquidity Adjustment for TIPS BEI

This chart plots the liquidity-adjusted 10-year TIPS BEI base on Equation (54) (thin blue line) together with the unadjusted series (red line) and the model-implied true TIPS BEI from Model L-IId (thick blue line).

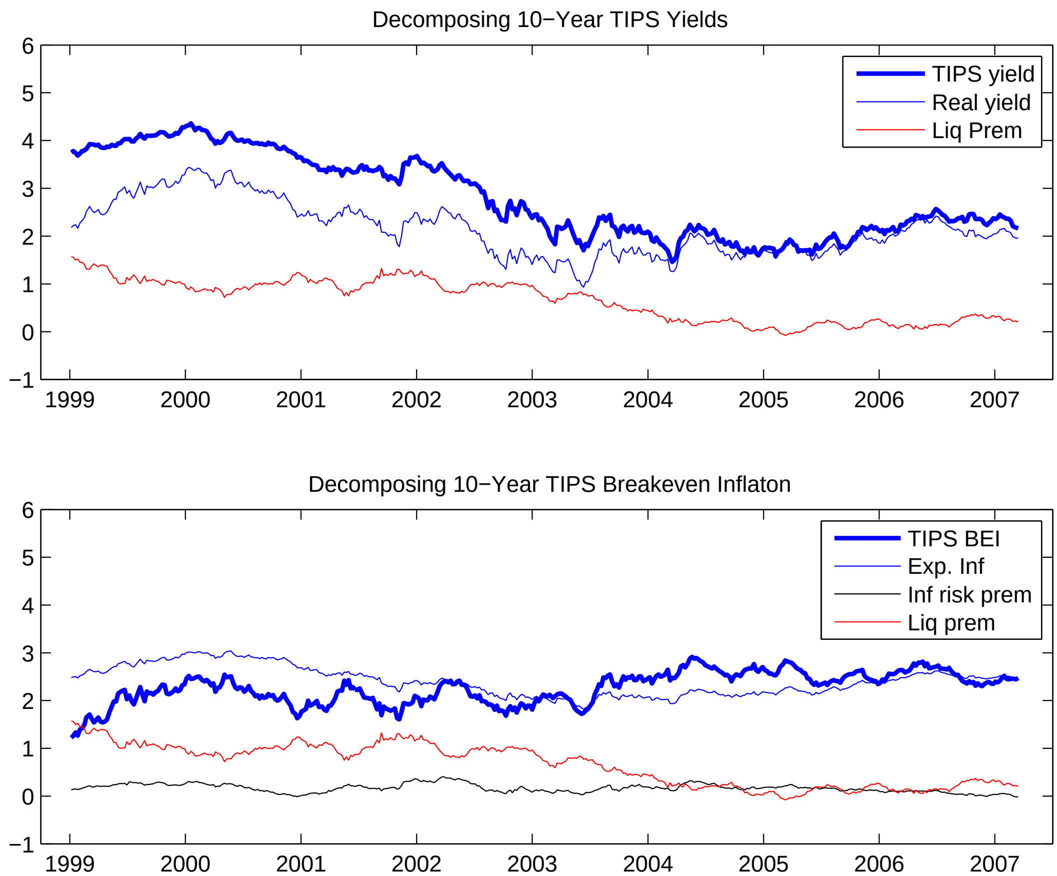


Figure 11: Decomposing TIPS Yields and TIPS Breakeven Inflation

The top panel decomposes the 10-year TIPS yields into the real yield and the TIPS liquidity premiums, while the bottom panel decomposes the 10-year TIPS breakeven inflation into the expected inflation, the inflation risk premium and the TIPS liquidity premium, all according to Equation (55).

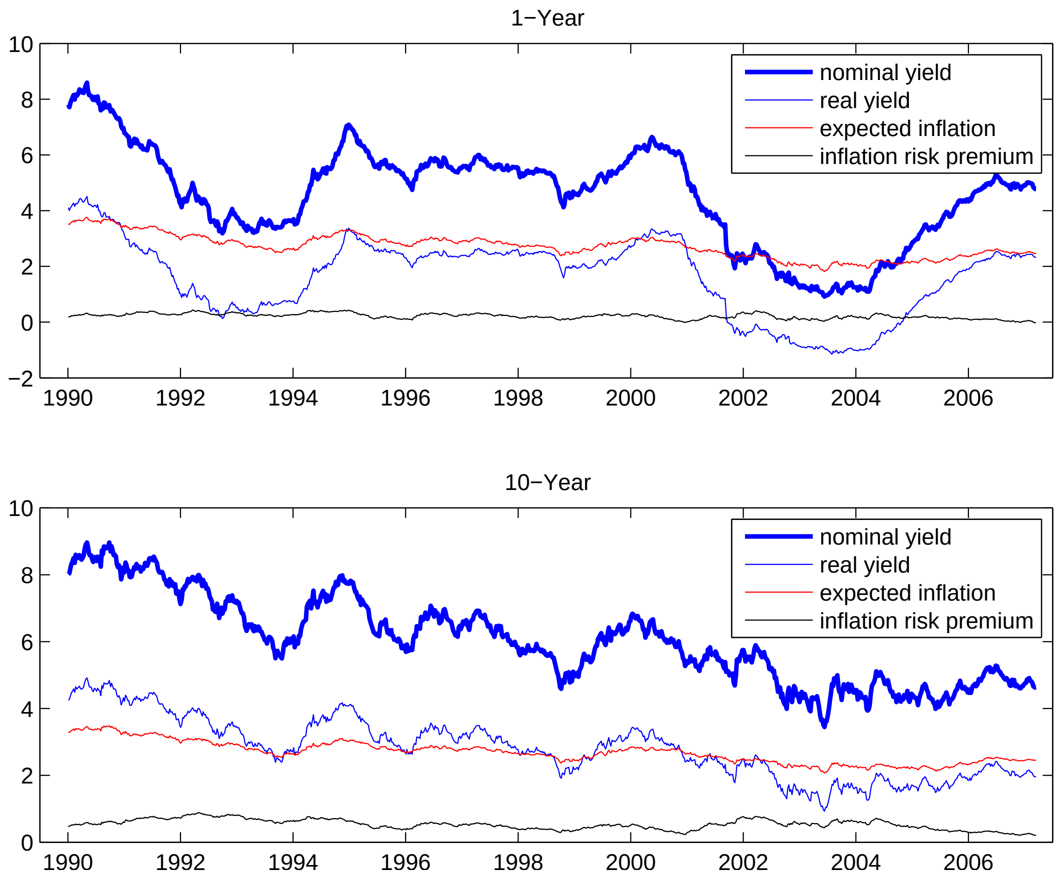
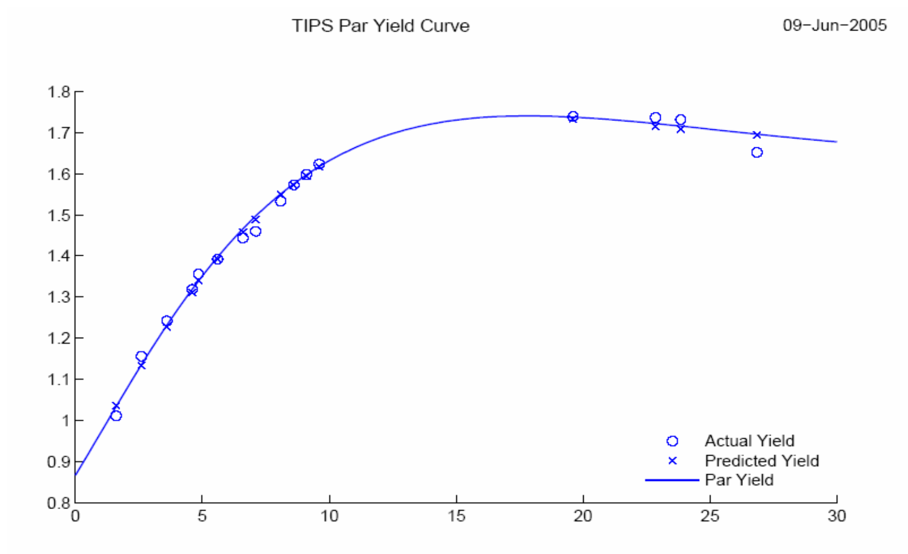
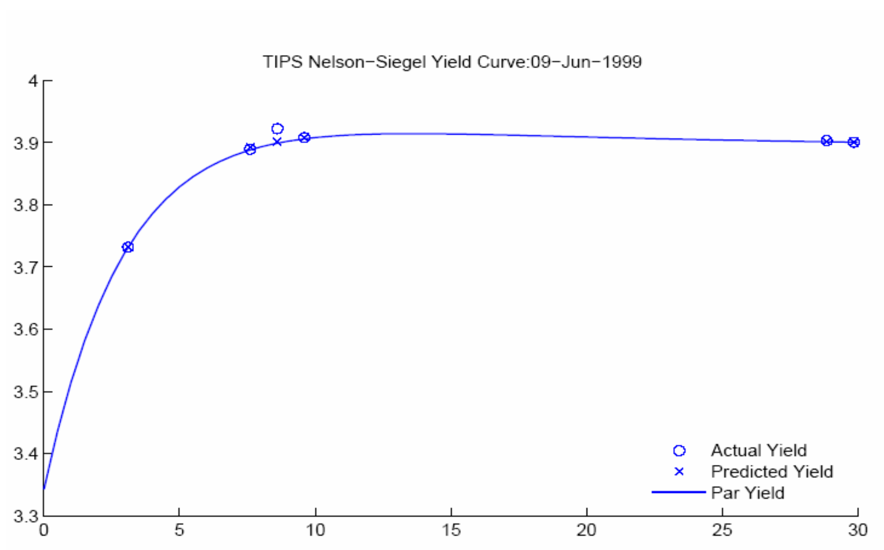


Figure 12: Decomposing Nominal Yields

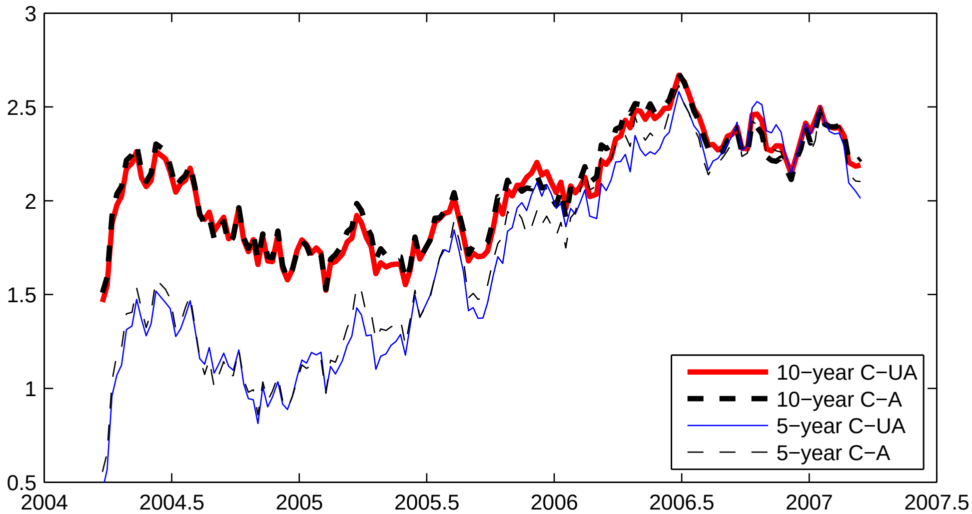
This chart decomposes the 1- and 10-year nominal yields into real yields, expected inflation and inflation risk premiums according to Equation (56).





Note: The top (bottom) panel plots the fitted TIPS par yield curve together with individual TIPS yields on June 9, 2005 (June 9, 1999).

Figure A1: TIPS Yield Curves



Note: This figure plots 10-year carry-unadjusted (carry-adjusted) TIPS yields in red solid (black dashed) line and 5-year carry-unadjusted (carry-adjusted) TIPS yields in blue solid (gray dashed) line.

Figure A2: TIPS Yields with and without Carry Adjustment

Measuring market inflation expectations

Will Devlin and Deepika Patwardhan[1]

Of the available measures of inflation expectations, those available with highest frequency are taken from financial market pricing — so-called 'break-even' inflation rates from the bond market and the market for inflation swaps. Bond market derived measures — which can be subject to both positive and negative biases — suggest medium-term inflation expectations are currently anchored within the Reserve Bank of Australia's target band. Inflation swap rates — which can be subject to their own biases — also suggest that medium-term expectations are well contained. Finally, forward inflation expectations derived from the inflation swaps curve suggest that the market concurs with Treasury estimates that the introduction of the carbon price will have a modest, one-off impact on headline CPI of around 0.7 per cent in 2012-13.

1 The authors are from Macroeconomic Policy Division, the Australian Treasury. This article has benefited from comments and suggestions provided by David Gruen, David Drage, Michael Bath (AOFM), James Kelly and Shane Johnson. The views in this article are those of the authors and not necessarily those of the Australian Treasury.

Introduction

Given their ability to influence price and wage-setting behaviour in particular, inflation expectations play a key role in the determination of future inflation outcomes. As such, timely and reliable estimates of inflation expectations are an important input into the inflation forecasting process and, more generally, the determination of macroeconomic policy settings.

Measures of inflation expectations can be grouped into two broad categories: survey and market-based measures. Survey-based measures ask particular sub-sections of the community — such as market economists, consumers or trade union officials — what their expectations are for inflation over some defined period. While these measures can contain useful information, they are typically released with a lag and can be distorted by the systematic biases of the surveyed respondents.

This paper focusses on market-based measures, which directly infer market participants' expectations for inflation from financial prices. These measures are readily available, updated in real time and, perhaps most importantly, reflect the collective actions of actors who have to back their views by 'putting their money where their mouths are.' Nonetheless, market-based measures are subject to their own biases, and the economic forecaster or macroeconomic policymaker must be aware of these when forming their views.

The paper is structured as follows. First, we examine inflation expectations taken from the market for government bonds, which have historically been the most widely used measure. Second, we look at the market for inflation swaps, which has developed into a viable alternative to bond market-derived measures. Using the inflation swaps curve to derive forward inflation expectations, we then assess the expected price impacts of the Government's *Clean Energy Future* package. Finally, we discuss reasons for divergences in implied inflation expectations between the bond and inflation swaps markets.

Bond market 'break-even' inflation rates

The most widely used market-based measures of medium to long-term inflation expectations are those derived from the market for government bonds. Their use is based on the premise that (nominal) Treasury bond yields can be decomposed into three main components:[2]

1. the real yield, which bond investors demand as compensation for postponing consumption;

2. compensation for expected inflation over the term of the bond; and

3. compensation for any potential variation in either of the above two components (also referred to as term and inflation risk premia, respectively).

In contrast, yields on Treasury indexed bonds — which pay a fixed coupon on the inflation-adjusted capital value of the bond — represent a real yield and compensation for its potential variation. By deduction, the difference between yields on nominal and indexed bonds — the 'break-even' inflation rate — can be regarded as representing the compensation investors demand for being exposed to inflation and to uncertainty around future inflation.[3]

The incorporation of an inflation risk premium potentially distorts bond market break-evens as a measure of inflation expectations. While it is possible to decompose break-even rates to get a cleaner estimate of the expected inflation component, this is a complex modelling exercise and, particularly given data limitations in the Australian market, is subject to some degree of imprecision (see, for example, Finlay and Wende 2011).

The use of bond market break-evens is also made somewhat problematic by the limited size and liquidity of the indexed bond market in Australia. While the market for (nominal) Treasury bonds is quite liquid, the market for Treasury indexed bonds is significantly less liquid (see Box 1). As a consequence, yields on Treasury indexed bonds likely trade at some premium *relative* to nominal Treasury bond yields — since investors will demand compensation for holding this liquidity risk. This, in turn, biases down implied inflation expectations taken from calculated break-even rates.

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2 Note, compensation for default risk on Australian government debt is assumed to be negligible. Australia is currently one of only seven sovereigns globally to hold a AAA rating with a stable outlook from all three of the major credit rating agencies.

3 It is termed the 'break-even' rate since if future inflation turned out to be equal to this rate then the realised real return from holding a nominal bond and an indexed bond would be exactly the same.

Box 1: The markets for nominal and indexed Treasury bonds

The Australian Government, via the Australian Office of Financial Management (AOFM), issues two types of medium to long-term debt securities to the public:[4]

- **Treasury nominal bonds**, which carry an annual (nominal) rate of interest fixed over the life of the security, payable six-monthly.
- **Treasury indexed bonds**, where the capital value of the security is adjusted for movements in the Consumer Price Index. Interest is paid quarterly, at a fixed rate, on the adjusted capital value. At maturity, investors receive the adjusted capital value of the security.

The bulk of the Commonwealth's debt raising task has typically been met by the issuance of Treasury bonds, and the Treasury bond market has historically been the largest Commonwealth Government Securities (CGS) market as a consequence. Since the 2002-03 Review of the CGS market successive governments have committed to retaining a liquid and efficient CGS market. As discussed in the 2011-12 Budget, a panel of financial market experts reported that the CGS market should be maintained at around 12 to 14 per cent of GDP over time (around $200 billion at present), significantly higher than the previous target of $50 billion. There are currently 18 Treasury bond lines on issue, with maturities ranging from late 2012 out to 2027.

The issuance of Treasury indexed bonds was halted in 2003, and maturing bond lines saw the market shrink to a low of around $6 billion outstanding in 2008. In late 2009, however, the AOFM resumed its indexed bond issuance program and the market has since grown to just over $16 billion outstanding. At the 2011-12 Budget the Government announced it would support liquidity in the indexed bond market by maintaining around 10 to 15 per cent of the total CGS market in indexed securities. There are currently five indexed bond lines on issue, with maturities ranging from 2015 to 2030.

Owing partly to its limited size, the market for Treasury indexed bonds has typically been regarded as a significantly less liquid market. Since they are highly prized by portfolio managers with longer term inflation-linked liabilities to hedge — such as life insurers — Treasury indexed bonds tend to be very tightly held. As a result, secondary market trading in indexed bonds can be quite limited, particularly relative to (nominal) Treasury bonds.

That said, the size of this relative liquidity difference appears to have narrowed over recent years, largely due to reduced turnover of nominal Treasury bonds (Chart 1). There are likely several reasons for this reduction in turnover. It may reflect an increased preference by investors and bond traders to use derivatives referencing Treasury bonds (such as futures and swaps) to adjust their portfolio and trading positions, rather than trades involving the physical securities.

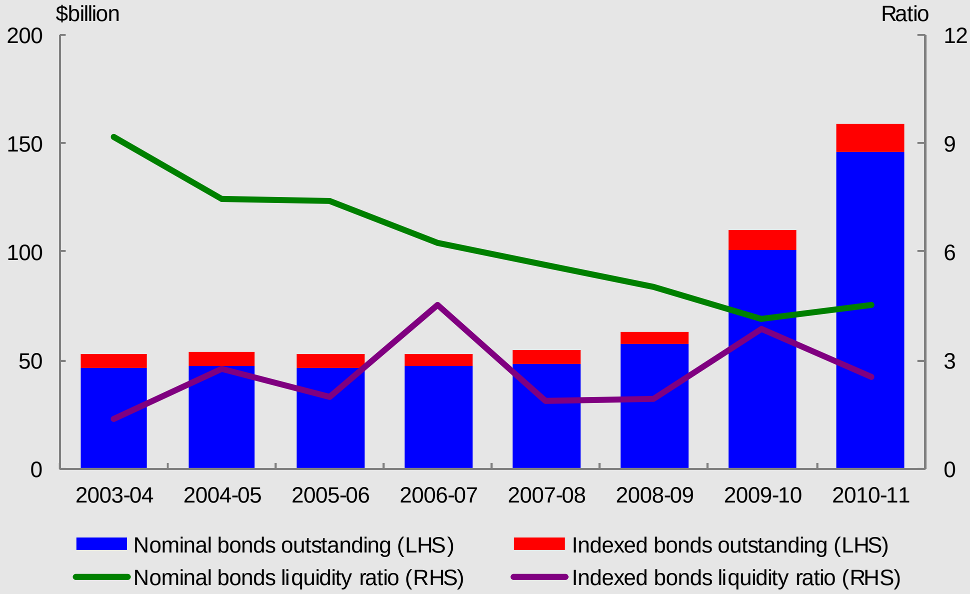
An increase in the proportion of Treasury bonds held by passive (or, 'buy and hold') investors, such as foreign reserve asset managers and institutional investors, may also

4 The Commonwealth also issues Treasury Notes, which are a short-term debt security issued to assist with the Australian Government's within-year financing task.

Box 1: The markets for nominal and indexed Treasury bonds (continued)

have contributed to the decline in secondary market turnover (AOFM 2007-08). Finally, an increasing proportion of Treasury bonds are being held by domestic banks as they seek to enhance the quality of their liquid asset holdings ahead of the new Basel III liquidity rules.

Chart 1: The markets for nominal and indexed Treasury bonds[(a)]



(a) The liquidity ratio is the ratio of annual turnover to total outstandings, where outstandings are an average of monthly data on CGS published by the AOFM.

Source: AOFM, Australian Financial Markets Association and Treasury.

The limited number of indexed bond lines on issue also means that, since break-even rates must be calculated using bonds on a comparable tenor basis, interpolation is usually necessary to fill in points on the real yield curve.[5] Moreover, since Treasury

5 We use the linear interpolation method, where the real yield at any given point in time, $r_{0,T}$, is given by a weighted average of the yields on the two indexed bonds with maturity dates closest to the target maturity date:

$$r_{0,T} = (1-\lambda) * r_M + \lambda * r_N$$

$$M < T < N$$

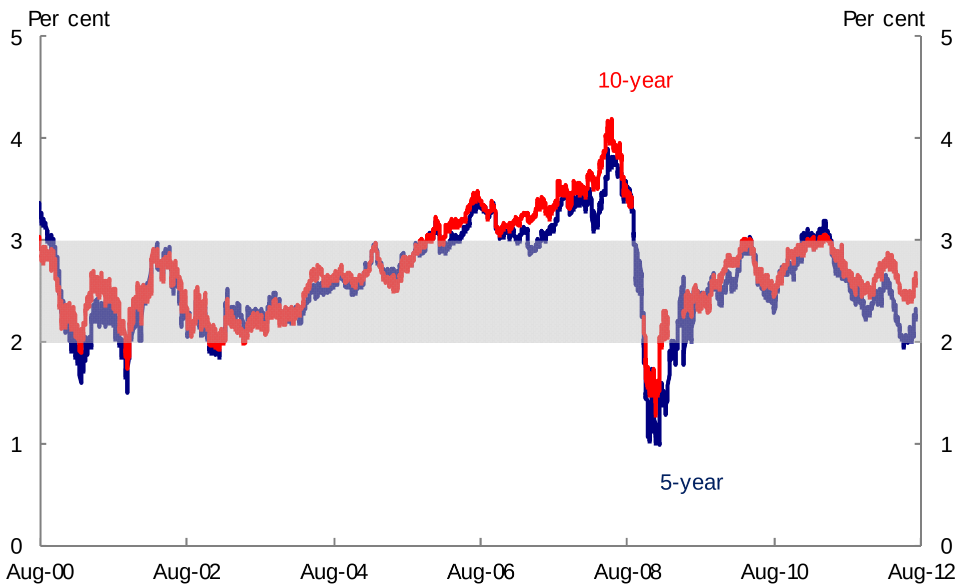
where M is the number of days until maturity of the indexed bond that matures before the target maturity date, T, and N is the number of days until maturity of the indexed bond that matures after the target maturity date. The weights are calculated based on the relative proximity (in days) to the target maturity date:

$$\lambda = \frac{days_{0,T} - days_M}{days_N - days_M}$$

indexed bond lines have typically been issued with maturities spaced every five years, a reliable time series of break-even rates can only be calculated at tenors of five years or more.

These caveats notwithstanding, the five-year bond break-even rate — which shows expectations for average annual inflation over the next five years, abstracting from the influence of any risk premia — is currently in the lower half of the Reserve Bank of Australia's (RBA) target band (Chart 2).[6] At the longer 10-year horizon, expectations are currently around the mid-point of the target band.

Chart 2: Bond market break-even inflation rates[(b)]



(b) There are two breaks in the 10-year break-even series — between September and November 2008, and February and June 2009 — owing to a lack of reliable pricing data for the 10-year indexed bond during those periods.

Source: Bloomberg and Treasury.

It is difficult to be precise about the relative magnitudes of the competing biases on bond break-even rates — there are likely to be periods when the positive inflation risk bias dominates and other periods when the negative liquidity risk bias dominates.[7] Nevertheless, over relatively short periods, an assumption of constant inflation risk and liquidity premia is likely to be a reasonable one such that, while the relative

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6 Bond market break-evens should technically be adjusted to account for different compounding frequencies between (nominal) Treasury bonds (which pay semi-annual coupons) and indexed bonds (which pay quarterly coupons). In practice, however, this does not materially affect estimates of expected inflation taken from bond market break-evens.

7 Finlay and Wende (2011), for example, estimate extended periods of both positive and negative inflation risk premia, where they attribute episodes of negative inflation risk premia to the influence of liquidity premia (the two are not modelled separately).

magnitude of these competing biases at any one time may distort the implied *level* of expected inflation, short-term changes in break-even rates should represent changes in actual market inflation expectations reasonably well.

Over longer periods of time, however, both of these biases are likely to exhibit some variability. While relative liquidity conditions between the indexed and nominal bond markets may be reasonably stable during normal times, the relative liquidity premium incorporated in real bond yields can become more elevated during periods of heightened risk aversion (when investors show a strong preference for more liquid assets). Inflation risk premia, on the other hand, are likely to rise and fall with, for instance, unexpected volatility in realised inflation outcomes, announced government policy changes, volatility in world oil prices and a range of other influences.

Inflation swap rates

Inflation swap rates provide an alternative to bond market-derived measures of market expectations for inflation. An inflation swap is a bilateral agreement that requires one party (the 'inflation payer') to pay realised cumulative inflation over the period of the swap in return for receiving a fixed interest rate (the inflation swap rate) from a second party (the 'inflation receiver') (see Box 2).

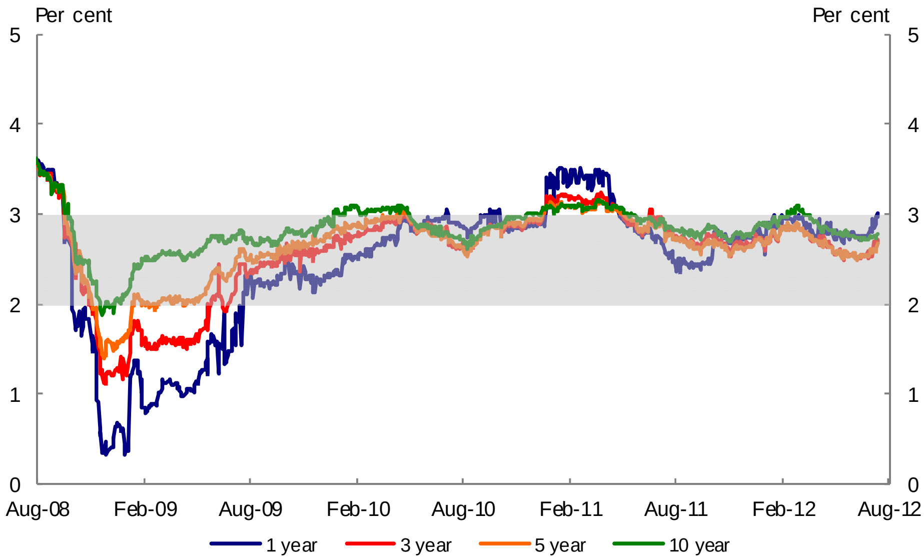
As a measure of market inflation expectations, inflation swap rates (also called inflation swap 'break-evens') offer some advantages over bond market break-evens. They are available over a much wider range of tenors — quoted rates are available from one–year out to 30 years — and, thus, are able to provide a read on both short and long-horizon inflation expectations. As a primary (or, dealers) market, where contracts can be created as required, inflation swap rates are not subject to the kind of liquidity premia that can affect bond market break-evens. While inflation swap rates may incorporate some premium for counterparty risk, this is likely to be negligible since contracts are negotiated with reference to notional amounts (that is, there is no exchange of principal) and make use of standard agreements that provide some legal protection in the event of counterparty default (Hurd and Relleen 2006).

However, despite their advantages, inflation swaps are also unlikely to give a perfectly clean measure of market inflation expectations. As with bond market break-evens, inflation swap rates likely incorporate some premia for inflation risk — compensation demanded by the inflation payer for potential volatility in realised inflation over the term of the swap. Moreover, while inflation swaps are more liquid than Treasury indexed bonds in the sense that they can be created as required, the tailoring of contracts and their bilateral nature makes inflation swaps less liquid 'on the way out' — since the holder of an inflation swap who wished to exit the contract early would have to renegotiate terms with the original issuer, who may or may not be willing to do so. Compensation for this risk may bias inflation swap rates away from the market's true expected inflation rate.

Further, regulatory changes enacted in recent years have meant that banks dealing in the inflation swaps market are required to set aside significantly more capital against any derivatives exposures. Compensation demanded by banks for these higher capital charges may also have introduced a systematic bias into inflation swap rates.

Chart 3 below shows the three, five and ten-year swap rates are currently in the top half of the target band.

Chart 3: Inflation swap rates



Source: Bloomberg.

Since quoted rates are available at yearly intervals from 1 year out to 10 years, we can decompose inflation swap rates into a series of shorter spot and implied forward rates.[8] A useful application of forward rates is to isolate the expected price impacts of announced policy changes that are due to take effect at some point in the future. In July 2011, the Government announced the introduction of a $23 a tonne carbon price beginning on 1 July 2012. At the time of the announcement the Government released the results of Treasury modelling which estimated the policy would result in a one-off rise in headline CPI of 0.7 per cent in the September quarter 2012.[9]

8 The implied one-year forward swap rate, and any subsequent forwards, are calculated as:

$$f_{l-s} = \frac{s_l l - s_s s}{l - s}$$

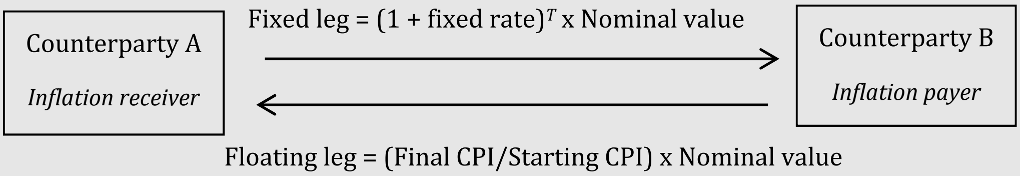
Where f_{l-s} is the forward rate over the period l - s and s_l is the swap rate for a particular maturity, l, and s_s is the swap rate for a shorter maturity, s (Pepper and Cassino 2011).

9 A smaller step up in headline CPI, of 0.2 per cent, was expected to occur in 2015-16, when the scheme moves to the international carbon price (Commonwealth of Australia 2011).

Box 2: The inflation swaps market

While a variety of inflation swaps are transacted in Australia, the most common is the zero-coupon inflation swap. This has the most basic structure, with payments exchanged only on maturity (Figure 1). Zero-coupon swaps have become the standard for which rates are quoted by brokers of these products (generally the major Australian banks and international banks dealing in the Australian swaps market).

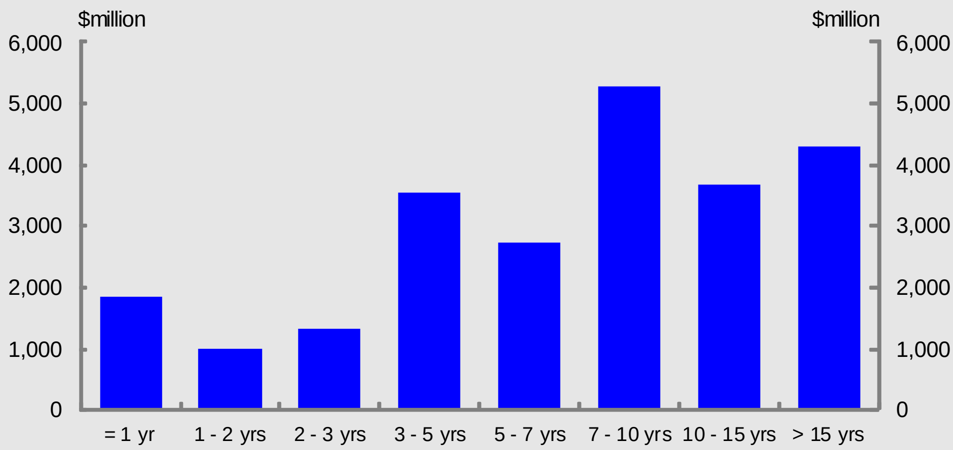
Figure 1: Indicative cash flows of a zero-coupon inflation swap contract



Where the fixed rate is quoted as an effective percentage rate per annum and T is the number of years between the start and end dates.

The inflation swap market is transacted over-the-counter, rather than via an organised exchange, so comprehensive data on market activity are not readily available. However, according to a survey by the Australian Financial Markets Association (AFMA) there were $23.7 billion of inflation swaps outstanding as at May 2011 — the majority of which were for terms of three years or more — with annual turnover (to end-June 2011) of $12.2 billion (Chart 4) (AFMA 2011).

Chart 4: Inflation swaps outstanding by tenor
As at May 2011



Source: AFMA.

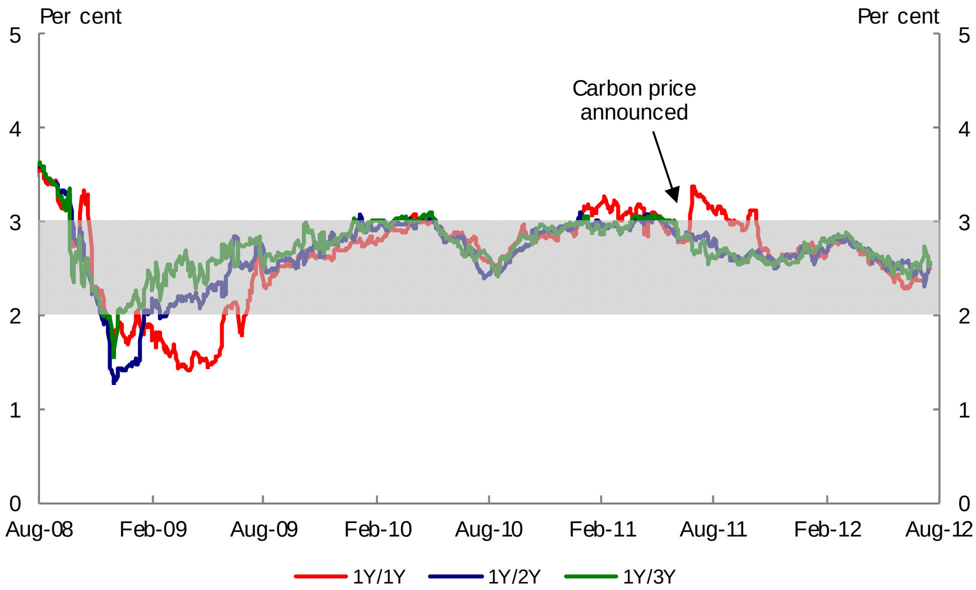
AFMA only began collecting survey data on the inflation swaps market in 2010-11, but by all indications the market has expanded quite rapidly over the past decade. For instance, in August 2001 the Reserve Bank of Australia (RBA) estimated there were only around $500 million in inflation swaps outstanding (RBA 2001).

Activity in the inflation swaps market surrounding the announcement suggests these estimates were viewed as credible, with the implied one-year ahead forward rate rising by between 0.6 and 0.7 per cent upon the announcement (Chart 5). This level jump was maintained until end-October 2011 (since, following the release of the September quarter 2012 CPI in late October 2012, the impact of the introduction of the carbon price on the CPI is expected to have largely passed).

Currently, the one, two, and three-year ahead forward rates — which reflect expectations over time windows in which the introduction of the carbon price is not expected to have a material price impact — are currently around the mid-point of the target band (Chart 5).

Chart 5: Implied forward swap rates

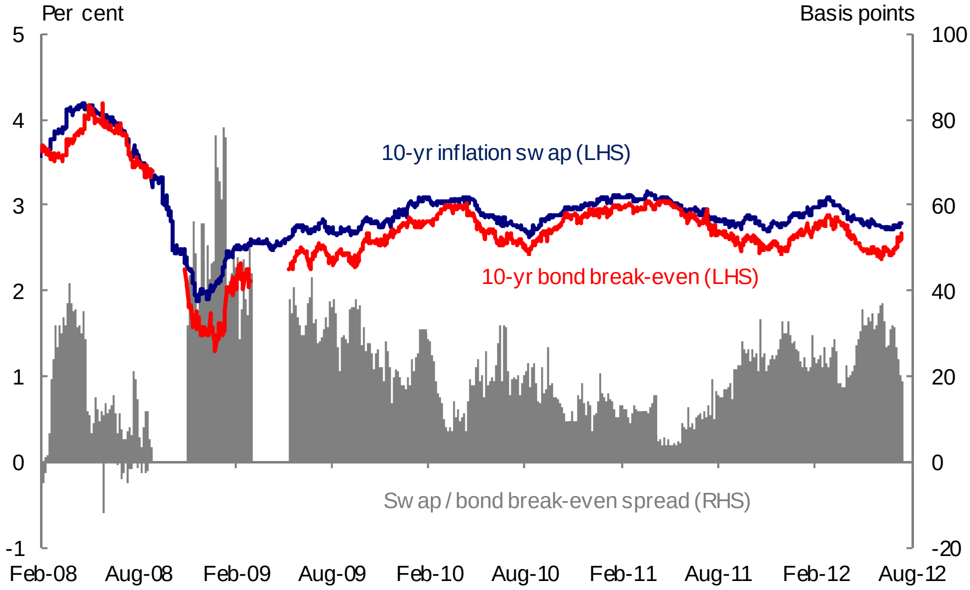
5-day moving averages



Source: Bloomberg and Treasury.

In summary, measures of inflation expectations taken from both the Treasury bond and inflation swaps markets are subject to a range of potential biases, the relative magnitudes of which will vary over time. As a consequence, inflation expectations implied by these two measures can diverge. While inflation swap rates generally move closely in line with bond market break-evens, they have typically been around 20 basis points higher at the 10-year tenor (Chart 6).

Chart 6: Bond market break-evens vs inflation swaps



Source: Bloomberg and Treasury.

Of course, in a world of perfect markets, arbitrage should ensure that the inflation compensation implied by the difference between nominal and indexed bond yields be equal to that implied by inflation swap rates.[10] At a broad level, the reason for the observed divergence is that there may be specific factors that inhibit participants from fully arbitraging away any differences between the two markets.

On the one hand, the limited range of maturities available in the indexed bond market means it is difficult to fully replicate the inflation exposure in a given swaps position with simultaneous trades in the indexed and nominal bond markets. Further, one of the counterparties to an inflation swap will usually be a swaps dealer, who may seek to hedge their inflation exposure with parallel trades in the indexed bond market. Because a cash position in the indexed bond market necessarily entails a capital cost, and because indexed bonds are relatively illiquid, the swaps dealer may demand additional compensation for the cost and potential difficulties involved in hedging this risk. This, in turn, may drive a wedge between inflation swap rates and bond break-evens.

10 Since the payoffs involved in entering an inflation swap can be replicated using nominal and inflation-indexed bonds, and two portfolios with identical future payoffs should, under the assumption of perfect markets, have the same price via arbitrage (Hurd and Relleen 2006).

Conclusion

This article has examined two market-based measures of inflation expectations. The inflation compensation implied by the difference between the yields on nominal and indexed Treasury bonds — which can also incorporate time-varying premia for inflation and liquidity risk — suggest medium to long-term expectations are currently well contained within the RBA's target band. Inflation swap rates, which can be subject to their own biases, point to expectations being within the top half of the target band.

Given the limited number of indexed bonds on issue in Australia, one clear advantage of inflation swap rates as a measure of inflation expectations is their ability to be easily decomposed into implied forward rates. A useful application of forward rates is to gauge the expected price impact of impending policy changes. For instance, forward inflation swap rates suggest the market concurs with Treasury estimates that the introduction of the carbon price will result in a modest, one-off increase in headline CPI of around 0.7 per cent in 2012-13.

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Reserve Bank of Australia

RESEARCH DISCUSSION PAPER

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Richard Finlay and Sebastian Wende

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Economic Research Department
Reserve Bank of Australia

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Author: finlayr at domain rba.gov.au

Media Office: rbainfo@rba.gov.au

Abstract

We estimate inflation expectations and inflation risk premia using inflation forecasts from Consensus Economics and Australian inflation-indexed bond price data. Inflation-indexed bond prices are assumed to be non-linear functions of latent factors, which we model via an affine term structure model. We solve the model using a non-linear Kalman filter. While our results should not be interpreted too precisely due to data limitations and model complexity, they nonetheless suggest that long-term inflation expectations are well anchored within the 2 to 3 per cent inflation target range, while short-run inflation expectations are more volatile and more closely follow contemporaneous inflation. Further, while long-term inflation expectations are generally stable, inflation risk premia are much more volatile. This highlights the potential benefits of our measures over break-even measures of inflation which include both components.

JEL Classification Numbers: E31, E43, G12

Keywords: inflation expectations, inflation risk premia, affine term structure model, break-even inflation, non-linear Kalman filter

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ESTIMATING INFLATION EXPECTATIONS WITH A LIMITED NUMBER OF INFLATION-INDEXED BONDS

Richard Finlay and Sebastian Wende

1. Introduction

Reliable and accurate estimates of inflation expectations are important to central banks given the role of these expectations in influencing inflation and economic activity. Inflation expectations may also indicate over what horizon individuals believe that a central bank will achieve its inflation target, if at all.

The difference between the yields on nominal and inflation-indexed bonds, referred to as the inflation yield or break-even inflation, is often used as a measure of inflation expectations.[1] Since nominal bonds are not indexed to inflation, investors in these bonds require higher yields, relative to those available on inflation-indexed bonds, as compensation for inflation. The inflation yield may not give an accurate reading of inflation expectations, however. This is because investors in nominal bonds will likely demand a premium, over and above their inflation expectations, for bearing inflation risk. That is, the inflation yield will include a premium that will depend positively on the extent of uncertainty about future inflation. If we wish to estimate inflation expectations we must separate this inflation risk premia from the inflation yield. By treating inflation as a random process, we are able to model expected inflation and the cost of the uncertainty associated with inflation separately.

Inflation expectations and inflation risk premia have been estimated for the United Kingdom and the United States using models similar to the one used in this paper. Beechey (2008) and Joyce, Lildholdt and Sorensen (2010) find that inflation risk premia decreased in the UK, first after the Bank of England adopted an inflation target and then again after it was granted independence. Using US Treasury Inflation-Protected Securities (TIPS) data, Durham (2006) estimates expected inflation and inflation risk premia, although he finds that inflation risk

1 The income stream from an inflation-indexed bond is adjusted by the rate of inflation and maintains its value in real terms. Terms and conditions of Treasury inflation-indexed bonds are available at http://www.aofm.gov.au/content/borrowing/terms/indexed_bonds.asp.

premia are not significantly correlated with measures of the uncertainty of future inflation or monetary policy. Also using TIPS data, D'Amico, Kim and Wei (2008) find inconsistent results due to the decreasing liquidity premia in the US, although their estimates are improved by including survey forecasts and using a sample over which the liquidity premia are constant.

In this paper we estimate a time series for inflation expectations for Australia at various horizons, taking into account inflation risk premia, using a latent factor affine term structure model which is widely used in the literature. Compared to the United Kingdom and the United States, there are a very limited number of inflation-indexed bonds on issue in Australia. This complicates the estimation but also highlights the usefulness of our approach. In particular, the limited number of inflation-indexed bonds means that we cannot reliably estimate a zero-coupon real yield curve and so cannot estimate the model in the standard way. Instead, we develop a novel technique that allows us to estimate the model using the *price* of coupon-bearing inflation-indexed bonds instead of zero-coupon real yields. The estimation of inflation expectations and risk premia for Australia, as well as the technique we employ to do so, are the chief contributions of this paper to the literature.

To better identify model parameters we also incorporate inflation forecasts from Consensus Economics in the estimation. Inflation forecasts provide shorter maturity information (for example, forecasts exist for inflation next quarter), as well as information on inflation expectations that is separate from risk premia. Theoretically the model is able to estimate inflation expectations and inflation risk premia purely from the nominal and inflation-indexed bond data – inflation risk premia compensate investors for exposure to variation in inflation, which should be captured by the observed variation in prices of bonds at various maturities. This is, however, a lot of information to extract from a limited amount of bond data. Adding forecast data helps to better anchor the model estimates of inflation expectations and so improves model fit.

Inflation expectations as estimated in this paper have a number of advantages over using the inflation yield to measure expectations. For example, 5-year-ahead inflation expectations as estimated in this paper (i) account for risk premia and (ii) can measure expectations of the inflation rate *in five years time* (as well as the average expectation over the next five years). In contrast, the 5-year inflation yield ignores risk premia and only gives an *average* of inflation rates *over the next five years*.[2] The techniques used in the paper are potentially useful for other countries with a limited number of inflation-indexed bonds on issue, such as Germany or New Zealand.

In Section 2 we outline the model. Section 3 describes the data, estimation of the model parameters and latent factors, and how these are used to extract our estimates of inflation expectations. Results are presented in Section 4 and conclusions are drawn in Section 5.

2. Model

2.1 Yields and Forward Rates

To make subsequent discussion clear we first briefly define yields and forward rates in our model. Unless otherwise stated, yields in this paper are gross, zero-coupon and continuously compounded. So, for example, the nominal τ-maturity yield at time t is given by $y^n_{t,\tau} = -\log(P^n_{t,\tau})$ where $P^n_{t,\tau}$ is the price at time t of a zero-coupon nominal bond paying one dollar at time $t+\tau$. The equivalent real yield is given by $y^r_{t,\tau} = -\log(P^r_{t,\tau})$ where $P^r_{t,\tau}$ is the price at time t of a zero-coupon inflation-indexed bond, which pays the equivalent of the value one time t dollar at time $t+\tau$.[3] The inflation yield is the difference between the yields of nominal and inflation-indexed zero-coupon bonds of the same maturity. So the inflation yield between time t and $t+\tau$ is

$$y^i_{t,\tau} = y^n_{t,\tau} - y^r_{t,\tau}.$$

The inflation yield describes the cumulative increase in prices over a period. In continuous time, the inflation yield between t and $t+\tau$ is related to the inflation forward rates applying over that period by

$$y^i_{t,\tau} = \int_t^{t+\tau} f^i_{t,s} \mathrm{d}s$$

2 In addition, due to the lack of zero-coupon real yields in Australia's case, yields-to-maturity of coupon-bearing nominal and inflation-indexed bonds have historically been used when calculating the inflation yield. This restricts the horizon of inflation yields that can be estimated to the maturities of the existing inflation-indexed bonds, and is not a like-for-like comparison due to the differing coupon streams of inflation-indexed and nominal bonds.

3 These are hypothetical constructs as zero-coupon government bonds are not issued in Australia.

where $f^i_{t,s}$ is the instantaneous inflation forward rate determined at time t and applying at time s.[4]

2.2 Affine Term Structure Model

Following Beechey (2008), we assume that the inflation yield can be expressed in terms of an inflation Stochastic Discount Factor (SDF). The inflation SDF is a theoretical concept, which for the purpose of asset pricing incorporates all information about income and consumption uncertainty in our model. Appendix A provides a brief overview of the inflation, nominal and real SDFs.

We assume that the inflation yield can be expressed in terms of an inflation SDF, M^i_t, according to

$$y^i_{t,\tau} = -\log\left(\mathbb{E}_t\left(\frac{M^i_{t+\tau}}{M^i_t}\right)\right).$$

We further assume that the evolution of the inflation SDF can be approximated by a diffusion equation,

$$\frac{\mathrm{d}M^i_t}{M^i_t} = -\pi^i_t \mathrm{d}t - \boldsymbol{\lambda}^{i\prime}_t\, \mathrm{d}\mathbf{B}_t. \tag{1}$$

According to this model, $\mathbb{E}_t(\mathrm{d}M^i_t/M^i_t) = -\pi^i_t \mathrm{d}t$, so that the instantaneous inflation rate is given by π^i_t. The inflation SDF also depends on the term $\boldsymbol{\lambda}^{i\prime}_t \mathrm{d}\mathbf{B}_t$. Here $\mathbf{B}_t$ is a Brownian motion process and $\boldsymbol{\lambda}^i_t$ relates to the market price of this risk. $\boldsymbol{\lambda}^i_t$ determines the risk premium and this set-up allows us to separately identify inflation expectations and inflation risk premia. This approach to bond pricing is standard in the literature and has been very successful in capturing the dynamics of nominal bond prices (see Kim and Orphanides (2005), for example).

We model both the instantaneous inflation rate and the market price of inflation risk as affine functions of three latent factors. The instantaneous inflation rate is

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4 At time t, the inflation *forward* rate at time $s > t$, $f^i_{t,s}$, is known as it is determined by known inflation yields. The inflation rate, π^i_s, that will prevail at s is unknown, however, and in our model is a random variable (π^i_s can be thought of as the annualised increase in the CPI at time s over an infinitesimal time period). π^i_s is related to the known inflation yield by $\exp(-y^i_{t,\tau}) = \mathbb{E}_t(\exp(-\int_t^{t+\tau} \pi^{i*}_s \mathrm{d}s))$ so that $y^i_{t,\tau} = -\log(\mathbb{E}_t(\exp(-\int_t^{t+\tau} \pi^{i*}_s \mathrm{d}s)))$, where π^{i*}_s is the so-called 'risk-neutral' version of π^i_s (see Appendix B for details).

given by

$$\pi_t^i = \rho_0 + \boldsymbol{\rho}'\mathbf{x}_t \tag{2}$$

where $\mathbf{x}_t = [x_t^1, x_t^2, x_t^3]'$ are our three latent factors.[5] Since the latent factors are unobserved, we normalise $\boldsymbol{\rho}$ to be a vector of ones, $\mathbf{1}$, so that the inflation rate is the sum of the latent factors and a constant, ρ_0. We assume that the price of inflation risk has the form

$$\boldsymbol{\lambda}_t^i = \boldsymbol{\lambda}_0 + \Lambda\mathbf{x}_t \tag{3}$$

where $\boldsymbol{\lambda}_0$ is a vector and Λ is a matrix of free parameters.

The evolution of the latent factors $\mathbf{x}_t$ is given by an Ornstein-Uhlenbeck process (a continuous time mean-reverting stochastic process)

$$\mathrm{d}\mathbf{x}_t = K(\boldsymbol{\mu} - \mathbf{x}_t)\mathrm{d}t + \Sigma\,\mathrm{d}\mathbf{B}_t \tag{4}$$

where: $K(\boldsymbol{\mu} - \mathbf{x}_t)$ is the drift component; K is a lower triangular matrix; $\mathbf{B}_t$ is the same Brownian motion used in Equation (1); and Σ is a diagonal scaling matrix. In this instance we set $\boldsymbol{\mu}$ to zero so that $\mathbf{x}_t$ is a zero mean process, which implies that the average instantaneous inflation rate is ρ_0.

Equations (1) to (4) can be used to show that the inflation yield is a linear function of the latent factors (see Appendix B for details). In particular

$$y_{t,\tau}^i = \alpha_\tau^* + \boldsymbol{\beta}_\tau^{*\prime}\mathbf{x}_t \tag{5}$$

where α_τ^* and $\boldsymbol{\beta}_\tau^*$ are functions of the underlying model parameters. In the standard estimation procedure, when a zero-coupon inflation yield curve exists, this function is used to estimate the values of $\mathbf{x}_t$.

5 Note that one can specify models in which macroeconomic series take the place of latent factors, as done for example in Hördahl (2008). Such models have the advantage of simpler interpretation but, as argued in Kim and Wright (2005), tend to be less robust to model misspecification and generally result in a worse fit of the data.

2.3 Pricing Inflation-indexed Bonds in the Latent Factor Model

We now derive the price of an inflation-indexed bond as a function of the model parameters, the latent factors and nominal zero-coupon bond yields, denoted $H1(\mathbf{x}_t)$. This function will later be used to estimate the model as described in Section 3.2.

As is the case with any bond, the price of an inflation-indexed bond is the present value of its stream of coupons and its par value. In an inflation-indexed bond, the coupons are indexed to inflation so that the real value of the coupons and principal is preserved. In Australia, inflation-indexed bonds are indexed with a lag of between 4½ and 5½ months, depending on the particular bond in question. This means that for future indexations part of the change in the price level has already occurred, while part is yet of occur. We denote the time lag by Δ and the historically observed increase in the price level between $t-\Delta$ and t by $I_{t,\Delta}$. Then at time t, the implicit nominal value of the coupon paid at time $t+\tau_s$ is given by the real (at time $t-\Delta$) value of that coupon, C_s, adjusted for the historical inflation that occurred between $t-\Delta$ and t, $I_{t,\Delta}$, and adjusted by the current market-implied change in the price level between periods t and $t+\tau_s-\Delta$ using the inflation yield, $\exp(y^i_{t,\tau_s-\Delta})$. So the implied nominal coupon paid becomes $C_s I_{t,\Delta}\exp(y^i_{t,\tau_s-\Delta})$. The present value of this nominal coupon is then calculated using the nominal discount factor between t and $t+\tau_s$, $\exp(-y^n_{t,\tau_s})$. So if an inflation-indexed bond pays a total of m coupons, where the par value is included in the last of these coupons, then the price at time t of this bond is given by

$$P^r_t = \sum_{s=1}^{m}\left(C_s I_{t,\Delta} e^{y^i_{t,\tau_s-\Delta}}\right)e^{-y^n_{t,\tau_s}} = \sum_{s=1}^{m} C_s I_{t,\Delta} e^{y^i_{t,\tau_s-\Delta}-y^n_{t,\tau_s}}.$$

We noted earlier that the inflation yield is given by $y^i_{t,\tau} = \alpha^*_\tau + \boldsymbol{\beta}^{*\prime}_\tau \mathbf{x}_t$ so the bond price can be written as

$$P^r_t = \sum_{s=i}^{m} C_s I_{t,\Delta} e^{-y^n_{t,\tau_s}+\alpha^*_{\tau_s-\Delta}+\boldsymbol{\beta}^{*\prime}_{\tau_s-\Delta}\mathbf{x}_t} = H1(\mathbf{x}_t). \qquad (6)$$

Note that $\exp(-y^n_{t,\tau_s})$ can be estimated directly from nominal bond yields (see Section 3.1). So the price of a coupon-bearing inflation-indexed bond can be expressed as a function of the latent factors $\mathbf{x}_t$ as well as the model parameters, nominal zero-coupon bond yields and historical inflation. We define $H1(\mathbf{x}_t)$ as the non-linear function that transforms our latent factors into bond prices.

2.4 Inflation Forecasts in the Latent Factor Model

In the model, inflation expectations are a function of the latent factors, denoted $H2(\mathbf{x}_t)$. Inflation expectations are not equal to expected inflation yields since yields incorporate risk premia whereas forecasts do not. Inflation expectations as reported by Consensus Economics are expectations at time t of how the CPI will increase between time s in the future and time $s+\tau$ and are therefore given by

$$\mathbb{E}_t\left(\exp\left(\int_s^{s+\tau}\pi_u^i \mathrm{d}u\right)\right) = H2(\mathbf{x}_t)$$

where π_t^i is the instantaneous inflation rate at time t. In Appendix B we show that one can express $H2(\mathbf{x}_t)$ as

$$H2(\mathbf{x}_t) = \exp(-\bar{\alpha}_\tau - \bar{\boldsymbol{\beta}}'_\tau(e^{-K(s-t)}\mathbf{x}_t + (I - e^{-K(s-t)})\boldsymbol{\mu}) + \frac{1}{2}\bar{\boldsymbol{\beta}}'_\tau\Omega_{s-t}\bar{\boldsymbol{\beta}}_\tau). \quad (7)$$

The parameters $\bar{\alpha}_\tau$ and $\bar{\boldsymbol{\beta}}_\tau$ (and Ω_{s-t}) are defined in Appendix B, and are similar to α_τ^* and $\boldsymbol{\beta}_\tau^*$ from Equation (5).

3. Data and Model Implementation

3.1 Data

Four types of data are used in this analysis: nominal zero-coupon bond yields derived from nominal Australian Commonwealth Government bonds; Australian Commonwealth Government inflation-indexed bond yields; inflation forecasts from Consensus Economics; and historical inflation.

Nominal zero-coupon bond yields are estimated using the approach of Finlay and Chambers (2009). These nominal yields correspond to y_{t,τ_s}^n and are used in computing our function $H1(\mathbf{x}_t)$ from Equation (6). Note that the Australian nominal yield curve has a maximum maturity of roughly 12 years. We extrapolate nominal yields beyond this by assuming that the nominal and real yield curves have the same slope. This allows us to utilise the prices of all inflation-indexed bonds, which have maturities of up to 24 years (in practice the slope of the real yield curve beyond 12 years is very flat, so that if we instead hold the nominal yield curve constant beyond 12 years we obtain virtually identical results).

We calculate the real prices of inflation-indexed bonds using yield data.[6] Our sample runs from July 1992 to December 2010, with the available data sampled at monthly intervals up to June 1994 and weekly intervals thereafter. Bonds with less than one year remaining to maturity are excluded. By comparing these computed inflation-indexed bond prices, which form the P_t^r in Equation (6), with our function $H1(\mathbf{x}_t)$, we are able to estimate the latent factors. We assume that the standard deviation of the bond price measurement error is 4 basis points. This is motivated by market liaison which suggests that, excluding periods of market volatility, the bid-ask spread has stayed relatively constant over the period considered, at around 8 basis points. Some descriptive statistics for nominal and inflation-indexed bonds are given in Table 1.

Table 1: Descriptive Statistics of Bond Price Data

		Time period			
Statistic		1992–1995	1996–2000	2001–2005	2006–2010
Number of bonds:	nominal	12–19	12–19	8–12	8–14
	inflation-indexed	3–5	4–5	3–4	2–4
Maximum tenor:	nominal	11–13	11–13	11–13	11–14
	inflation-indexed	13–21	19–24	15–20	11–20
Average outstanding:	nominal	49.5	70.2	50.1	69.5
	inflation-indexed	2.1	5.0	6.5	7.1

Notes: Tenor in years; outstandings in billions; only bonds with at least one year to maturity are included

Note that inflation-indexed bonds are relatively illiquid, especially in comparison to nominal bonds.[7] Therefore, inflation-indexed bond yields potentially incorporate liquidity premia, which could bias our results. As discussed we use inflation forecasts as a measure of inflation expectations. These forecasts serve to tie down inflation expectations, and as such we implicitly assume that liquidity premia are included in our measure of risk premia. We also assume that the

6 Available from statistical table F16 at http://www.rba.gov.au/statistics/tables/index.html.

7 Average yearly turnover between 2003/04 and 2007/08 was roughly $340 billion for nominal Government bonds and $15 billion for inflation-indexed bonds, which equates to a turnover ratio of around 7 for nominal bonds and 2½ for inflation-indexed bonds (see AFMA 2008).

existence of liquidity premia causes a level shift in estimated risk premia but does not greatly bias the estimated *changes* in risk premia.[8]

The inflation forecasts are taken from Consensus Economics. We use three types of forecast:

1. Monthly forecasts of the average percentage change in CPI over the current and the subsequent year.
2. Quarterly forecasts of the year-on-year percentage change in the CPI for 7 or 8 quarters in the future.
3. Biannual forecasts of the year-on-year percentage change in the CPI for each of the next 5 years, as well as from 5 years in the future to 10 years in the future.

We use the function $H2(\mathbf{x}_t)$ to relate these inflation forecasts to the latent factors, and use the past forecasting performance of the inflation forecasts relative to realised inflation to calibrate the standard deviation of the measurement errors.

Historical inflation enters the model in the form of $I_{t,\Delta}$ from Section 2.3, but otherwise is not used in estimation. This is because the fundamental variable being modelled is the *current instantaneous* inflation rate. Given the inflation law of motion (implicitly defined by Equations (2) to (4)), inflation expectations and inflation-indexed bond prices are affected by current inflation and so can inform our estimation. By contrast, the published inflation rate is always 'old news' from the perspective of our model and so has nothing direct to say about current instantaneous inflation.[9]

8 Inflation swaps are now far more liquid than inflation-indexed bonds and may provide alternative data for use in estimating inflation expectations at some point in the future. Currently, however, there is not a sufficiently long time series of inflation swap data to use for this purpose.

9 Note that our model is set in continuous time; data are sampled discretely but all quantities, for example the inflation law of motion as well as inflation yields and expectations, evolve continuously. π_t^i from Equation (2) is the current instantaneous inflation rate, not a 1-month or 1-quarter rate.

3.2 The Kalman Filter and Maximum Likelihood Estimation

We use the Kalman filter to estimate the three latent factors using data on bond prices and inflation forecasts. The Kalman filter can estimate the state of a dynamic system from noisy observations. It does this by using information about how the state evolves over time, as summarised by the state equation, and relating the state to noisy observations using the measurement equation. In our case, the latent factors constitute the state of the system and our bond prices and forecast data the noisy observations. From the latent factors we are able to make inferences about inflation expectations and inflation risk premia.

The standard Kalman filter was developed for a linear system. Although our state equation (given by Equation (B1)) is linear, our measurement equations, using $H1(\mathbf{x}_t)$ and $H2(\mathbf{x}_t)$ as derived in Sections 2.3 and 2.4, are not. This is because we work with coupon-bearing bond prices instead of zero-coupon yields. We overcome this problem by using a central difference Kalman filter, which is a type of non-linear Kalman filter.[10]

The approximate log-likelihood is evaluated using the forecast errors of the Kalman filter. If we denote the Kalman filter's forecast of the data at time t by $\hat{\mathbf{y}}_t\left(\zeta, \mathbf{x}_t(\zeta, \mathbf{y}_{t-1})\right)$, which depends on the parameters (ζ) and the latent factors $(\mathbf{x}_t(\zeta, \mathbf{y}_{t-1}))$, which in turn depend on the parameters and the data observed up to time $t-1$ $(\mathbf{y}_{t-1})$, then the approximate log-likelihood is given by

$$\mathscr{L}(\zeta) = -\sum_{t=1}^{T}\left(\log|P_{\mathbf{y}_t}| + (\mathbf{y}_t - \hat{\mathbf{y}}_t)\, P_{\mathbf{y}_t}^{-1}\,(\mathbf{y}_t - \hat{\mathbf{y}}_t)'\right).$$

Here the estimated covariance matrix of the forecast data is denoted by $P_{\mathbf{y}_t}$.[11] In the model the parameters are given by $\boldsymbol{\zeta} = (K, \boldsymbol{\lambda}_0, \Lambda, \rho_0, \Sigma)$.

We numerically optimise the log-likelihood function to obtain parameter estimates. From the parameter estimates, we use the Kalman filter to obtain estimates of the latent factors.

10 See Appendix C for more detail on the central difference Kalman filter.

11 In actual estimation we exclude the first six months of data from the likelihood calculation to allow 'burn in' time for the Kalman filter.

3.3 Calculation of Model Estimates

For a given set of model parameters and latent factors, we can calculate inflation forward rates, expected future inflation rates and inflation risk premia.

In Appendix B we show that the expected future inflation rate at time t for time $t+\tau$ can be expressed as

$$\mathbb{E}_t(\pi^i_{t+\tau}) = \rho_0 + \mathbf{1}' e^{-K\tau}\mathbf{x}_t.$$

The inflation forward rate at time t for time $t+\tau$, $f^i_{t,t+\tau}$, is the rate of inflation at time $t+\tau$ implied by market prices of nominal and inflation-indexed bonds trading at time t. As bond prices incorporate inflation risk, so does the inflation forward rate. In our model the inflation forward rate is given by

$$\begin{aligned} f^i_{t,t+\tau} = &\rho_0 + \mathbf{1}'(e^{-K^*\tau}\mathbf{x}_t + (I - e^{-K^*\tau})\boldsymbol{\mu}^*) \\ &- \frac{1}{2}(\mathbf{1}'(I - e^{-K^*\tau})K^{*-1}\Sigma)(\mathbf{1}'(I - e^{-K^*\tau})K^{*-1}\Sigma)'. \end{aligned}$$

See Appendix B for details on the above and definitions of K^* and $\boldsymbol{\mu}^*$.

The inflation risk premium is given by the difference between the inflation forward rate, which incorporates risk aversion, and the expected future inflation rate, which is free of risk aversion. The inflation risk premium at time t for time $t+\tau$ is given by

$$f^i_{t,t+\tau} - \mathbb{E}_t(\pi^i_{t+\tau}).$$

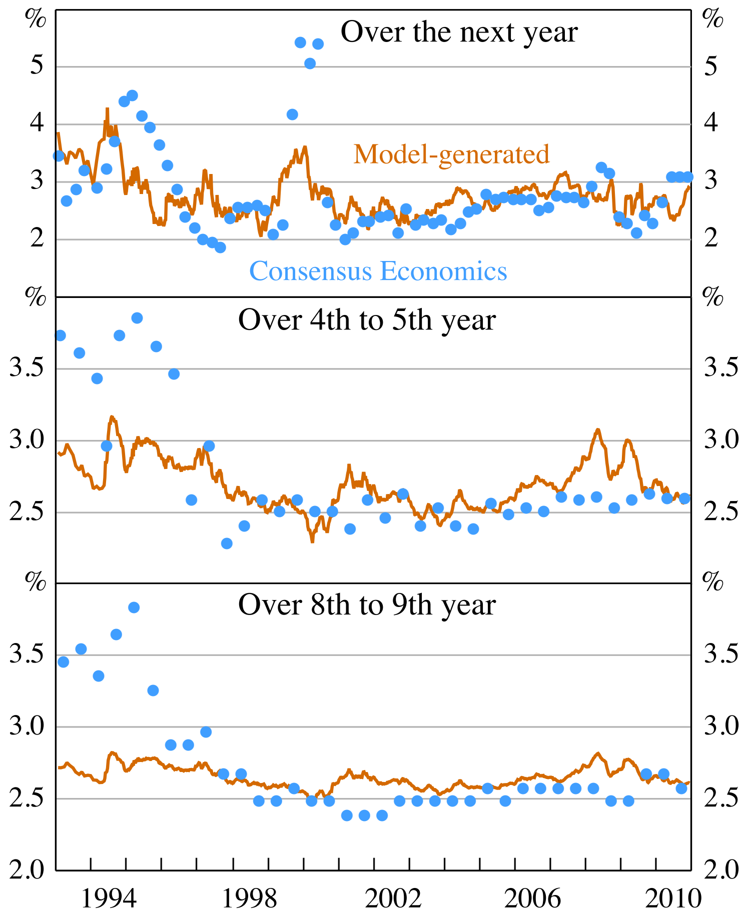
4. Results

4.1 Model Parameters and Fit to Data

We estimate the model over the period 31 July 1992 to 15 December 2010 using a number of different specifications. First we estimate both two- and three-factor versions of our model. Using a likelihood-ratio test we reject the hypothesis that there is no improvement of model fit between the two-factor model and three-factor model and so use the three-factor model. (Three factors are usually considered sufficient in the literature, with, for example, the overwhelming majority of variation in yields captured by the first three principal components.)

We also consider the three-factor model both with and without forecast data. Both models are able to fit the inflation yield data well; the model without forecast data, however, gives unrealistic estimates of inflation expectations and inflation risk premia. The 10-year-ahead inflation expectations are implausibly volatile and can be as high as 8 per cent and as low as -1 per cent, which is not consistent with economists' forecasts. These findings are consistent with those of Kim and Orphanides (2005), where the use of forecast data is advocated as a means of separating expectations from risk premia. Note, however, that estimates from the model with forecast data are not solely determined by the forecasts; the model estimates of expected future inflation only roughly match the forecast data and on occasion deviate significantly from them, as seen in Figure 1.

Figure 1: Forecast Change in CPI



Sources: Consensus Economics; authors' calculations

Our preferred model is thus the three-factor model estimated using forecast data. Likelihood ratio tests indicate that two parameters of that model (Λ_{11} and Λ_{21})

are statistically insignificant and so they are excluded. Our final preferred model has 20 freely estimated parameters which are given in Table 2. We note that the estimate of ρ_0, the steady-state inflation rate in our model, is 2.6 per cent, which is within the inflation target range. The persistence of inflation is essentially determined by the diagonal entries of the K matrix, which drives the inflation law of motion as defined by Equations (2) to (4). The first diagonal entry of K is 0.19, which in a single-factor model would imply a half-life of the first latent factor (being the time taken for the latent factor, and so inflation, to revert halfway back to its mean value after experiencing a shock) of around 3½ years. The half-lives of the other two latent factors would be 5 and 10 months.

Table 2: Parameter Estimates for Final Model
Model estimated 1992–2010

	Index number (i)					
Parameter	1		2		3	
ρ_0	2.64	(0.26)	na		na	
$(K)_{1i}$	0.19	(0.02)	0		0	
$(K)_{2i}$	−2.88	(0.05)	1.75	(0.05)	0	
$(K)_{3i}$	1.11	(0.05)	1.74	(0.05)	0.80	(0.01)
$(\Sigma)_{ii}$	0.11	(0.02)	1.51	(0.10)	0.96	(0.02)
$\boldsymbol{\lambda}_{0,i}$	0.12	(0.01)	0.10	(0.01)	−0.01	(0.00)
$(\Lambda)_{1i}$	0		55.44	(0.32)	15.31	(0.06)
$(\Lambda)_{2i}$	0		−107.80	(0.26)	−8.91	(0.06)
$(\Lambda)_{3i}$	−12.38	(0.08)	−144.22	(0.45)	−73.07	(0.20)

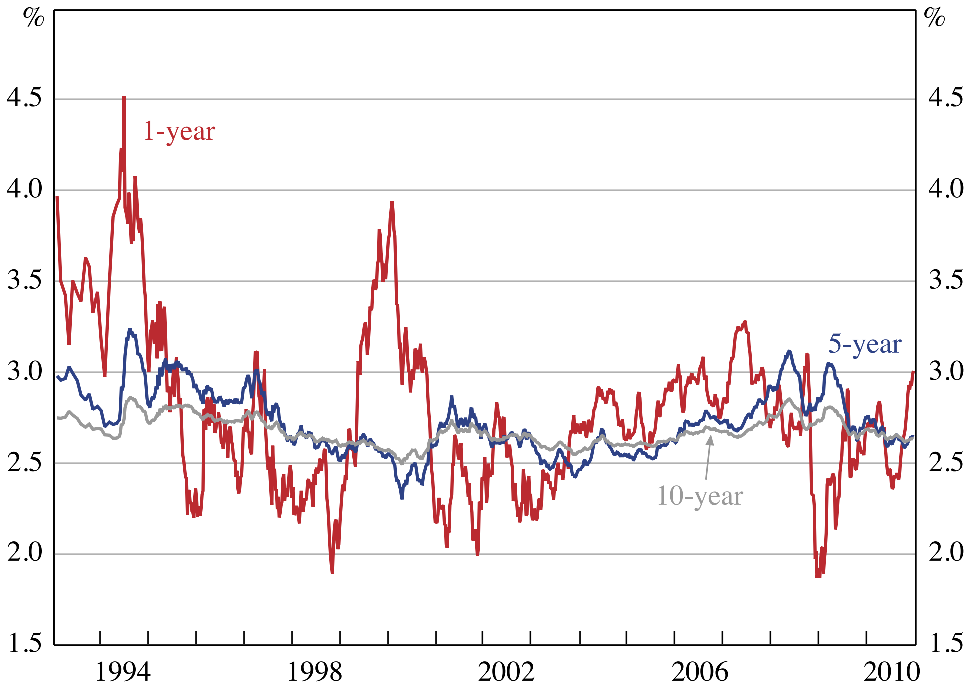
Notes: ρ_0 and $(\Sigma)_{ii}$ are given in percentage points. Standard errors are shown in parentheses.

4.2 Qualitative Discussion of Results

4.2.1 Inflation expectations

Our estimated expected future inflation rates at horizons of 1, 5 and 10 years are shown in Figure 2. Two points stand out immediately: 1-year-ahead inflation expectations are much more volatile than 5- and 10-year-ahead expectations and, as may be expected, are strongly influenced by current inflation (not shown); and longer-term inflation expectations appear to be well anchored within the 2 to 3 per cent target range.

Figure 2: Expected Inflation Rate



We see that there is a general decline in inflation expectations from the beginning of the sample until around 1999, the year before the introduction of the Goods and Services Tax (GST). The estimates suggest that the introduction of the GST on 1 July 2000 resulted in a large one-off increase in short-term inflation expectations. This is reflected in the run-up in 1-year-ahead inflation expectations over calendar year 1999, although the peak in the estimated expectations is below the actual peak in year-ended CPI growth of 6.1 per cent.[12] Of particular interest, however, is the non-responsiveness of 5- and 10-year-ahead expectations, which should be the case if the inflation target is seen as credible.

Long-term expectations increased somewhat between mid 2000 and mid 2001, perhaps prompted by easier monetary conditions globally as well as relatively high inflation in Australia. Interestingly, there appears to have been a sustained general rise in inflation expectations between 2004 and 2008 at all horizons. Again this was a time of rising domestic inflation, strong world growth, a boom in the terms of trade and rising asset prices.

12 The legislation introducing the GST was passed through Federal Parliament in June 1999.

In late 2008 the inflation outlook changed and short-term inflation expectations fell dramatically, likely in response to expectations of very weak global demand caused by the financial crisis. Longer-term expectations also fell, before rising over the early part of 2009 as authorities responded to the crisis. The subsequent moderation of longer-term expectations, as well as the relative stabilisation of short-term expectations, over 2010 suggests that financial market participants considered the economic outlook and Australian authorities' response to the crisis sufficient to maintain inflation within the target range.

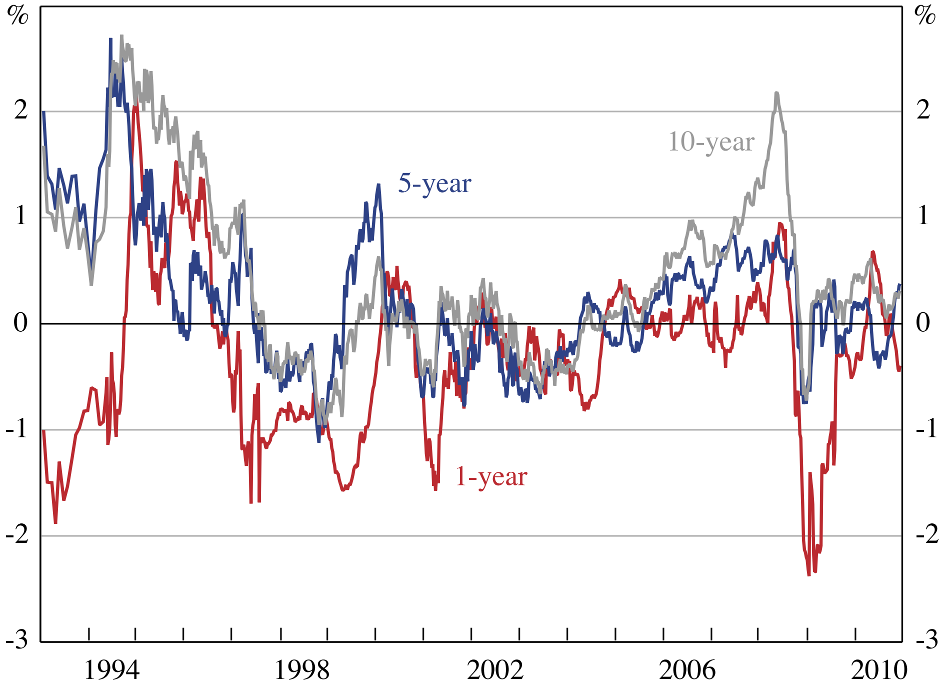
The latest data, corresponding to December 2010, show 1-year-ahead inflation expectations reaching 3 per cent, close to the Reserve Bank of Australia forecast for inflation of 2¾ over the year to December 2011 given in the November 2010 *Statement on Monetary Policy*. Longer-term model-implied inflation expectations as at December 2010 are for inflation close to the middle of the 2 to 3 per cent target range.

4.2.2 Inflation risk premia

Although more volatile than our long-term inflation expectation estimates, long-term inflation risk premia broadly followed the same pattern – declining over the first third of the sample, gradually increasing between 2004 and 2008 before falling sharply with the onset of the global financial crisis, then rising again as markets reassessed the likelihood of a severe downturn in Australia (Figure 3). The main qualitative point of difference between the two series is in their reaction to the GST. As discussed earlier, the estimates of long-term inflation expectations remained well-anchored during the GST period, whereas as we can see from Figure 3, the estimates of long-term risk premia rose sharply. As the terminology suggests, inflation expectations represent investors' central forecast for inflation, while risk premia can be thought of as representing second-order information – essentially how uncertain investors are about their central forecasts and how much they dislike this uncertainty. So while longer-dated expectations of inflation did not change around the introduction of the GST, the rise in risk premia indicates a more variable and uncertain inflation outlook.

Although our estimates show periods of negative inflation risk premia, indicating that investors were happy to be exposed to inflation risk, this is probably not the case in reality. In our model, inflation risk premia are given by forward rates

Figure 3: Inflation Risk Premia

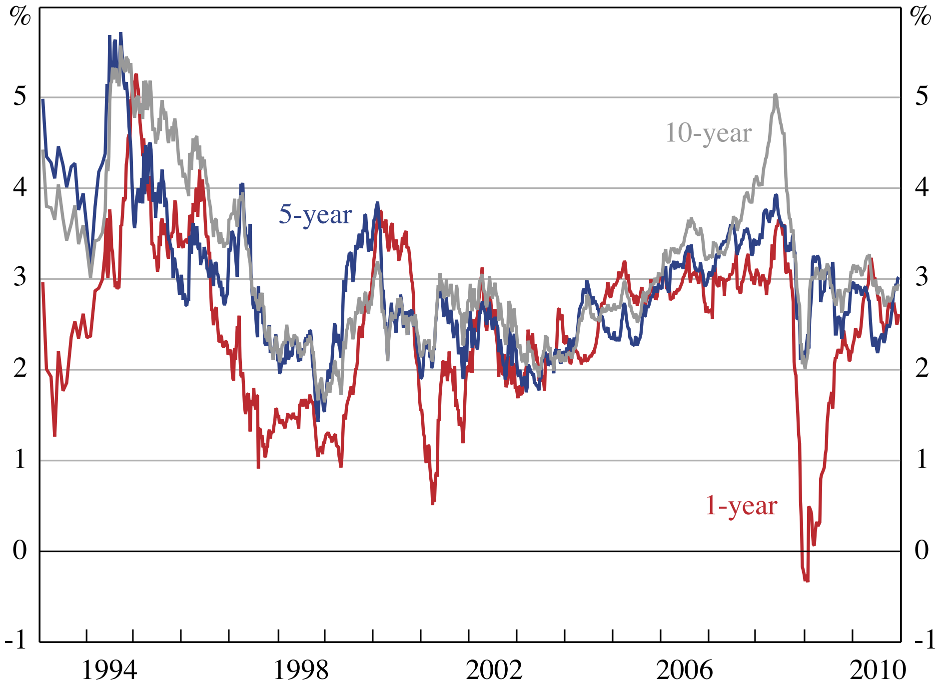


of inflation (as implied by the inflation yield curve) less inflation expectations. The inflation yield curve is given as the difference between nominal and real yields. Hence if real yields contain a liquidity premium, they will be higher, shifting the inflation yield curve down and reducing the estimated inflation risk premia to below their true level. The inflation-indexed bond market is known to be relatively illiquid in comparison to the nominal bond market and this provides a plausible explanation for our negative estimates. Note, however, that if the illiquidity in the inflation-indexed bond market is constant through time, then the level of the our estimated risk premia will be biased but *changes* in the risk premia should be accurately estimated. Market liaison suggests that an assumption of relatively constant liquidity is not an unreasonable one; as noted earlier for example, bid-ask spreads have stayed relatively constant over most of the period under consideration.

4.2.3 Inflation forward rates

The inflation forward rate reflects the relative prices of traded nominal and inflation-indexed bonds and is given by the sum of inflation expectations and inflation risk premia. As estimates of longer-term inflation expectations are relatively stable, movements in the 5- and 10-year inflation forward rates tend to be driven by changes in estimated risk premia. The inflation forward rate, as shown in Figure 4, generally falls during the first third of the sample, rises around the time of the GST, and rises between 2004 and 2008, before falling sharply with the onset of the financial crisis then rising again.[13]

Figure 4: Inflation Forward Rates



One notable feature of Figure 4 are the negative inflation forward rates recorded in late 2008. This phenomenon is essentially due to very low break-even inflation rates embodied in the bond price data (2-year-ahead nominal less real yields were only around 90 basis points at this time), together with high realised inflation over 2008 – as break-even inflation rates reflect around five months of historical

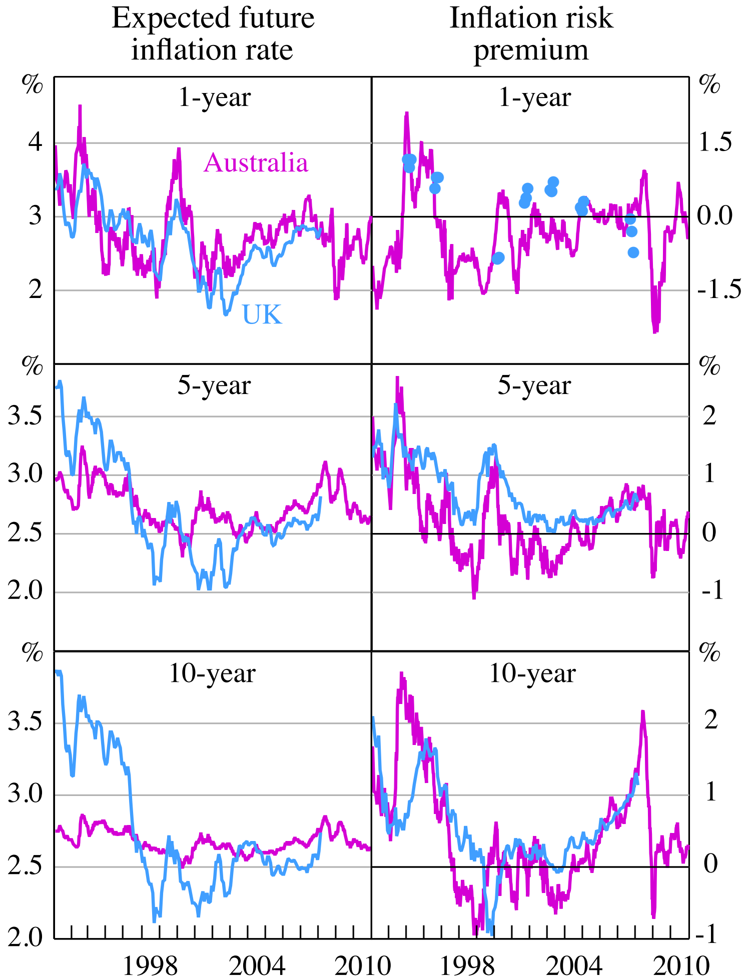
13 Note that studies using US and UK data essentially start with the inflation forward rate, which they decompose into inflation expectations and inflation risk premia. Due to a lack of data we cannot do this and instead estimate inflation forward rates as part of our model.

inflation, a low 2-year break-even inflation rate and high historical inflation necessarily implies a very low or even negative inflation forward rate in the near future. The low break-even inflation rates in turn are due to the yields on inflation-indexed bonds rising relative to the yields on nominal bonds. While it is possible that inflation forward rates were negative at this time, reflecting concern about the economic outlook, an alternative interpretation is that liquidity premia for inflation-indexed bonds increased (in line with increases in liquidity premia for most assets beyond highly rated and highly liquid government securities at this time). This would contradict our assumption of constant liquidity premia, and would result in indexed bond yields rising relative to (more liquid) nominal bond yields, and so in low inflation forward rates.

4.2.4 Comparisons with other studies

We compare our estimates of inflation expectations and inflation risk premia with those derived for UK data by Joyce *et al* (2010). In Figure 5, the 1-year-ahead inflation expectations in the United Kingdom and Australia are seen to display very similar trends. Interestingly, UK inflation expectations also increased over 1999, suggesting the spike in Australia may have been influenced by some global factors in addition to the introduction of the GST. At longer horizons there is greater difference between UK and Australian inflation expectations, with the United Kingdom in particular experiencing a large drop in 10-year-ahead expectations around 1997, the year that the Bank of England was granted independence. The magnitude of the changes in inflation risk premia are a little larger in Australia but the trends are broadly consistent in both countries (here UK inflation risk premia include the 'residual term' estimated by Joyce *et al* (2010), so that inflation expectations plus inflation risk premia equal the inflation forward rate, as is the case in our study).

Figure 5: Comparisons with UK Data



Note: UK inflation risk premia include residual term
Sources: Joyce *et al* (2010); authors' calculations

5. Discussion and Conclusion

The model just described is designed to give policy-makers accurate and timely information on market-implied inflation expectations. It has a number of advantages over existing sources for such data, which primarily constitute either break-even inflation derived from bond prices or inflation forecasts sourced from market economists.

As argued, break-even inflation as derived directly from bond prices has a number of drawbacks as a measure of inflation expectations: such a measure gives average inflation over the tenor of the bond, not inflation as at a certain date in the future; Government bonds in Australia are coupon-bearing, which means that yields of similar maturity nominal and inflation-indexed bonds are not strictly comparable; there are very few inflation-indexed bonds on issue in Australia which means that break-even inflation can only be calculated at a limited number of tenors which change over time; inflation-indexed bonds are indexed with a lag which means that their yields also reflect historical inflation, not just future expected inflation; and finally, inflation-indexed bond yields incorporate risk premia so that the level, and even changes in break-even inflation, need not give an accurate read on inflation expectations. Our model addresses each of these issues: we model inflation-indexed bonds as consisting of a stream of payments where the value of each payment is determined by nominal interest rates, historical inflation, future inflation expectations and inflation risk premia. This means we are able to produce estimates of expected future inflation at any time and for any tenor which are free of risk premia and are not effected by historical inflation.

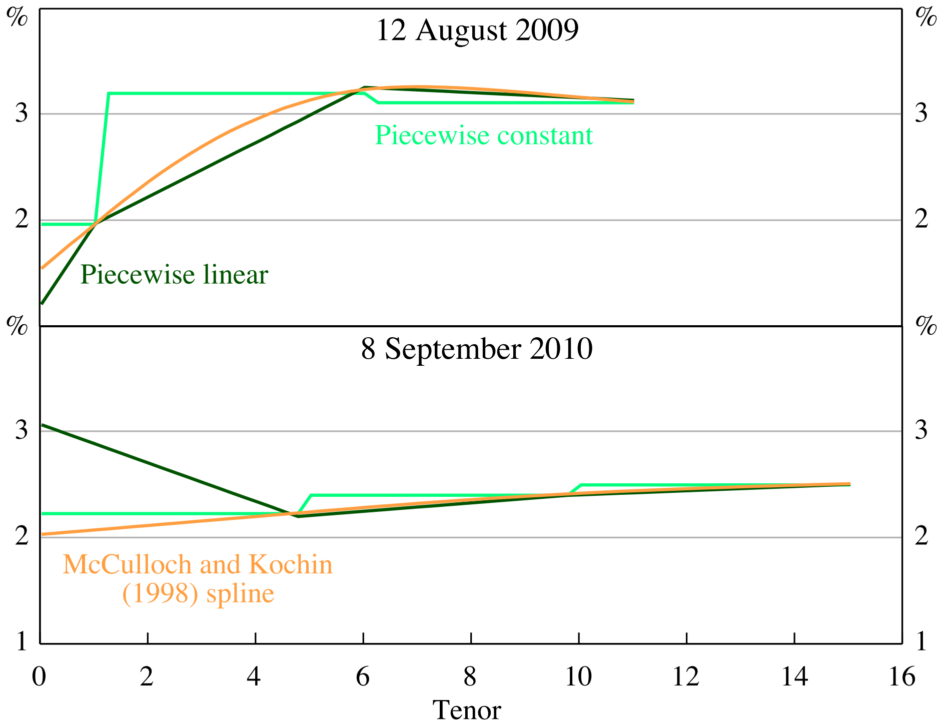
Model-derived inflation expectations also have a number of advantages over expectations from market economists: unlike survey-based expectations they are again available at any time and for any tenor; and they reflect the agglomerated knowledge of all market participants, not just the views of a small number of economists. By contrast, the main drawback of our model is its complexity – break-even inflation and inflation forecasts have their faults but are transparent and simple to measure, whereas our model, while addressing a number of faults, is by comparison complex and difficult to estimate.

Standard affine term structure models, which take as inputs zero-coupon yield curves and give as outputs expectations and risk premia, have existed in the literature for some time. Our main contribution to this literature, apart from the estimation of inflation expectations and inflation risk premia for Australia, is our reformulation of the model in terms of coupon-bearing bond prices instead of zero-coupon yields.

In practice zero-coupon yields are not directly available but must be estimated, so by fitting the affine term structure model directly to prices we avoid inserting a second arbitrary yield curve model between the data and our final model. When many bond prices are available this is only a small advantage as accurate zero-coupon yields can be recovered from the well-specified coupon-bearing yield curve. When only a small number of bond prices are available our method provides a major advantage – one can fit a zero-coupon yield curve to only two or three far-spaced coupon-bearing yields, and indeed McCulloch and Kochin (1998) provide a procedure for doing this, but there are limitless such curves that can be fitted with no *a priori* correct criteria to choose between them.

The inability to pin down the yield curve is highlighted in Figure 6 which shows three yield curves – one piecewise constant, one piecewise linear and starting from the current six-month annualised inflation rate, and one following the method of McCulloch and Kochin (1998) – all fitted to inflation-indexed bond yields on two different dates. All curves fit the bond data perfectly, as would any number of other curves, so there is nothing in the underlying data to motivate a particular choice, yet different curves can differ by as much as one percentage point. Our technique provides a method for removing this intermediate curve-fitting step and estimating directly with the underlying data instead of the output of an arbitrary yield curve model. The fact that we price bonds directly in terms of the underlying inflation process also allows for direct modelling of the lag involved in inflation-indexation and the impact that historically observed inflation has on current yields, a second major advantage.

Figure 6: Zero-coupon Real Yield Curves



In sum, the affine term structure model used in this paper addresses a number of problems inherent in alternative approaches to measuring inflation expectations, and produces plausible measures of inflation expectations over the inflation-targeting era. Given the complexity of the model and the limited number of inflation-indexed bonds on issue, some caution should be applied in interpreting the results. A key finding of the model is that long-term inflation expectations appear to have been well-anchored to the inflation target over most of the sample. Conversely, 1-year-ahead inflation expectations appear to be closely tied to CPI inflation and are more variable than longer-term expectations. Given the relative stability of our estimates of long-term inflation expectations, changes in 5- and 10-year inflation forward rates, and so in break-even inflation rates, are by implication driven by changes in inflation risk premia. As such, our measure has some benefits over break-even inflation rates in measuring inflation expectations.

Appendix A: Yields and Stochastic Discount Factors

The results of this paper revolve around the idea that inflation expectations are an important determinant of the inflation yield. In this appendix we make clear the relationships between real, nominal and inflation yields, inflation expectations and inflation risk premia. We also link these quantities to standard asset pricing models, as discussed, for example, in Cochrane (2005).

A.1 Real Yields and the Real SDF

Let M_t^r be the real SDF or pricing kernel, defined such that

$$P_{t,\tau} = \mathbb{E}_t\left(\frac{M_{t+\tau}^r}{M_t^r}\, x_{t+\tau}\right) \tag{A1}$$

holds for any asset, where $P_{t,\tau}$ is the price of the asset at time t which has (a possibly random) pay-off $x_{t+\tau}$ occurring at time $t+\tau$. A zero-coupon inflation-indexed bond maturing at time $t+\tau$ is an asset that pays one real dollar, or equivalently one unit of consumption, for certain. That is, it is an asset with payoff $x_{t+\tau} \equiv 1$. If we define the (continuously compounded) gross real yield by $y_{t,\tau}^r = -\log(P_{t,\tau}^r)$, that is, as the negative log of the inflation-indexed bond price, we can use Equation (A1) with $x_{t+\tau} = 1$ to write

$$y_{t,\tau}^r = -\log(P_{t,\tau}^r) = -\log\left(\mathbb{E}_t\left(\frac{M_{t+\tau}^r}{M_t^r}\right)\right). \tag{A2}$$

This defines the relationship between real yields and the continuous time real SDF.

A.2 Nominal Yields and the Nominal SDF

A zero-coupon nominal bond maturing at time $t+\tau$ is an asset that pays one nominal dollar for certain. If we define Q_t to be the price index, then the pay-off of this bond is given by $x_{t+\tau} = Q_t/Q_{t+\tau}$ units of consumption. For example, if the price level has risen by 10 per cent between t and $t+\tau$, so that $Q_{t+\tau} = 1.1 \times Q_t$, then the nominal bond pays off only $1/1.1 \approx 0.91$ units of consumption. Taking

$x_{t+\tau} = Q_t/Q_{t+\tau}$ in Equation (A1), we can relate the gross nominal yield $y^n_{t,\tau}$ to the nominal bond price $P^n_{t,\tau}$ and the continuous time real SDF by

$$y^n_{t,\tau} = -\log(P^n_{t,\tau}) = -\log\left(\mathbb{E}_t\left(\frac{M^r_{t+\tau}}{M^r_t}\frac{Q_t}{Q_{t+\tau}}\right)\right).$$

Motivated by this result, we define the continuous time *nominal* SDF by $M^n_{t+\tau} = M^r_{t+\tau}/Q_{t+\tau}$, so that

$$y^n_{t,\tau} = -\log(P^n_{t,\tau}) = -\log\left(\mathbb{E}_t\left(\frac{M^n_{t+\tau}}{M^n_t}\right)\right). \tag{A3}$$

A.3 Inflation Yields and the Inflation SDF

The inflation yield is defined to be the difference in yield between a zero-coupon nominal bond and a zero-coupon inflation-indexed bond of the same maturity

$$y^i_{t,\tau} = y^n_{t,\tau} - y^r_{t,\tau}. \tag{A4}$$

As in Beechey (2008), we define the continuous time *inflation* SDF, $M^i_{t+\tau}$, such that the pricing equation for inflation yields holds. That is, such that

$$y^i_{t,\tau} = -\log\left(\mathbb{E}_t\left(\frac{M^i_{t+\tau}}{M^i_t}\right)\right). \tag{A5}$$

All formulations of $M^i_{t+\tau}$ which ensure that Equations (A2), (A3) and (A4) are consistent with Equation (A5) are equivalent from the perspective of our model, since only inflation yields are seen by the model. One such formulation is to define the inflation SDF as

$$M^i_{t+\tau} = \frac{M^n_{t+\tau}}{\mathbb{E}_t(M^r_{t+\tau})}. \tag{A6}$$

We can then obtain Equation (A5) by substituting Equations (A2) and (A3) into Equation (A4) and using the definition of the inflation SDF given in Equation (A6).

In this case we have

$$\begin{aligned} y^i_{t,\tau} &= y^n_{t,\tau} - y^r_{t,\tau} \\ &= -\log\left(\mathbb{E}_t\left(\frac{M^n_{t+\tau}}{M^n_t}\right)\right) + \log\left(\mathbb{E}_t\left(\frac{M^r_{t+\tau}}{M^r_t}\right)\right) \\ &= -\log\left(\frac{M^r_t}{M^n_t}\mathbb{E}_t\left(\frac{M^n_{t+\tau}}{\mathbb{E}_t\left(M^r_{t+\tau}\right)}\right)\right) \\ &= -\log\left(\mathbb{E}_t\left(\frac{M^i_{t+\tau}}{M^i_t}\right)\right) \end{aligned}$$

as desired. If one assumed that $M^r_{t+\tau}$ and $Q_{t+\tau}$ were uncorrelated, a simpler formulation would be to take $M^i_{t+\tau} = 1/Q_{t+\tau}$. Since $M^n_{t+\tau} = M^r_{t+\tau}/Q_{t+\tau}$, in this case we would have $\mathbb{E}_t(M^n_{t+\tau}/M^n_t) = \mathbb{E}_t(M^r_{t+\tau}/M^r_t)\mathbb{E}_t(Q_t/Q_{t+\tau})$ so that $y^n_{t,\tau} = -\log(\mathbb{E}_t(M^r_{t+\tau}/M^r_t)) - \log(\mathbb{E}_t(Q_t/Q_{t+\tau}))$ and $y^i_{t,\tau} = y^n_{t,\tau} - y^r_{t,\tau} = -\log(\mathbb{E}_t(Q_t/Q_{t+\tau})) = -\log(\mathbb{E}_t(M^i_{t+\tau}/M^i_t))$ as desired.

A.4 Interpretation of Other SDFs in our Model

We model M^i_t directly as $\mathrm{d}M^i_t/M^i_t = -\pi^i_t\mathrm{d}t - \boldsymbol{\lambda}^{i\prime}_t\mathrm{d}\mathbf{B}_t$, where we take π^i_t as the instantaneous inflation rate and $\boldsymbol{\lambda}^i_t$ as the market price of inflation risk. Although very flexible, this set-up means that in our model the relationship between different stochastic discount factors in the economy is not fixed.

In models such as ours there are essentially three quantities of interest, any two of which determine the other: the real SDF, the nominal SDF and the inflation SDF. As we make assumptions about only one of these quantities we do not tie down the model completely. Note that we *could* make an additional assumption to tie down the model. Such an assumption would not affect the model-implied inflation yields or inflation forecasts however, which are the only data our model sees, and so in the context of our model would be arbitrary.

Note that this situation of model ambiguity is not confined to models of inflation compensation such as ours. The extensive literature which fits affine term structure models to nominal yields contains a similar kind of ambiguity. Such models typically take the nominal SDF as driven by $\mathrm{d}M^n_t/M^n_t = -r^n_t\mathrm{d}t - \boldsymbol{\lambda}^{n\prime}_t\mathrm{d}\mathbf{B}_t$, where once again the real SDF and inflation process are not explicitly modelled, so that, similar to our case, the model is not completely tied down.

A.5 Inflation Expectations and the Inflation Risk Premium

Finally, we link our inflation yield to inflation expectations and the inflation risk premium. The inflation risk premium arises because people who hold nominal bonds are exposed to inflation, which is uncertain, and so demand compensation for bearing this risk. If we set $m_{t,\tau} = \log(M^r_{t+\tau}/M^r_t)$ and $q_{t,\tau} = \log(Q_{t+\tau}/Q_t)$, which are both assumed normal, and use the identity $\mathbb{E}_t(\exp(X)) = \exp(\mathbb{E}_t(X) + \frac{1}{2}\mathbb{V}_t(X))$ where X is normally distributed and $\mathbb{V}(\cdot)$ is variance, we can work from Equation (A4) to derive

$$y^i_{t,\tau} = \mathbb{E}_t\left(q_{t,\tau}\right) - \frac{1}{2}\mathbb{V}_t(q_{t,\tau}) + \mathbb{C}\mathrm{ov}_t\left(m_{t,\tau}, q_{t,\tau}\right).$$

The first term above is the expectations component of the inflation yield while the last two terms constitute the inflation risk premium (incorporating a 'Jensen's' or 'convexity' term).

Appendix B: The Mathematics of Our Model

We first give some general results regarding affine term structure models, then relate these results to our specific model and its interpretation.

B.1 Some Results Regarding Affine Term Structure Models

Start with the latent factor process

$$\mathrm{d}\mathbf{x}_t = K(\boldsymbol{\mu} - \mathbf{x}_t)\mathrm{d}t + \Sigma\, \mathrm{d}\mathbf{B}_t.$$

Given $\mathbf{x}_t$ we have, for $s > t$ (see, for example, p 342 of Duffie (2001))

$$\begin{aligned}\mathbf{x}_s &= e^{-K(s-t)}\left(\mathbf{x}_t + \int_t^s e^{K(u-t)}K\boldsymbol{\mu}\mathrm{d}u + \int_t^s e^{K(u-t)}\Sigma\mathrm{d}\mathbf{B}_u\right)\\ &\overset{D}{=} e^{-K(s-t)}\mathbf{x}_t + (I - e^{-K(s-t)})\boldsymbol{\mu} + \boldsymbol{\varepsilon}_{t,s}\end{aligned} \tag{B1}$$

where $\overset{D}{=}$ denotes equality in distribution and $\boldsymbol{\varepsilon}_{t,s} \sim N(\mathbf{0}, \Omega_{s-t})$ with

$$\Omega_{s-t} = e^{-K(s-t)}\left(\int_t^s e^{K(u-t)}\Sigma\Sigma' e^{K'(u-t)}\mathrm{d}u\right)e^{-K'(s-t)} = \int_0^{s-t} e^{-Ku}\Sigma\Sigma' e^{-K'u}\mathrm{d}u.$$

Further, if we define

$$\pi_t = \rho_0 + \boldsymbol{\rho}'\mathbf{x}_t$$

then since $\int_t^{t+\tau}\pi_s\mathrm{d}s$ is normally distributed,

$$\mathbb{E}_t\left(\exp\left(-\int_t^{t+\tau}\pi_s\mathrm{d}s\right)\right) = \exp\left(-\mathbb{E}_t\left(\int_t^{t+\tau}\pi_s\mathrm{d}s\right) + \frac{1}{2}\mathbb{V}_t\left(\int_t^{t+\tau}\pi_s\mathrm{d}s\right)\right)$$

with

$$\begin{aligned}&\int_t^{t+\tau}\pi_s\mathrm{d}s = \int_t^{t+\tau}\rho_0 + \boldsymbol{\rho}'\mathbf{x}_s\mathrm{d}s\\ &= \int_t^{t+\tau}\rho_0 + \boldsymbol{\rho}'\left(e^{-K(s-t)}\mathbf{x}_t + \left(I - e^{-K(s-t)}\right)\boldsymbol{\mu} + e^{-K(s-t)}\int_t^s e^{K(u-t)}\Sigma\mathrm{d}\mathbf{B}_u\right)\mathrm{d}s\\ &= \int_t^{t+\tau}\rho_0 + \boldsymbol{\rho}'\left(e^{-K(s-t)}\mathbf{x}_t + \left(I - e^{-K(s-t)}\right)\boldsymbol{\mu}\right)\mathrm{d}s\\ &\qquad + \int_t^{t+\tau}\boldsymbol{\rho}'\left(\int_u^{t+\tau}e^{-K(s-t)}\mathrm{d}s\right)e^{K(u-t)}\Sigma\,\mathrm{d}\mathbf{B}_u\end{aligned} \tag{B2}$$

where we have used a stochastic version of Fubini's theorem to change the order of integration (see, for example, p 109 of Da Prato and Zabczyk (1992)). Evaluating the inner integral of line (B2), using Itô's Isometry (see, for example, p 82 of Steele (2001)) and making the change of variable $s = t + \tau - u$ we have

$$\mathbb{E}_t\left(\int_t^{t+\tau} \pi_s \mathrm{d}s\right) = \int_0^{\tau} \rho_0 + \boldsymbol{\rho}'\left(e^{-Ks}\mathbf{x}_t + \left(I - e^{-Ks}\right)\boldsymbol{\mu}\right)\mathrm{d}s$$

$$\mathbb{V}_t\left(\int_t^{t+\tau} \pi_s \mathrm{d}s\right) = \int_0^{\tau} \left(\boldsymbol{\rho}'\left(I - e^{-Ks}\right)K^{-1}\Sigma\right)^2 \mathrm{d}s$$

where for $\mathbf{x}$ a vector we define $\mathbf{x}^2 = \mathbf{x}'^2$ as the vector dot-product $\mathbf{x}'\mathbf{x}$. Hence

$$\begin{aligned}\mathbb{E}_t\left(\exp\left(-\int_t^{t+\tau} \pi_s \mathrm{d}s\right)\right) = \exp\Bigg(&-\int_0^{\tau} \boldsymbol{\rho}' e^{-Ks}\mathbf{x}_t \mathrm{d}s \\ &-\int_0^{\tau} \rho_0 + \boldsymbol{\rho}'\left(I - e^{-Ks}\right)\boldsymbol{\mu} - \frac{1}{2}\left(\boldsymbol{\rho}'\left(I - e^{-Ks}\right)K^{-1}\Sigma\right)^2 \mathrm{d}s\Bigg).\end{aligned}$$

Now for $M'_{1,\tau} = (I - e^{-K\tau})K^{-1}$ we have,

$$\int_0^{\tau} \boldsymbol{\rho}' e^{-Ks}\mathbf{x}_t \mathrm{d}s = \boldsymbol{\rho}'\left(I - e^{-Kt}\right)K^{-1}\mathbf{x}_t = \boldsymbol{\rho}' M'_{1,\tau}\mathbf{x}_t$$

while

$$\int_0^{\tau} \boldsymbol{\rho}'\left(I - e^{-Ks}\right)\boldsymbol{\mu}\mathrm{d}s = \boldsymbol{\rho}'\left(\tau I + e^{-K\tau}K^{-1} - K^{-1}\right)\boldsymbol{\mu} = \boldsymbol{\rho}'\left(\tau I - M'_{1,\tau}\right)\boldsymbol{\mu},$$

and

$$\begin{aligned}&\int_0^{\tau} -\frac{1}{2}\left(\boldsymbol{\rho}'\left(I - e^{-Ks}\right)K^{-1}\Sigma\right)^2 \mathrm{d}s \\ &\quad = -\frac{1}{2}\boldsymbol{\rho}' K^{-1}\left(\int_0^{\tau}\left(I - e^{-Ks}\right)\Sigma\Sigma'\left(I - e^{-K's}\right)\mathrm{d}s\right)K^{-1'}\boldsymbol{\rho} \\ &\quad = -\frac{1}{2}\boldsymbol{\rho}' K^{-1}\left(\tau\Sigma\Sigma' - \Sigma\Sigma' M_{1,\tau} - M'_{1,\tau}\Sigma\Sigma' + M_{2,\tau}\right)K^{-1'}\boldsymbol{\rho}\end{aligned}$$

where from Kim and Orphanides (2005) for example,

$$\begin{aligned}M_{2,\tau} &= \int_0^{\tau} e^{-Ks}\Sigma\Sigma' e^{-K's}\mathrm{d}s \\ &= -vec^{-1}\left(\left((K \otimes I) + (I \otimes K)\right)^{-1} vec\left(e^{-K\tau}\Sigma\Sigma' e^{-K'\tau} - \Sigma\Sigma'\right)\right).\end{aligned}$$

Putting this together we have

$$\mathbb{E}_t\left(\exp\left(-\int_t^{t+\tau}\pi_s \mathrm{d}s\right)\right) = \exp(-\alpha_\tau - \boldsymbol{\beta}'_\tau \mathbf{x}_t) \tag{B3}$$

with

$$\begin{aligned}\alpha_\tau &= \tau\rho_0 + \boldsymbol{\rho}'(\tau I - M'_{1,\tau})\boldsymbol{\mu} \\ &\quad - \frac{1}{2}\boldsymbol{\rho}'K^{-1}\left(\tau\Sigma\Sigma' - \Sigma\Sigma' M_{1,\tau} - M'_{1,\tau}\Sigma\Sigma' + M_{2,\tau}\right)K^{-1'}\boldsymbol{\rho} \qquad \text{(B4)} \\ \boldsymbol{\beta}_\tau &= M_{1,\tau}\boldsymbol{\rho}. \qquad \text{(B5)}\end{aligned}$$

Equivalent formula are available in Kim and Orphanides (2005).

B.2 Bond Price Formula

If we model the SDF according to

$$\begin{aligned}\mathrm{d}M_t/M_t &= -\pi_t \mathrm{d}t - \boldsymbol{\lambda}'_t \mathrm{d}\mathbf{B}_t \\ \pi_t = \rho_0 + \boldsymbol{\rho}'\mathbf{x}_t,\ \boldsymbol{\lambda}_t &= \boldsymbol{\lambda}_0 + \Lambda \mathbf{x}_t \\ \mathrm{d}\mathbf{x}_t &= K(\boldsymbol{\mu} - \mathbf{x}_t)\mathrm{d}t + \Sigma\, \mathrm{d}\mathbf{B}_t\end{aligned} \tag{B6}$$

then the price of a zero-coupon bond at t paying one dollar at $t+\tau$ is given by (see, for example, Cochrane (2005))

$$\begin{aligned}\mathbb{E}_t\left(\frac{M_{t+\tau}}{M_t}\right) &= \mathbb{E}_t\left(\exp\left(-\int_t^{t+\tau}\pi_t + \frac{1}{2}\boldsymbol{\lambda}'_t\boldsymbol{\lambda}_t \mathrm{d}t - \int_t^{t+\tau}\boldsymbol{\lambda}'_t \mathrm{d}\mathbf{B}_t\right)\right) \\ &= \mathbb{E}_t\left(\exp\left(-\int_t^{t+\tau}\pi^*_s \mathrm{d}s\right)\right) \qquad \text{(B7)}\end{aligned}$$

where π^*_s is like π_s in Equation (B6) above but with

$$\mathrm{d}\mathbf{x}_t = K^*(\boldsymbol{\mu}^* - \mathbf{x}_t)\mathrm{d}t + \Sigma\, \mathrm{d}\mathbf{B}_t$$

where $K^* = (K + \Sigma\Lambda)$ and $\boldsymbol{\mu}^* = K^{*-1}(K\boldsymbol{\mu} - \Sigma\boldsymbol{\lambda}_0)$. (Here π^*_s is the 'risk neutral' version of π_s.) Hence we can price bonds via Equation (B3) using K^* and $\boldsymbol{\mu}^*$ in place of K and $\boldsymbol{\mu}$ in Equations (B4) and (B5). We can write Equation (B7) as

$$\exp(-\alpha^*_\tau - \boldsymbol{\beta}^{*\prime}_\tau \mathbf{x}_t) = \mathbb{E}_t\left(\exp\left(-\int_t^{t+\tau}\pi^*_s \mathrm{d}s\right)\right).$$

In terms of the inflation yield from Equation (A5) this can be written as

$$y^i_{t,\tau} = \alpha^*_\tau + \boldsymbol{\beta}^{*\prime}_\tau \mathbf{x}_t.$$

B.3 Inflation Forecast Formula

Inflation expectations are reported in terms of percentage growth in the consumer price index, *not* average inflation (the two differ by a Jensen's inequality term). As such, expectations at time t of how the CPI will grow between time $s > t$ and time $s+\tau$ in the future correspond to a term of the form

$$\begin{aligned}
\mathbb{E}_t\left(\exp\left(\int_s^{s+\tau}\pi_u \mathrm{d}u\right)\right) &= \mathbb{E}_t\left(\mathbb{E}_s\left(\exp\left(-\int_s^{s+\tau}-\pi_u \mathrm{d}u\right)\right)\right) \\
&= \mathbb{E}_t\left(\exp\left(-\bar{\alpha}_\tau - \bar{\boldsymbol{\beta}}_\tau'\mathbf{x}_s\right)\right) \\
&= \exp\left(-\bar{\alpha}_\tau - \bar{\boldsymbol{\beta}}_\tau'\left(e^{-K(s-t)}\mathbf{x}_t + \left(I - e^{-K(s-t)}\right)\boldsymbol{\mu}\right) + \frac{1}{2}\bar{\boldsymbol{\beta}}_\tau'\Omega_{s-t}\bar{\boldsymbol{\beta}}_\tau\right)
\end{aligned}$$

where the last line follows since $\mathbf{x}_s|\mathbf{x}_t \sim N\left(e^{-K(s-t)}\mathbf{x}_t + \left(I - e^{-K(s-t)}\right)\boldsymbol{\mu}, \Omega_{s-t}\right)$. Here $\bar{\alpha}_\tau$ and $\bar{\boldsymbol{\beta}}_\tau$ are equivalent to α_τ and $\boldsymbol{\beta}_\tau$ from Equations (B4) and (B5) respectively but with the market price or risk $\boldsymbol{\lambda}_t$ set to zero and using $-\rho_0$ and $-\boldsymbol{\rho}$ in place of ρ_0 and $\boldsymbol{\rho}$. So if the CPI is expected to grow by 3 per cent between s and $s+\tau$ for example, we would have

$$\tau\log(1+3\%) = -\bar{a}_\tau - \bar{\boldsymbol{\beta}}_\tau'\left(e^{-K(s-t)}\mathbf{x}_t + \left(I - e^{-K(s-t)}\right)\boldsymbol{\mu}\right) + \frac{1}{2}\bar{\boldsymbol{\beta}}_\tau'\Omega_{s-t}\bar{\boldsymbol{\beta}}_\tau.$$

Appendix C: Central Difference Kalman Filter

The central difference Kalman filter is a type of sigma-point filter. Sigma-point filters deal with non-linearities in the following manner:

- First, a set of points *around* the forecast of the state is generated. The distribution of these points depends on the variance of the forecast of the state.
- The measurement equations (functions $H1(\mathbf{x}_t)$ and $H2(\mathbf{x}_t)$) are used to calculate a set of forecast observation points. This set of points is used to estimate a mean and variance of the data forecasts.
- The mean and variance of the data forecasts are then used to update the estimates of the state and its variance.

The algorithm we use is that of an additive noise central difference Kalman filter, the details of which are given below. For more detail on sigma-point Kalman filters see van der Merwe (2004).

Step 1: Initialise the state vector and its covariance matrix to their unconditional expected values,

$$\hat{\mathbf{x}}_0 = [0,0,0]'$$
$$P_{\mathbf{x}_0} = \Omega_\infty.$$

Step 2: Loop over $k = 1 : n$ where n is the length of our data set.

Step 2.k.1: Time-update equations:

$$\hat{\mathbf{x}}_k^- = e^{-\mathbf{K}d_k}\hat{\mathbf{x}}_{k-1}$$
$$\mathbf{P}_{\mathbf{x}_k}^- = e^{-\mathbf{K}d_k}\mathbf{P}_{\mathbf{x}_{k-1}}e^{-\mathbf{K}'d_k} + \Omega_{d_k}$$

where d_k is the time in years between data point k and data point $k-1$.

Step 2.k.2: Create the sigma points,

$$\boldsymbol{\chi}_k^0 = \hat{\mathbf{x}}_k^-$$
$$\boldsymbol{\chi}_k^i = \hat{\mathbf{x}}_k^- + \left(h\sqrt{\mathbf{P}_{\mathbf{x}_k}^-}\right)_i \qquad i = 1,\ldots,L$$
$$\boldsymbol{\chi}_k^i = \hat{\mathbf{x}}_k^- - \left(h\sqrt{\mathbf{P}_{\mathbf{x}_k}^-}\right)_i \qquad i = L+1,\ldots,2L$$

where $\left(\sqrt{P_{\mathbf{x}_k}^-}\right)_i$ is the ith column of the matrix square root of $P_{\mathbf{x}_k}^-$, L is the number of latent factors and h is the central difference step size, which is set to $\sqrt{3}$.

Step 2.k.3: Propagate the sigma points through the pricing functions $H1(\cdot)$ and $H2(\cdot)$. Let m_k be the number of observed inflation-indexed bond prices in period k. Let n_k be the number of observed inflation forecasts in period k. For each observed price $j = 1,\ldots,m_k$ we propagate each sigma point $\boldsymbol{\chi}_k^i$, $i = 0,\ldots,2L$ through the pricing function for bond j in period k, $H1_{k,j}(\cdot)$. For each observed forecast $j = m_k+1,\ldots,m_k+n_k$ we propagate each sigma point $\boldsymbol{\chi}_k^i$, $i = 0,\ldots,2L$ through the pricing function for forecast j in period k, $H2_{k,j}(\cdot)$. Denote the output by φ_k, which is a matrix of dimension n_k+m_k by $2L+1$ with elements

$$(\varphi_k)_{j,i} = \begin{cases} H1_{k,j}(\boldsymbol{\chi}_i) & i = 0,\ldots,2L, \quad j = 1,\ldots,m_k \\ H2_{k,j}(\boldsymbol{\chi}_i) & i = 0,\ldots,2L, \quad j = m_k+1,\ldots,m_k+n_k. \end{cases}$$

Denote the ith column of φ_k by $\boldsymbol{\varphi}_k^i$.

Step 2.k.4: Observation update equations. For weightings of

$$w_0^{(m)} = \frac{h^2-L}{h^2} \qquad w_i^{(m)} = \frac{1}{2h^2} \qquad \forall i \geq 1$$

$$w_i^{(c_1)} = \frac{1}{4h^2} \qquad w_i^{(c_2)} = \frac{h^2-1}{4h^4} \qquad \forall i \geq 1$$

the estimate of the price vector is given by a weighted average of the $\boldsymbol{\varphi}_k^i$s

$$\hat{\mathbf{y}}_k = \sum_{i=0}^{2L} w_i^{(m)} \boldsymbol{\varphi}_k^i$$

and the estimated covariance matrix of $\hat{\mathbf{y}}_k$ is given by

$$P_{\mathbf{y}_k} = \sum_{i=1}^{L} \left[w_i^{(c_1)} (\boldsymbol{\varphi}_k^i - \boldsymbol{\varphi}_k^{L+i})^{[2]} + w_i^{(c_2)} (\boldsymbol{\varphi}_k^i + \boldsymbol{\varphi}_k^{L+i} - 2\boldsymbol{\varphi}_k^0)^{[2]} \right] + R_k$$

where R_k is the covariance matrix of the noise present in the observed prices. Here $(\cdot)^{[2]}$ denotes the vector outer product.

Next the estimate of the covariance between the state estimate and the price estimate is given by

$$P_{\mathbf{x}_k\mathbf{y}_k} = \sqrt{w_1^{(c1)} P_{\mathbf{x}_k}^-}\left[\boldsymbol{\varphi}_k^{1:L} - \boldsymbol{\varphi}_k^{L+1:2L}\right]^T.$$

Step 2.k.5: Calculate the Kalman gain matrix G_k

$$G_k = P_{\mathbf{x}_k\mathbf{y}_k} P_{\mathbf{y}_k}^{-1}.$$

Step 2.k.6: Update the state estimates,

$$\hat{\mathbf{x}}_k = \hat{\mathbf{x}}_k^- + G_k\left(\mathbf{y}_k - \hat{\mathbf{y}}_k\right)$$
$$P_{\mathbf{x}_k} = P_{\mathbf{x}_k}^- - G_k P_{\mathbf{y}_k} G_k^T$$

where $\mathbf{y}_k$ is the vector of observed prices.

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Inflation Risk Premium: Evidence from the TIPS market

Olesya V. Grishchenko and Jing-zhi Huang

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Inflation Risk Premium: Evidence from the TIPS Market*

Olesya V. Grishchenko†
Federal Reserve Board
and
Jing-zhi Huang‡
Penn State University

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Abstract

In this paper we study the term structure of real interest rates, expected inflation and inflation risk premia using data on prices of Treasury Inflation Protected Securities (TIPS) over the period 2000-2008. The approach we use to estimate inflation risk premium is arbitrage free, largely model free, and easy to implement. We also make distinction between TIPS yields and real yields and take into account explicitly the three-month indexation lag of TIPS in the analysis. In addition, we propose a new liquidity measure based on TIPS prices. Accounting for it, we find that the inflation risk premium is time-varying: it is negative (positive) in the first (second) half of the sample period. The average 10-year inflation risk premium ranges from -16 to 10 basis points over the full sample depending on the proxy used for expected inflation. More specifically, the estimates of the 10-year inflation risk premium range between 14 and 19 basis points for 2004-2008 period.

JEL Classification: E31, E43, E44
Keywords: TIPS market, inflation risk premium, expected inflation, term structure of real rates

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†Division of Monetary Affairs, Federal Reserve Board, Washington, DC 20551; Olesya.V.Grishchenko@frb.gov
‡Smeal College of Business, Penn State University, University Park, PA 16802; jxh56@psu.edu

Inflation Risk Premium: Evidence from the TIPS Market

Abstract

In this paper we study the term structure of real interest rates, expected inflation and inflation risk premia using data on prices of Treasury Inflation Protected Securities (TIPS) over the period 2000-2008. The approach we use to estimate inflation risk premium is arbitrage free, largely model free, and easy to implement. We also make distinction between TIPS yields and real yields and take into account explicitly the three-month indexation lag of TIPS in the analysis. In addition, we propose a new liquidity measure based on TIPS prices. Accounting for it, we find that the inflation risk premium is time-varying: it is negative (positive) in the first (second) half of the sample period. The average 10-year inflation risk premium ranges from -16 to 10 basis points over the full sample depending on the proxy used for expected inflation. More specifically, the estimates of the 10-year inflation risk premium range between 14 and 19 basis points for 2004-2008 period.

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1 Introduction

Recently there has been a considerable interest in Treasury Inflation-Protected Securities (TIPS) amid concerns about inflation. For instance, according to a recent fund flows update from Morningstar, total net asset values of TIPS funds increased by more than 54% over the one-year period January 2009 - January 2010 and investors added $19.5 billion to TIPS funds during the same period. As we know, both the principal and coupon payments from TIPS are linked to the value of an official price index - the Consumer Price Index (CPI), and as such are denominated in real rather than nominal so TIPS can be considered to be almost free of inflation risk.[1] The difference between nominal Treasury and TIPS yields of equivalent maturities is known as a TIPS breakeven inflation rate and represents a compensation to investors for bearing inflation risk.[2] This compensation includes both expected inflation and the inflation risk premium due to inflation uncertainty. The focus of this study is to estimate the latter component based on TIPS breakeven rates.

Indeed, as Federal Reserve Board Chairman Bernanke (2004) stressed, estimating the magnitude of the inflation risk premium is important for the purpose of deriving the correct measure of market participants' expected inflation. Furthermore, having a good estimate of the inflation risk premium is important for both the demand and the supply sides of the economy. On the demand side, such a measure would allow investors to hedge effectively against inflation risk. On the supply side, this measure would allow the Treasury to tune the supply of TIPS. The former Federal Reserve Chairman Greenspan (1985) also emphasized the importance of the inflation risk premium: *"The real question with respect to whether indexed debt will save taxpayer money really gets down to an evaluation of the size and persistence of the so-called inflation risk premium that is associated with the level of nominal interest rates."*

[1] The qualifier "almost" is related to the fact that TIPS prices are adjusted based on the inflation index lagged three months rather than to a current inflation rate. We provide an estimate for the impact of the indexation lag on real yields later in the paper.

[2] As we make distinction between TIPS yields and real yields in this study, *a TIPS breakeven rate* here differs from *a breakeven inflation rate*. The latter is defined to be the difference between nominal and real yields with the same maturity, and sometimes referred to as *the inflation compensation* (see, e.g., Ang, Bekaert, and Wei (2008) and Gurkaynak, Sack, and Wright (2010)).

However, the inflation risk premium is not directly observable. The literature on estimating the magnitude and the volatility of the inflation risk premium is also rather limited. Furthermore, there seems no consensus so far on the magnitude of the inflation risk premium and those obtained in the literature have a wide range of values. For instance, some of the estimates, especially those based on a long sample period, are higher than perceived by the Federal Reserve. For instance, Bernanke (2004) comments that *"Estimates of the inflation risk premium for bonds maturing during the next five to ten years are surprisingly large, generally in a range between 35 and 100 basis points, depending on the time period studied."* On the other hand, estimates based on more recent and shorter sample periods tend to be lower. In addition to the time period studied, the nominal and real term structure models used may be another reason for the wide range of inflation risk premium estimates. Also, there are very few studies of inflation risk premium that are based on TIPS data, which is not surprising to certain extent because the TIPS market is relatively young.

In this paper, we extract the inflation risk premium from TIPS market prices, motivated by the insight of Bernanke (2004) that *"the inflation-indexed securities would appear to be the most direct source of information about inflation expectations and real rates."* The approach we use to estimate inflation risk premium is a "model free" one in the spirit of Evans (1998), and is arbitrage free. Furthermore, this estimation approach is easy to implement, takes nominal and TIPS yields as given, and does not assume any specifications of the nominal and real term structures. As such, the approach is especially useful for the purpose of obtaining estimates of inflation risk premium.

In our empirical analysis we implement the estimation approach using monthly yields on zero-coupon TIPS and nominal Treasury bonds of 5-, 7-, and 10-year maturities from the Federal Reserve (and also from Barclays Capital) over the period 2000-2008. Depending on the proxy used for expected inflation, we find that in the full sample the average 10-year inflation risk premium ranges from -16 to 10 basis points. Furthermore, the risk premium is found to be negative in the first half of our sample period and this appears to be due to a combination of illiquidity of TIPS and deflation scare in 2002-2003. However, we find that in the second half of the sample period, the inflation risk premium is significantly positive and the 10-year premium varies from 14 to 19 basis points, depending on the proxy used for expected inflation.[3] Inflation risk premium is also found to be considerably less volatile during the 2004-2008 period. This indicates that the monetary policy of the Fed has been credible in recent years and inflation expectations are well anchored.

In our analysis we make two adjustments to market prices of TIPS. First, we propose a new liquidity measure based on TIPS prices and provide a liquidity correction for the inflation risk premium. TIPS market is known to contain a sizable liquidity component especially during early years of its operation (see, e.g., Roll (2004), D'Amico, Kim, and Wei (2009), Pflueger and Viceira (2011)). For this reason TIPS yields are biased upward with respect to the true real yields, that are used in deriving inflation expectations. To measure TIPS liquidity we use an average fitting error of TIPS individual issues' yields with respect to the Svensson (1994) yield curve. Hu, Pan, and Wang (2010) provide a rationale for such a measure and apply it to nominal U.S. Treasury debt market. They argue that in times when capital is abundant the arbitrage forces smooth out the Treasury yield curve so the average fitting errors are low. On the other hand, at the times of scarce capital, investors have harder time to smooth out arbitrage trades and this results in relatively high fitting errors of the Treasury curve. We apply a similar reasoning to the TIPS market that the divergence of model and market prices represents a shortage of arbitrage capital on the TIPS market, and therefore, proxies for worsening liquidity market conditions.[4] Such a measure is attractive because it is based solely on TIPS prices that are also used in the computation of the inflation risk premium. We obtain that our liquidity measure does not exceed on average 6 basis points in our sample, but exhibits several significant spikes throughout the sample. Such increases (roughly 30∼35 b.p.) occur, for example, between 2002 and 2003 when the number of outstanding TIPS issues was particularly small. Our measure also shows a gradual increase from 2007 to the end of our sample, the end of 2008, when market conditions started to deteriorate significantly.

[3]When core CPI instead of CPI is used as a proxy for expected inflation, all inflation risk premium estimates are much higher and in the range of 40 to 50 basis points. This is not surprising because core inflation rate (with food and energy prices excluded) is much lower and less volatile.

[4]This measure is also closely watched by the Federal Reserve Board as a measure of a "normality" of TIPS market functioning.

Second, we make a distinction between TIPS yields and real yields in order to take into account explicitly the three-month indexation lag of TIPS in the analysis and provide a corresponding estimate. Such a difference between TIPS and real yields is largely ignored in the literature and especially in the financial media. We find that the magnitude of this correction ranges from about 0.03 b.p. for one-year TIPS yields to about 4.2 b.p. for 10-year TIPS. Although the magnitude for the latter looks small, it accounts for a significant portion of the estimated inflation risk premium over long horizons.

To summarize, the main contribution of our study to the literature is to show that we can obtain estimates of inflation risk premium (in the range of 14∼19 b.p.) with data on TIPS and nominal yields, using a simple and easy-to-implement method that is arbitrage free and that otherwise imposes no restrictions on real and nominal term structures.

The rest of the paper is organized as follows. Section 2 discusses the studies that form the background for our paper. Section 3 provides an overview of the TIPS market and describes the data used in our empirical analysis. Section 4 describes the methodology. Section 5 presents estimation results for real yields, expected inflation, the inflation risk premium, and compares our results with those in existing studies. Finally, Section 6 concludes.

2 Literature review

Campbell and Shiller (1996) pioneer the approach obtaining estimates of the inflation risk premium using the information from nominal yields (before the arrival of TIPS). Their estimates of the inflation risk premium based on the nominal term premium are between 50 and 100 b.p. Campbell and Viceira (2001) estimate that the inflation risk premium is 35 b.p. in a three-month T-bill and slightly over 1.1% for the 10-year horizon using data on nominal bond prices and inflation over the period 1952-1996. Buraschi and Jiltsov (2005) analyze both nominal and real risk premia of the U.S. term structure of interest rates based on the structural monetary version of a real business cycle model. They find that the 10-year inflation risk premium is on average 0.7% and varies from 0.2% to 1.4% over a 40-year period. Ang, Bekaert, and Wei (2008) develop a three-factor regime-switching term structure model and estimate the model using nominal rates and inflation data over the period 1952-2004. They document that the unconditional real yield curve is fairly flat around 1.3% but the term structure of inflation risk premium is upward sloping. In addition, they find that the unconditional five-year inflation risk premium is 1.14% on average, but its estimates vary with regimes from 0.42% (in the high real rate regime) to 1.25% (in a regime with higher and more volatile inflation). They also find that the inflation risk premium declined to 0.15% in deflation-scare period after the 2001 recession but started to bounce back to about 1% in December 2004, the end of the sample. Chernov and Mueller (2011) find that inflation risk premia can be positive or negative in their proposed model of the term structure of inflation expectations. Specifically, the premium ranges from 0.2% for one-year to 2% for 10-year maturity when the model is augmented with inflation forecasts from surveys but the range of the estimate becomes -0.07% to -0.3% when no forecast data are used in the model estimation.

Among recent studies using TIPS data, D'Amico, Kim, and Wei (2009) consider a three- and four-factor Gaussian term structure model of interest rates and inflation. They estimate the model using realized inflation series, nominal and TIPS yields, as well survey forecasts of short rates. Their estimates of the inflation risk premium are negative and in the range of -1% to -50 b.p. when no liquidity factor is taken into account. However, when the fourth (liquidity) factor is introduced, inflation risk premium estimates become positive and in the range of 0 and 1%, where its magnitude depends on whether liquidity factor is correlated with other factors or not. Adrian and Wu (2010) fit an eight-factor term structure model to both nominal and real yields and also find that the inflation risk premium can be negative. Haubrich, Pennacchi, and Ritchken (2011) estimate a term structure model of real and nominal yields using data on nominal Treasury yields, survey forecasts of inflation, and inflation swap rates. Their estimated 10-year inflation risk premium is between 28 and 62 basis points, and on average 48 basis points over the sample period 1982-2009.

Campbell, Shiller, and Viceira (2009) argue that TIPS risk premia should be low or even negative. D'Amico, Kim, and Wei (2009) and Wright (2009) reason that the risk premium ought to be positive. Evans (1998) notes that, in general, the inflation risk premium can be positive or negative depending on how the real pricing kernel covaries with inflation. Taking a similar view, Hördahl and Tristani (2007) argue that this correlation translates into a correlation between consumption growth and inflation in some simple models and is negative, implying positive inflation risk premium.[5] However, they note that more general models do not necessary result in this simple intuition because in this case the pricing kernel depends on the marginal utility of consumption, not necessarily proportional to consumption growth. In particular, Hördahl, Tristani, and Vestin (2007) calibrate a general equilibrium model with habit persistence and nominal rigidities and find that the inflation risk premium is positive and small around one-year maturity and essentially zero for all other maturities.

Campbell, Shiller, and Viceira (2009) provide a detailed and comprehensive overview of inflation-indexed markets in the U.S. and also in the U.K. In another recent comprehensive survey paper, Bekaert and Wang (2010) note that the estimates of the inflation risk premium in the literature vary depending on the data, models, and methods used. As such, there appears no consensus so far in the literature as to not only the magnitude of the inflation risk premium but also its sign.

Our study complements the aforementioned studies on the inflation risk premium in that we can obtain estimates of the premium using a simple and easy-to-implement method that also takes into account the impact of the indexation lag in TIPS on real yields.[6] These estimates are substantially lower than those obtained by Campbell and Shiller (1996), Campbell and Viceira (2001), Buraschi and Jiltsov (2005), Ang, Bekaert, and Wei (2008), and Haubrich, Pennacchi, and Ritchken (2011), as well as by D'Amico, Kim, and Wei (2009).

Our inflation risk premium estimates are liquidity corrected ones. The literature on TIPS liquidity is quite scarce as of now, as the market itself is quite recent. D'Amico et al. provide a measure of liquidity premium by introducing a separate (fourth) factor into their term structure model of nominal and real yields. By decomposing liquidity component into deterministic part and stochastic part they find that deterministic trend went down from

[5]They find that in the U.S. data such a correlation is -0.15 over the 1960-1997 period.

[6]As noted earlier, this method is in the spirit of Evans (1998), who obtains the indexation-lag correction in the real yields using data on U.K. inflation-index bonds (but does not estimate the inflation risk premium). In a concurrent study, Haubrich, Pennacchi, and Ritchken (2011) also includes an indexation lag in the valuation of inflation-adjusted bonds.

120 basis points in 1999 to roughly 10 basis points in 2004 with the stochastic component fluctuating between -50 to 50 basis points. Pflueger and Viceira (2011) use a regression-based approach to estimate liquidity premium. Among their proxies are transaction volume for TIPS, the financing cost for buying TIPS, the 10-year nominal off-the-run spread and the Ginnie Mae (GNMA) spread. Overall, they find that liquidity component varies between 40 and 70 basis points.

However, the results in these studies may not be directly comparable to ours due to differences in sample periods, estimation methods, and data sets used. In particular, our estimates are extracted from TIPS over a more recent and relatively low inflation period. Moreover, we stop our sample in October 2008, the beginning of the financial crisis, to get inflation risk premium estimates during "normal" market functioning period. D'Amico, Kim, and Wei (2009) also do not include data beyond March 2007. Gurkaynak and Wright (2010) document that comparable maturity bonds were trading at quite different prices in November and December of 2008 (see Figure 7 in their paper). Fleckenstein, Longstaff, and Lustig (2010) also document that TIPS market during that period represented exceptional arbitrage opportunities and that prices were far from being rational ones. These considerations might potentially complicate the inference about inflation risk premium, the focus of our paper.[7]

3 Data description

In this section we first provide a brief review of the TIPS market and then describe the TIPS and inflation data sets used in our analysis.

Treasury Inflation-Protected Securities (TIPS) were first issued by the U.S. Treasury Department in 1997. Although initially called TIPS, inflation-indexed bonds are now officially referred to as Treasury Inflation Indexed Securities. Nevertheless, market participants

[7]A few studies use TIPS data but do not focus on the inflation risk premium. For instance, Jarrow and Yildirim (2003) and Chen, Liu, and Cheng (2010) estimate term structure models using TIPS data. Kothari and Shanken (2004), Roll (2004), Huang and Zhong (2010), and Campbell, Shiller, and Viceira (2009) examine diversification benefits of TIPS. The latter two provide further evidence on negative correlations between TIPS and stock returns. For instance, Huang and Zhong document that the dynamic conditional correlation of Engle (2002) between TIPS and the S&P 500 index is mostly negative during the period 1999-2005 and that the unconditional correlation between the two asset classes is -0.18 over the same period. Campbell, Shiller, and Viceira show that TIPS and the CRSP Value-Weighted Index are predominantly negatively correlated over the 1999-2009 period.

keep calling these instruments TIPS, so we retain this abbreviation for our study. The first inflation-indexed debt issue had a maturity of 10 years. Since then the Treasury has been issuing regularly additional 10-year debt, and 5-, 20-, and 30-year debt irregularly. However, the 20-year maturity is replaced by the new 30-year maturity in February 2010. Currently the U.S. Treasury auctions 5-year TIPS in April and October, 10-year TIPS in January, April, July, and October, and 30-year TIPS in February and August.

The TIPS market has been growing significantly since its inception. It is now the world's largest inflation-indexed securities market with over $550 billion of TIPS outstanding and an average daily turnover over $5 billion, and accounts for about 8% of Treasury's marketable debt portfolio (by the Treasury Department's own estimate). To put all this in a perspective, the TIPS market had $450 billion of outstanding, representing roughly 10% of Treasury debt, and an average daily turnover over $8 billion, in September 2007.

Our sample period extends from January 2000 to September 2008. Although data on TIPS before 2000 are also available, we do not include them in the sample due to concerns of the low liquidity in the TIPS market prior to 2000. It is believed that liquidity problems plagued this market in its early period (see, e.g., Roll (2004), Shen (2006), and D'Amico, Kim, and Wei (2009)). In fact, at one time in May 2001 the Treasury Advisory Committee of the Bond Market Association even recommended the TIPS program to be discontinued. We use smoothed data on monthly zero-coupon yields of 5-, 7-, and 10-year maturities for both TIPS and nominal Treasury bonds constructed by Gurkaynak, Sack, and Wright (2010) (hence, GSW data) and pulled from the public website of the Federal Reserve Board.[8] We have also used TIPS data set from Barclays Capital Bank in some earlier drafts of the paper before the GSW data set became available to general public in 2008. The results are essentially identical so we report only the results based on the GSW data in the analysis that follows. The end point of our sample is motivated by the fact that bond market conditions have deteriorated significantly with in the end of 2008, especially in November and December of 2008, so we have excluded last quarter of 2008 from our sample. Gurkaynak and Wright (2010) discuss bond market functioning around this period.

[8]For construction of this data, see Gurkaynak, Sack, and Wright (2010).

Panels A and B of Figure 1 plot monthly term structure of nominal Treasury bonds and TIPS, respectively. Observe from the figures that essentially, both nominal and TIPS yields decrease steadily since the beginning of our sample period until 2004. The period of low long-term rates between 2004 and 2006 is often called "conundrum," referring to the fact that the increase in the short-term rates did not lead to a consequent increase in the long-term rates. (The Federal Open Market Committee increased the federal funds rate 17 times from 1% up to 5.25% between June 2004 and June 2006.) The mild increase in nominal and TIPS long-term rates in 2006 and 2007 is associated with the lower volatility of interest rates than in the first half of our sample. Panel C of Figure 1 shows the TIPS breakeven rate defined as the difference between 10-year nominal and TIPS zero-coupon yields. Clearly, the breakeven rate is relatively low and volatile in the first half of the sample and relatively high and less volatile in the second half.

To calculate the inflation risk premium, we need to estimate expected inflation. Our first proxy for expected inflation is the unconditional estimate of inflation forecasts based on two measures of realized inflation. One is the seasonally-unadjusted Consumer Price Index for All Urban Consumers (CPI-U), to which TIPS are linked, and the other is the core CPI (Consumer Price Index Excluding Food and Energy). (We use CPI-U and CPI interchangeably in the paper.)

To construct the second proxy for expected inflation, we entertain a Vector Autoregression (VAR) model to estimate expected inflation, following Ang and Piazzesi (2003) and Chernov and Mueller (2011). We include in the VAR real activity and inflation variables. Real activity variables include the log growth rates of $HELP$ - Index of Help Wanted Advertising in the Newspapers, $EMPLOY$ - civil U.S. employment, IP - industrial production index IP, and, finally, UE - the unemployment rate. This represents the standard list of variables used in monthly VARs in macroeconomic literature (see, e.g. Ang and Piazzesi (2003)). Realized inflation variables used in our VAR include are available on monthly basis. In particular, we include the seasonally-unadjusted consumer price index CPI, the Core CPI, and the production price index inflation rate PPI in our VAR regression.

The third proxy for expected inflation we use is surveys of inflation forecasts. This is motivated by Ang, Bekaert, and Wei (2007), who find that survey measures forecast inflation the best. One proxy we use is from the Survey of Professional Forecasters (SPF) conducted by the Federal Reserve Bank of Philadelphia every quarter and the other is the Blue Chip Forecasts provided by Aspen Publishers.[9] SPF forecasts of one- and 10-year ahead inflation are available on a quarterly basis while one-year ahead Blue Chip forecasts are available monthly.

Blue Chip inflation forecasts are not reported in a conventional way. Blue Chip Forecasts of Financial and Economic Indicators represent consensus forecasts of about 50 professional economists in the leading financial and economic advisory firms, and investment banks each month. The survey contains the forecasts of key financial and macroeconomic indicators, including the CPI inflation (inflation hereafter). In particular, Blue Chip Economic Indicators provide monthly estimates of one-year inflation forecast for both the current year and the next year. For instance, in January 1999, Blue Chip provides the expected inflation for both 1999 and 2000. In February 1999, survey participants also provide inflation forecasts for 1999 and 2000, but the forecast horizon is actually 11 months for 1999 and 23 months for 2000. In December 1999, analysts again provide forecasts of the 1999 and 2000 year inflation albeit with a forecast horizon of only one month for 1999 and 13 months for 2000. This feature of the survey results in a time-varying forecast horizon for any variable in question. In our empirical analysis we need monthly forecasts for a fixed horizon. For instance, in February 1999 we need a one-year ahead inflation forecast, but the Blue Chip Survey has only 11-month and 23-month ahead forecasts available. Therefore, we obtain monthly fixed horizon forecast by performing linear interpolations. Similar interpolations are performed in Chun (2011).

We now proceed to the summary statistics of the data used in our empirical analysis, reported in Table 1. The term structure of both nominal and TIPS yields is upward sloping. Average TIPS yields in our sample are between 2.09% and 2.49% for 5- and 10-year index-linked bonds, respectively (Panel A). Average nominal yields are between 4.13% (5-year

[9] We do not use the Livingston Survey because it is conducted only twice a year and, unlike other surveys, participants of this one are asked to provide their forecasts of 6- and 12-month ahead inflation only.

yields) and 4.82% (10-year yields) in our sample (Panel B). This indicates that the breakeven rate is between 2.04% and 2.33% depending on the maturity. As we mentioned earlier, the breakeven rate is also quite volatile (see Panel C of Figure 1).

Panel C of Table 1 reports statistics of various realized and expected inflation measures. The average realized CPI-based inflation is 2.89% with 0.94% volatility during our sample period, while the average realized core inflation is 2.20% and naturally, has a much lower volatility of only 0.42%, because Core index excludes very volatile energy and food prices. In addition, we report the statistics for Producer Price Index inflation, the variable that we use in the VAR estimation of expected inflation. On average, PPI inflation is 3.24% with 2.57% volatility. Next, we report the descriptive statistics for the Survey of Professional Forecasters (SPF) and Blue Chip Economic Indicators (BCF). SPF includes one- and 10-year forecasts of seasonally-unadjusted CPI and BCF produces one-year ahead CPI forecasts. The SPF forecasts are available quarterly, while BCF forecasts are available monthly. The average forecast of a 10-year CPI inflation rate reported by SPF is 2.49% per year with a standard deviation of only 0.04%. This allows us to proxy the SPF 10-year expected inflation by a single number, 2.5%. The average BCF one-year ahead forecast of the CPI-based inflation is 2.52% with a standard deviation of 0.45%. Note that this one-year forecast is higher than the forecast reported by SPF. Overall, summary statistics reported in Panel C indicates that the measures of realized and expected inflation far exceed the breakeven inflation.

Panel D reports sample summary statistics of the real activity variables that we use in our VAR(1) model for estimating expected inflation. All growth rates in Table 1 are the log differences of the index levels at time t and $t - 12$.

4 Methodology

We compute the inflation risk premium as the difference between the nominal-real yield spread and expected inflation. To proceed, we need to estimate both real yields and expected inflation. Notice that TIPS rates are not (true) real rates because TIPS coupon and principal payments are linked to the three-month lagged inflation index, rather than the current inflation index level.[10] In this section, we first establish a relationship between three term structures: the term structure of nominal rates, the TIPS term structure, and the term structure of real rates, that would allow us to estimate the latter rates. We then present three alternative proxies for expected inflation.

4.1 Notation

Before proceeding with our analysis, we define our notation as follows:

Nominal bonds. Let $Q_t(h)$ denote the time-t nominal price of a zero-coupon bond paying \$1 at period $t+h$. Then the continuously compounded yield on a bond of maturity h is given by

$$y_t(h) = -\frac{1}{h} \ln Q_t(h), \tag{1}$$

and the k-period nominal forward rate from (t+h) to (t+h+k) is given by

$$F_t(h,k) = \left[\frac{Q_t(h)}{Q_t(h+k)}\right]^{1/k} - 1. \tag{2}$$

Real bonds. Let $Q_t^R(h)$ denote the nominal price of a zero-coupon bond at period t paying $\$(P_{t+h}/P_t)$ at period $t+h$, where P_t is the (known) price level at t. $Q_t^R(h)$ also defines the real price of one consumption bundle at $t+h$. By definition, such a bond completely indexes against future movements in price levels h periods ahead. It then follows that the continuously compounded real yield on a bond of maturity h and the k-period forward rates are respectively given by

$$y_t^R(h) = -\frac{1}{h} \ln Q_t^R(h) \quad \text{and} \quad F_t^R(h,k) = \left[\frac{Q_t^R(h)}{Q_t^R(h+k)}\right]^{1/k} - 1. \tag{3}$$

Bonds with incomplete indexation. Let $Q_t^{IL}(h)$ denote the nominal price of an index-linked (IL) zero-coupon bond at period t paying $\$(P_{t+h-l}/P_t)$ at period $t+h$, where $l > 0$ is the indexation lag. When $h = l$, then such a bond pays out \$1 at maturity. Therefore, we have $Q_t(l) = Q_t^{IL}(l)$ in the absence of arbitrage. The yields and forward rates of IL bonds

[10] Sometimes this indexation lag is viewed to be two and a half months because CPI is released with a two-week delay. This does not make material difference to our results.

are as follows:

$$y_t^{IL}(h) = -\frac{1}{h} \ln Q_t^{IL}(h) \quad \text{and} \quad F_t^{IL}(h,k) = \left[\frac{Q_t^{IL}(h)}{Q_t^{IL}(h+k)}\right]^{1/k} - 1. \tag{4}$$

The TIPS indexation lag is three months, so $l = 3$ in our case.

4.2 Nominal, real, and index-linked term structure

We now proceed to establish the relationship between nominal, IL, and real prices: Q_t, Q_t^{IL}, and Q_t^R, using the stochastic discount factor approach in the spirit of Evans (1998). We assume that the price index P_t for the month t is known at the end of the period t. This seems to be a reasonable approximation of the US data since the index is published with a two-week delay only.

It is known that in the absence of arbitrage opportunities, there exists a stochastic discount factor M_{t+1} such that the one-period nominal returns for all traded assets, $i = 1, \ldots, N$, are given by

$$E_t[M_{t+1} R_{i,t+1}] = 1, \tag{5}$$

where $R_{i,t+1}$ is the gross return on asset i between t and $t+1$, and $E_t(\cdot)$ is the expectation conditional on the information set at time t. Namely, we have for $h > 0$:

$$Q_t(h) = E_t[M_{t+1} Q_{t+1}(h-1)]. \tag{6}$$

It also follows from (5) that

$$Q_t^R(h) = E_t[M_{t+1}^R Q_{t+1}^R(h-1)], \tag{7}$$

where $M_{t+1}^R = M_{t+1} \times \frac{P_{t+1}}{P_t}$. We can obtain the price of an IL claim in a similar fashion. Given that $Q_t(l) = Q_t^{IL}(l)$, we need prices only for IL claims with maturities $h > l$. It is straightforward to show that

$$Q_t^{IL}(h) = E_t[M_{t+1}^R Q_{t+1}^{IL}(h-1)]. \tag{8}$$

Let lowercase letters stand for the natural logarithms of their uppercase counterparts, e.g. $q_t(h) = \ln Q_t(h)$ and $m_t = \ln M_t$. Log-linearizing equations (6), (7), and (8), and applying $Q_t(0) = Q_t^R(0) = 1$, we have:

$$q_t(h) = E_t\left[\sum_{i=1}^{h} m_{t+i}\right] + \frac{1}{2}\text{Var}_t\left(\sum_{i=1}^{h} m_{t+i}\right), \tag{9}$$

$$q_t^R(h) = E_t\left[\sum_{i=1}^{h} m_{t+i}^R\right] + \frac{1}{2}\text{Var}_t\left(\sum_{i=1}^{h} m_{t+i}^R\right), \tag{10}$$

$$\begin{aligned} q_t^{IL}(h) &= E_t\left[\sum_{i=1}^{\tau} m_{t+i}^R + q_{t+\tau}(l)\right] + \text{Cov}_t\left(\sum_{i=1}^{\tau} m_{t+i}^R, q_{t+\tau}(l)\right) \\ &\quad + \frac{1}{2}\left[\text{Var}_t\left(\sum_{i=1}^{h} m_{t+i}^R\right) + \text{Var}_t(q_{t+\tau}(l))\right], \end{aligned} \tag{11}$$

where $\tau \equiv h - l$, $\text{Var}_t(\cdot)$ and $\text{Cov}_t(\cdot,\cdot)$ represent the time-t conditional variance and covariance, respectively. The equations are approximations in general, but hold exactly if the joint distribution for $\{M_{t+j}, P_{t+i+1}/P_{t+i}\}_{j>0,i>0}$ conditional on the period t information is log normal.

4.3 Term structure of real interest rates

Now let $\Delta^\tau p_{t+\tau} \equiv \ln(P_{t+\tau}/P_t)$, and, in particular, $\Delta p_{t+1} = \ln(P_{t+1}/P_t)$. Using (9), (10), (11), and the definition of $m_{t+1}^R \equiv m_{t+1} + \Delta p_{t+1}$, we can link the log prices of nominal, real, and IL bonds by the following formula:

$$q_t^{IL}(h) = q_t^R(\tau) + [q_t(h) - q_t(\tau)] + \gamma_t(\tau), \quad \tau = h - l \tag{12}$$

where $\gamma_t(\tau)$ represents the conditional covariance between the $\tau-$period future inflation and future nominal prices as the following:

$$\gamma_t(\tau) \equiv \text{Cov}_t(q_{t+\tau}(l), \Delta^\tau p_{t+\tau}). \tag{13}$$

Eq. (13) shows that the log price of real bonds is not only a function of nominal prices and IL prices, but also depends on $\gamma_t(\tau)$ that represents the compensation for the risk of high inflation. By no-arbitrage condition, the IL bond prices depend on future nominal bond prices $q_{t+\tau}(l)$, and this affects the choice between real and IL bonds. In the periods of high expected inflation, future nominal prices drop and this causes negative $\gamma_t(\tau)$. Therefore, IL bonds will sell at a discount (compared to real bonds) to compensate for this risk.

In order to derive the estimates of the real term structure, we rewrite Eq. (12) in terms of yields. Let $y_t(h)$, $y_t^R(h)$, and $y_t^{IL}(h)$ be the continuously compounded yields for nominal, real, and IL bonds, respectively. It follows that:

$$y_t^R(\tau) = \frac{h}{\tau} y_t^{IL}(h) - \frac{l}{\tau} f_t(\tau, l) + \frac{1}{\tau}\gamma_t(\tau). \tag{14}$$

As such, in order to estimate real yields y_t^R, we just need to estimate $\gamma_t(\tau)$ as both IL yields y_t^{IL} and log nominal forward rates f_t are observable.

To proceed, we follow the VAR methodology proposed by Evans (1998). We consider the following first-order vector autoregression:

$$z_{t+1} = Az_t + e_{t+1}, \tag{15}$$

where $z_t' \equiv [\Delta p_t, q_t(l), x_t]$ and x_t is a vector of conditioning variables that can potentially include relevant macro-variables which would affect the covariance between inflation and nominal bond prices. For now, we just choose x_t to be a $(T \times 1)$ one-vector. As a result of estimated (15), $\gamma_t(\tau)$ is given by:

$$\gamma_t(\tau) = i_1' \left[\sum_{i=1}^{\tau} A^{\tau-i} \left(\sum_{j=1}^{i} A^{i-j} V(e_{t+j}|z_t) A^{i-j'} \right) \right] i_2, \tag{16}$$

where i_k, $k = 1, 2$, is the selection vector such that $\Delta p_t = i_1' z_t$ and $q_t(l) = i_2' z_t$. Equation (16) shows how the covariance between $\Delta^\tau p_{t+\tau}$ and $q_{t+\tau}(l)$ conditioned on z_t is defined through the coefficient matrix A and the innovation variances $V(e_{t+j}|z_t)$.[11] The VAR(1)

[11]It seems that there is a typo in the derivation of $\gamma_t(\tau)$ in Evans (1998) and we present the corrected formula here.

results are presented in Table 2. In our empirical implementation, we define annual inflation rate as a year-to-year inflation $\Delta p_t = \ln(P_t/P_{t-12})$. We estimate $\gamma_t(\tau)$ for each date t using information available at time t (e.g., monthly inflation series Δp_t and log prices $q_t(l)$ prior to the date t). We discuss further the properties and the magnitude of $\gamma_t(\tau)$ in more detail in Section 5.

4.4 Proxies for expected inflation

Recall that in addition to nominal-real yield spreads, we also need expected inflation in order to estimate the inflation risk premium. Below we consider three alternative proxies for expected inflation. We report estimates of expected inflation based on each of the three methods in Section 5.

4.4.1 Expected inflation based on historical average

One straightforward way is to compute expected inflation as the average of historical inflation rates over the past T years. Namely, we estimate a $\tau-$period expected inflation as follows

$$E_t\pi_{t+\tau}(\tau) = \frac{1}{T}\sum_{k=1}^{T}\frac{1}{\tau}(p_{t-k} - p_{t-k-\tau}), \tag{17}$$

where the $\tau-$period inflation rate over $[t, t+\tau]$ is given by

$$\pi_{t+\tau}(\tau) = \frac{1}{\tau}\ln\left(\frac{P_{t+\tau}}{P_t}\right) = \frac{1}{\tau}\Delta^\tau p_{t+\tau}. \tag{18}$$

In our empirical analysis, we vary both the estimation horizon T and the inflation horizon τ.

4.4.2 Expected inflation based on the VAR

In the second approach we use a VAR model to estimate expected inflation. Assume that the state vector of the economy is governed by the vector $z_t = (r_t', i_t')'$, where r_t is the vector of real activity variables, and i_t is the vector of inflation variables. We assume further that the state vector z_t evolves according to the following VAR(1) process:

$$z_t = \mu + \Phi_1 z_{t-1} + \epsilon_t, \tag{19}$$

where $\epsilon_t \sim N(0, \Sigma)$. It is known that the $\tau-$period ahead conditional expectation of z_t is given by:

$$E_t(z_{t+\tau}) = \Psi^\tau \mu + \Phi^\tau z_t, \tag{20}$$

where

$$\Psi^\tau = \sum_{l=1}^{\tau-1} \Phi^l = (I - \Phi)^{-1}(I - \Phi^\tau). \tag{21}$$

In our empirical implementation, for each date t inflation forecast, we estimate VAR(1) using a 10-year sample of z_t prior to date t.

The use of real activity variables here is motivated by the idea behind Phillips curve that they should be important in predicting inflation. Following Ang and Piazzesi (2003), we form the vector of real activity variables r_t as follows: $r_t = (HELP_t, UE_t, EMPLOY_t, IP_t)$, where $HELP_t$ is the log growth rate of the Index of Help Wanted Advertising in the Newspapers, $EMPLOY_t$ is the log growth rate of civil employment, IP_t is the log growth rate of the industrial production index, and UE_t is the unemployment rate. Inflation variables used include year-to-year rates based on CPI_t, $Core_t$, and PPI_t inflation series, respectively. Namely, $i_t = (CPI_t, Core_t, PPI_t)$.[12]

4.4.3 Surveys' inflation forecasts

Last, but not least, we use three forecasts of inflation from the Survey of Professional Forecasters and the Blue Chip Economic Indicators. Quarterly Surveys of Professional Forecasters produce one-year ahead and 10-year ahead forecasts. Monthly Blue Chip Economic Indicators data are used to construct one-year ahead forecasts.

As mentioned before, Ang, Bekaert, and Wei (2007) conclude that surveys outperform other forecasting models and methods. However, Blue Chip Forecasts are not included in

[12] We examined the robustness of VAR estimates including other variables such as Blue Chip inflation forecasts and found that our results are not sensitive to it.

their study. In a related study, Chernov and Mueller (2011) include Blue Chip Forecasts among others and conclude that their model, which combines yields and survey data inflation, produces dominating out-of-sample forecasts of both inflation and yields compared with the model where no survey forecasts is included in the model.[13]

4.5 Inflation risk premium

In order to define the inflation risk premium, consider log-linearized nominal and real yields given by Eqs. (9) and (10), respectively. Using the definition of continuously compounded yields (1) and (3) and the fact that $m^R_{t+1} = m_{t+1} + \pi_{t+1}$, we obtain:

$$-\tau y_t(\tau) = E_t\left[\sum_{i=1}^{\tau} m_{t+i}\right] + \frac{1}{2}\text{Var}_t\left(\sum_{i=1}^{\tau} m_{t+i}\right) \tag{22}$$

and

$$\begin{aligned} -\tau y^R_t(\tau) &= E_t\left[\sum_{i=1}^{\tau} m^R_{t+i}\right] + \tfrac{1}{2}\text{Var}_t\left(\sum_{i=1}^{\tau} m^R_{t+i}\right) \\ &= E_t\left[\sum_{i=1}^{\tau} m_{t+i} + \sum_{i=1}^{\tau} \pi_{t+i}\right] + \tfrac{1}{2}\text{Var}_t\left(\sum_{i=1}^{\tau} m_{t+i}\right) \\ &\quad + \tfrac{1}{2}\text{Var}_t\left(\sum_{i=1}^{\tau} \pi_{t+i}\right) + \text{Cov}_t\left(\sum_{i=1}^{\tau} m_{t+i}, \sum_{i=1}^{\tau} \pi_{t+i}\right). \end{aligned} \tag{23}$$

Therefore,

$$\begin{aligned} y_t(\tau) - y^R_t(\tau) &= \frac{1}{\tau}E_t\left[\sum_{i=1}^{\tau} \pi_{t+i}\right] - \frac{1}{\tau}\text{Cov}_t\left(\sum_{i=1}^{\tau} m_{t+i}, \sum_{i=1}^{\tau} \pi_{t+i}\right) \\ &\quad + \frac{1}{2\tau}\text{Var}_t\left(\sum_{i=1}^{\tau} \pi_{t+i}\right). \end{aligned} \tag{24}$$

Notice that the first term on the RHS of equation (24) represents the $\tau-$period expected inflation, that the second term is the inflation risk premium, and that the last term is the Jensen's correction. Below we ignore the last term for the purpose of computing inflation risk premium because several studies have pointed out that this convexity adjustment is small (see, e.g., Ang, Bekaert, and Wei (2008), and Haubrich, Pennacchi, and Ritchken (2011)). In fact, Ang et al. estimate it to be less than one basis point.

[13] See a survey paper by Kim (2009) and references therein for more discussion on the estimation of the expected inflation.

Using the fact that $\frac{1}{\tau}\sum_{i=1}^{\tau}\pi_{t+i} = \pi_{t+\tau}(\tau)$ we rewrite equation (24) as follows:

$$y_t(\tau) = y_t^R(\tau) + E_t\pi_{t+\tau}(\tau) + \text{IRP}_t(\tau), \tag{25}$$

where the inflation risk premium (IRP) term is given by

$$\text{IRP}_t(\tau) = \frac{1}{\tau}\text{Cov}_t\left(-\sum_{i=1}^{\tau} m_{t+i}, \sum_{i=1}^{\tau}\pi_{t+i}\right). \tag{26}$$

Eq. (25) presents a variation of the Fisher equation and equates the $\tau-$period nominal yield with the $\tau-$period real yield plus the $\tau-$step ahead expected inflation and the inflation risk premium $IRP_t(\tau)$.

An alternative approach to estimating the inflation risk premium is to specify the real pricing kernel in a model with a representative agent. Examples of this approach include Fisher (1975), Benninga and Protopapadakis (1983), Evans and Wachtel (1992), Buraschi and Jiltsov (2005), and Hördahl, Tristani, and Vestin (2007). For the purposes of this paper, we do not specify a stochastic discount factor and instead we use various measures of the expected inflation and the term structure of real and nominal interest rates to infer the inflation risk premium from Eq. (25).

4.6 Liquidity component of the TIPS yield

In this section we propose a measure of illiquidity in TIPS by following Hu, Pan, and Wang (2010, HPW), who measure the market illiquidity using the dispersion between observed Treasury nominal yields and the benchmark nominal yields generated from the Nelson and Siegel (1987) and Svensson (1994) model. Specifically, we define the liquidity component of TIPS yields at time t as follows:

$$y_t^L = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}[y_t^{i,o} - y_t^{i,b}]^2}, \tag{27}$$

where $y_t^{i,o}$ and $y_t^{i,b}$ represent the observed and benchmark yields, respectively, of the i-th

TIPS at time t, and N_t is the number of outstanding TIPS date t. This measure is not maturity-specific because it is a measure of the whole TIPS market liquidity. However, it can be maturity dependent if it applies to a particular maturity (or set of maturities) of bonds.[14] In our implementation of this liquidity measure, we calculate the benchmark yields using the Nelson-Siegel-Svensson procedure as well. For brevity, we do not describe this procedure here. See, e.g., Gurkaynak, Sack, and Wright (2010) and HPW for details of the Nelson-Siegel-Svensson model.

One advantage of the liquidity measure (27) is that it depends only on TIPS prices. Existing liquidity measures for TIPS all depend on the information other than TIPS prices, such as bid-ask spreads and trading volume.

5 Empirical results

In this section we implement the simple estimation approach introduced in Section 4 and present estimates of the real yields, expected inflation, and inflation risk premium. We also correct our estimates of the inflation risk premium for liquidity premium embedded in the real yields and discuss inflation risk premium results when we account for the liquidity premium in the real yields.

5.1 Estimated real yields

In order to compute a real yield, we first estimate first the covariance term $\gamma_t(\tau)$ given in Eq. (13), that accounts for the 3-month indexation lag of TIPS. Table 2 reports estimates of $\gamma_t(\tau)$ obtained using the VAR(1) model specified in Eq. (15). We provide sample averages of the indexation lag correction in the table. In order to estimate $\gamma_t(\tau)$ for a given t we use a 10-year sample of Δp_t and $q_t(l)$ variables prior to date t in our VAR regression. We repeat the estimation for every t and then average the obtained $\gamma_t(\tau)$ estimates. Table 2 reports the averages. Annualized $\gamma_t(\tau)$ estimates are obtained by multiplying their monthly counterparts by $1200/\tau$. The negative $\gamma_t(\tau)$ represents the correction to real yields due to the indexation

[14] More details are given in Section 5.4.

lag. Observe from the table that the estimated negative $\gamma_t(\tau)$ has a uniformly upward sloping term structure, an indication that the correction is more important for longer maturity TIPS. Intuitively, as τ increases, uncertainty over the covariance between a longer-term inflation rate $\Delta^\tau p_{t+\tau}$ and a future nominal log price $q_{t+\tau}(l)$ increases as well. The magnitude of this correction ranges from about 0.03 b.p. for one-year TIPS yields to about 4 b.p. for 10-year TIPS. Although these magnitudes look small, they account for a significant portion of the estimated inflation risk premium, as can be seen later in Section 5.3.

We then proceed to estimate real yields using Eq. (12). Table 3 reports estimated real yields and also TIPS yields for comparison. Observe first that the former yield is on average indeed lower than the latter yield due to both the forward rate and indexation lag corrections, and that this difference in yield ranges from around 13 b.p. for the 117-month horizon to about 16 b.p. for the 57-month horizon. Observe also that both real and TIPS yields are significantly higher and also more volatile in the first half of our sample period January 2000-May 2004 than in the second half from June 2004 until September 2008. For example, in the first half of the sample, real yields on average range from 2.35% to 2.82% depending on the maturity and have an upward-sloping term structure, and the volatility of the real yields on average ranges from 0.84% to 1.14% per year, and has a downward-sloping term structure. In the second half of the sample, the whole real yield curve shifts downward by around 90 b.p. and is still upward-sloping. The term structure of the real yield volatility on average moves downward by 0.5%.

The variation over time in real yields shown in Table 3 has implications for both breakeven rates and the estimate of inflation risk premium, the latter the focus of the analysis in Section 5.3. Panel A of Figure 2 plots the 10-year breakeven rate (the nominal-real yield spread) and the SPF 10-year ahead inflation forecast over the entire sample period. Observe that the breakeven rate is relatively low (high) in the first (second) half of the sample period, moving roughly in the opposite direction of the 10-yr real yield. Also, the breakeven rate stays largely below (above) the SPF inflation forecast in the first (second) half of the sample period. This basically implies a negative (positive) inflation risk premium in the first (second) half of the sample period, as the inflation risk premium is typically defined to be the difference between the breakeven inflation rate and expected inflation.

To see if the low breakeven rate in the first subperiod is caused more by low nominal yields or high real yields, we also compute the summary statistics on nominal yields by subperiods. Results (not tabulated) indicate that the nominal yield on average is actually higher in the first subperiod than in the second. The difference in the mean ranges from 9 b.p. for the 117-month horizon to 17 b.p. for the 57-month horizon. This evidence indicates that the low breakeven rate observed in the first subperiod is due to high real yields over the same period.

5.2 Expected inflation estimates

As mentioned before, we consider three alternative proxies for expected inflation: the average of past inflation rates, a VAR based inflation forecast, and the forecast from a professional survey.

Table 4 reports the average of historical inflation rates computed using Eq. (17) over various estimation horizons, based on both seasonally-unadjusted CPI data (Panel A) and Core CPI data (Panel B). Notice that in the table (and also the subsequent tables), we report the empirical results by bond maturities in months, namely, τ = 57, 81, and 117 (month), rather than by years, because corresponding maturities of TIPS yields and real yields differ by three months (the length of the indexation lag).

We make three observations from Panel A. First, when we use the estimation period of one year ($T = 1$), the average (proxy for expected inflation here) is mostly flat, around 2.5%, manifesting the unconditional nature of the estimates. Second, when $T > 1$ is used in the estimation, the term structure of the expected inflation is upward-sloping. For example, when $T = 5$ is used, the expected inflation ranges from 2.47% for the maturity of $\tau = 57$ months to 2.72% for the maturity of $\tau = 117$ months. Some other studies obtain similar estimates. In particular, Carlstrom and Fuerst (2004) find that 10-year ahead expected inflation varies between 2.5% and 2.6%. Finally, when a long estimation horizon, $T = 10$ (that includes periods of high inflation of early and mid-nineties), is used, the historical average is biased upward and close to 3% per year.

Observe from Panel B of Table 4 that the average core inflation rate displays patterns similar to their counterparts shown in Panel A. However, as expected, estimates here are lower than those based on the standard CPI index. On average, 10-year inflation forecasts based on the estimation period of $T = 1$, 3, and 5 years are around 2.5%.

Next, we examine forecasting errors of our three proxies for expected inflation, using seasonally-unadjusted CPI and/or core inflation indices as the benchmark. Table 5 reports the root of the mean squared error (RMSE) calculated for each of the three proxies. Notice that the RMSE of the survey measure is calculated against only the CPI benchmark as the survey forecasts CPI, but not core CPI. As indicated in the table, the VAR-based forecast has the smallest error, followed by the historical average inflation rate forecast, and then by the survey forecast, at least in our sample. In particular, the RMSE against CPI ranges from 0.5∼0.6 b.p. for VAR-based forecasts, to 10∼18 b.p. for historical-based forecasts, and as high as 37∼56 b.p. for surveys' forecasts. Observe also that the RMSE against CPI tends to decrease with the horizon for the historical mean and surveys' forecasts while VAR-based forecasts lend to almost uniform RMSE across different maturities. However, the opposite pattern is shown for the historical mean and the VAR-based forecast when the core CPI is used as the benchmark. The performance of the historical mean proxy across the horizon indicates that it can better forecast the more volatile CPI over a longer horizon than a shorter horizon, and can better forecast the less volatile core CPI over a shorter horizon. VAR-based forecast seems to be the most accurate and survey-based forecast - the least accurate in our sample.

There appears no consensus so far in the literature on the best proxy for expected inflation. For instance, Ang, Bekaert, and Wei (2007) study several methods for forecasting inflation over the period 1952-2004 and find that surveys outperform other forecasting methods both in-sample and out-of-sample. On the other hand, Chernov and Mueller (2011) find systematic biases in survey forecasts. Nevertheless, they find that surveys along with private sector inflation expectations produce realistic inflation forecasts. However, a comparison of our results with those from these two studies is not straightforward because first, our sample period is different and second, horizons of historical- and VAR-based forecasts are different from those of surveys' forecasts. As such, in the analysis below we consider all of the three proxies examined above for expected inflation.

5.3 Estimation of the inflation risk premium

In this section we present estimates of the inflation risk premium (IRP) obtained using each of three alternative proxies for expected inflation mentioned earlier.[15] The first proxy used in our analysis is the average historical inflation rate. The second one is the inflation forecast from the VAR(1) model specified in Eq. (15). Finally, the third proxy is inflation forecasts from the Survey of Professional Forecasters and the Blue Chip Economic Indicators.

Table 6 reports the inflation risk premium estimated over both the full sample and two subsamples, based on each of the three alternative proxies for expected inflation. Observe from the table that the estimates of IRP show several persistent patterns across different inflation forecasts. First, the term structure is upward-sloping regardless of the inflation forecast measure and the sample period used for estimation. Second, both 5- and 7-year CPI-based inflation risk premia are negative over the entire sample as well as over the first half of the sample (Panels A and B). And most of these estimates are statistically significant at the 1% level. The 5- and 7-year core-CPI based inflation risk premia are significantly negative (positive) in the first (second) half of the sample. Third, as can be seen from Panel A, most of the CPI-based 10-year inflation risk premia estimated over the full sample are negative and statistically significant with the exception of the premium based on 1-year CPI forecast reported by the Survey of Professional Forecasters, which is positive and statistically insignificant. The sign and the magnitude of the inflation risk premia based on Core CPI inflation forecast depends on the Core inflation forecast proxy. For instance, the 10-year premium is only -1.4 b.p. (statistically insignificant) in the case of historical-based forecast but is as high as 32 b.p. based on the 1-year VAR Core CPI (at the 1% significance level).

Finally, the 10-year inflation risk premia estimated over the second half of the sample

[15] We also test Fisher hypothesis by regressing $IRP_t(\tau)$ on the breakeven rate $y_t(\tau) - y_t^R(\tau)$. Our tests strongly reject Fisher hypothesis and therefore the zero inflation risk premium hypothesis. This result is consistent with the literature on rejection of Fisher hypothesis. See, e.g., Mundell (1963), Tobin (1965), Feldstein (1976), Fisher (1975), Fama and Gibbons (1992), Fama (1990), and Evans (1998) (on U.K. rates).

are positive in most cases except when BCF is used as a proxy for expected inflation (Panel C). More specifically, estimates based on CPI inflation forecasts range from 8 b.p. to 13 b.p. And estimates based on core CPI inflation forecasts are much higher, ranging from 38 b.p. to 50 b.p. Both sets of estimates are statistically significant. Obviously, estimates based on core CPI are higher because the core inflation rate on average is lower than the CPI rate. In our sample, the former on average is 2.20% and the latter on average is 2.89% (see Panel C of Table 1).

We also calculate the volatility of the IRP estimates in the two subsamples. Results (not reported) indicate that the estimated IRP is less volatile in the first half of the sample period than in the second.

Figure 3 plots the term structure of the inflation risk premium over time during the entire sample period. The inflation risk premium used in the graph in Panel A (B) is estimated with expected inflation proxied by the average of the historical CPI (core CPI) rates over the previous five years ($T = 5$). Both graphs show that the inflation risk premium is visibly negative and relatively more volatile in the first half of the sample but becomes positive and less volatile in the second half of the sample.

To summarize, we find that the pattern of negative versus positive premia in the two subsamples is robust with respect to the choice of inflation proxy, its horizon, and the estimation period (T) of the historical-based forecasts. This evidence indicates that there seems to be a significant shift in the behavior of the premium around 2003-2004. Also, Adrian and Wu (2010) report a structural break around 2002 (which, they argue, is the turning point in changing liquidity conditions on the TIPS market). However, what causes such a shift in the level of the inflation risk premium remains an open question. In the next subsection, we consider a few possible explanations.

5.4 Liquidity correction

Previous section discusses our estimates of the inflation risk premium without considering a possible bias in the estimates of the inflation risk premium caused by a relative illiquidity of TIPS in the early years of the program. As mentioned before, several studies find that such illiquidity concerns were quite severe. Indeed, D'Amico, Kim, and Wei (2009) find that the deterministic trend of the liquidity premium was as high as 120 basis points in 1999 and eventually went down to 10 basis points in 2004. Naturally, illiquidity drives TIPS market prices down and TIPS yields up, and thus, drives a wedge between real yields and TIPS yields. We have corrected TIPS yields for an indexation lag and now correct them for liquidity.

Let $y_t^R(\tau)$ refer to real yield not corrected for liquidity (this one is derived from TIPS yields and adjusted for indexation lag only), and $y_t^{R,L}(\tau)$ refers to real yield, corrected for liquidity. Naturally, the difference between the two is a liquidity correction:

$$y_t^R(\tau) = y_t^{R,L}(\tau) + y_t^L(\tau). \tag{28}$$

Therefore, the relationship between nominal, real, expected inflation, and inflation risk premium is given as:

$$y_t^N(\tau) = y_t^R(\tau) - y_t^L(\tau) + \mathbb{E}_t\pi_{t+\tau}(\tau) + IRP_{t,\tau}. \tag{29}$$

Last equation shows that inflation risk premium estimates might be understated if liquidity adjustment $y_t^L(\tau)$ is ignored. We define the TIPS liquidity adjustment $y_t^L(\tau)$ as the average fitting error (or, noise measure) at each point of time in our sample defined in Eq. (27) in Section 4.6. The notation τ is used here in the loose sense to indicate the bundle of maturities that are used in the construction of this variable.

We implement empirically this measure using individual observations of TIPS bonds with maturities between 3 and 10 years. As HPW point out, the short end of the curve of the bonds' market is considered to be noisier than other parts of the curve and also unlikely to be an object of arbitrage trades. For this reason, we exclude short maturities observations from the sample to preclude the possibility that our noise measure is driven by the short end effect. HPW use maturities between 1 and 10 years for constructing this measure using nominal Treasuries data. However, short-term TIPS are non-existent, as opposed to nominal Treasuries, and therefore, the fit of the short end of the TIPS curve is highly dependent on the long-term TIPS securities, so we have excluded bonds with maturities less than 3 years.[16] When we construct a noise measure, we also exclude outlier observations with yields more than 4 standard deviations away from the sample following HPW. There are less than 2% observations removed from the panel data (456 out of 26,391 bond/day observations). The number of bonds used for construction of noise measure varies from 3 (beginning of our sample) to 16 (end of our sample).

The results of the liquidity adjustment at a monthly and daily frequency are shown on Figure 4, Panels A and B correspondingly. We observe that this measure varies substantially throughout the sample. Panel B shows that there are a few peaks in the daily data in the sample around 2001 through 2003 (one of the peaks is clearly related to the 9/11 event) with the maximum of roughly 35 basis points in the middle of 2002. We observe that the $y_t^L(\tau)$ is relatively low and stable around 10 basis points between 2005 and 2008. It starts picking up again in 2008 with the development of the financial crisis. While we did not include the period of the financial crisis in our analysis due to the reasons discussed in Section 3, an extension of our liquidity measure indicates that the noise measure has reached as high as 60 basis points at the pinnacle of the financial crisis.[17,18]

Table 7 presents the results of liquidity estimates. Panel A shows that on average the liquidity measure (27) does not exceed 6 basis points for monthly data and 5 basis points for daily data. The standard deviation of $y_t^L(\tau)$ is around $3 \sim 4$ basis points. The maximum liquidity adjustment occurs on May 27, 2002 when it reaches 35.12 basis points. Monthly data are extracted from daily data as the last day of each month in the sample. With monthly data, the maximum liquidity adjustment is equal 29.37 basis points. We observe that the average daily $y_t^L(\tau)$ is higher in the second half of the sample (Panel C) than in the first half of the sample (Panel B) by about 25 basis points, but the maximum spike occurs still in the first half of the sample.

The above liquidity correction implies that the estimates of the inflation risk premium

[16] We have recomputed $y_t^L(\tau)$ for $\tau \in [2, 10]$ and found no substantial differences in our results.
[17] Results are not reported but available upon request.
[18] This confirms the finding of Gurkaynak and Wright (2010) who document that the prices of very similar maturities diverged significantly making the construction of the yield curve very unreliable at that time.

in Table 6 have to be adjusted for it. As Eq. (29) shows, $y_t^L(\tau)$ needs to be added to obtain liquidity-adjusted inflation risk premium. Overall, the 10-year liquidity unadjusted inflation risk premium is between -22 to 4 basis points based on the whole sample (Panel A of Table 6). If we add a monthly average liquidity adjustment to it (5.59 b.p., Panel A of Table 7), we obtain the estimates that vary from -16 to 10 basis points, a finding largely consistent with Adrian and Wu (2010) but obtained using a different and a much simpler method. Similar estimates can be obtained for the first and the second parts of the sample. Panel C of Table 6 reports that the 10-year inflation risk premium varies between 8 and 13 basis points. Adding a monthly average of 5.64 basis points (Panel C of Table 7) we obtain that 10-year inflation risk premium is between 14 and 19 basis points in the second half of our sample 2004:06-2008:09.

5.5 Discussion of the results

One main finding of the empirical analysis presented in the previous section is that the inflation risk premium is negative in the period January 2000-May 2004, the first half of our sample period even after we correct for liquidity adjustment. We have two instances when we use survey forecasts to assess inflation expectations and where 10-year inflation risk premium has been positive, but these estimates are not statistically significantly so we still interpret that the first half of our sample results in the negative inflation risk premium.[19] Although, by definition given in Eq. (26), inflation risk premium can be negative in theory, there might be two reasons for this finding. First reason is that the negative inflation risk premium obtained here still has some liquidity left which is not captured by our TIPS noise measure (28). A higher liquidity premium will result in higher liquidity adjustment and, consequently, bring inflation risk premium to higher levels.

Another possible reason for the negative inflation risk premium in January 2000 - May 2004 is deflation fears during fall 2002 - summer 2003. As chronicled in Bernanke, Reinhart, and Sack (2004), the Federal Open Market Committee (FOMC) members began to mention

[19] As we mentioned in Section 2, there seems to be no consensus so far on the sign of the risk premium. Interestingly, Evans (2003) documents a large negative inflation risk premium on the U.K. indexed bonds, which varies between negative 1% and 3.5%.

the risks of deflation going forward in the fall of 2002. In response to the concerns about the possibility of deflation in the U.S., the FOMC gradually lowered the federal-funds target rate during this deflation scare until the target was at a 45-year low of 1%. Both nominal and TIPS yields dropped substantially during the same period (see Figure 1). In the mean time, core inflation tumbled from 2% in November 2002 to about 1% one year later. However, as shown in Figure 2, both short- and long-term inflation expectations were still relatively high in that period. As a result, the breakeven inflation rate (namely, the nominal-real yield spread) stayed below the expected inflation during inflation scare, as illustrated in Panel A of Figure 2. This leads to the negative inflation risk premium from the fall of 2002 to the summer of 2003 that we observe in the data.

The estimated inflation risk premium is also negative in the fall of 2008 near the end of our sample period (see Figure 3) although the premium estimated using the entire second half of the sample is positive. (Notice also that both 10-year TIPS breakeven rate and breakeven inflation rate drop substantially at that time, as shown in Panel C of Figure 1 and Panel A of Figure 2, respectively.) As in 2002-2003, deflation scare reportedly occurred in the fall of 2008 after the Lehman default and the onset of the current recession. Several events in connection with the scare are worth mentioning here. First, CPI had a record monthly drop of 1% in October 2008 and the 5-year TIPS breakeven rate became negative for the first time in the same month. Then a November 19 article by Blackstone (2008) posted on the Wall Street Journal's website reported that the Fed Vice Chairman Donald Kohn said on the same day that although still small, the risk of deflation has increased since a few months ago. In addition, the minutes of the FOMC meeting on October 28-29 released also on November 19, 2008 mention that some FOMC members thought an aggressive easing policy should lower the risk of deflation. Yet, another factor that is believed to have influenced the behavior of TIPS during the fall of 2008 is illiquidity or market segmentation between the nominal and TIPS markets. Campbell, Shiller, and Viceira (2009) and Wright (2009) provide a more detailed discussion of high TIPS yields observed after the Lehman collapse. The latter study, in particular, argues that the inflation risk premium should be positive and that fear of deflation is a potential cause of the negative premium documented empirically. See also

Fleckenstein, Longstaff, and Lustig (2010) for a description of TIPS market mispricing and potential arbitrage opportunities around that period.

As a result of the above discussion of causes of negative inflation risk premia, we consider the estimates of inflation risk premium obtained over the second half of the sample period to be more reasonable. Furthermore, we focus on estimates relative to CPI but not core CPI as TIPS are indexed to the former. As such, we conclude that the 10-year inflation risk premium ranges between 14 and 19 b.p., depending on the proxy used for expected inflation, based on our empirical analysis and when we correct for liquidity using a liquidity adjustment (28).

These estimates of the inflation risk premium are substantially lower than those obtained by Campbell and Shiller (1996), Campbell and Viceira (2001), Buraschi and Jiltsov (2005), Ang, Bekaert, and Wei (2008), D'Amico, Kim, and Wei (2009), and Haubrich, Pennacchi, and Ritchken (2011). On the other hand, our estimates of the 10-year premium are higher than those obtained by some other studies. Ang et al. find that their estimated inflation risk premium reached a peak of 2.4% in the early 1980s, was below 0.5% over 2001-2003, and at one time even declined to 0.15% in 2002-2003 before climbing back to about 1% in December 2004, the end of their sample (see their Figure 5). Two other studies each obtain different estimates depending on the models and/or data used. Chernov and Mueller (2011) find that inflation risk premia can be positive or negative based on the model used: their estimates range from 0.2% to 2% when the model is augmented with survey forecasts, while they obtain negative estimates in the range -0.07% to -0.3% when no forecast data is used in the model estimation (see Table 5 in their paper). D'Amico et al. estimate a four-factor Gaussian term structure model of interest rates and inflation using both nominal and TIPS yields and survey forecasts of short rates. The estimates of the inflation risk premium fluctuate between 0 and 1% in this model.

Our estimates of the inflation risk premium over the full sample period are somewhat consistent with the ones obtained by Hördahl, Tristani, and Vestin (2007) without using TIPS data, who calibrate a general equilibrium model with habit persistence and nominal rigidities and find that the inflation risk premium is small around 1-year maturity and essentially zero for other maturities. The benefit of our approach is that it is a "model-free" to a large extent and uses information about TIPS yields directly from TIPS market data. Of course, the sign of the inflation risk premium would crucially depend on the model, a measure of inflation expectations and a sample period.

However, we caution against a direct comparison of our results and those obtained in other related studies because different sample periods, estimation methods, and data sets are used in the latter ones. In particular, our estimates are based on TIPS yields over a more recent and relatively low inflation period.

6 Conclusion

This paper represents one of the first attempts to estimate inflation risk premium directly using the prices of Treasury Inflation Protected Securities (TIPS). More importantly, we make distinction between TIPS yields and real yields, taking into account (i) the three-month indexation lag of TIPS, and (ii) liquidity premium embedded in the TIPS yields. We then extract inflation risk premium from the nominal-real yield spread using various measures of inflation expectations.

The estimation approach used in our analysis is arbitrage free, largely model free, and easy to implement. In addition, the implementation of the approach requires only data on historical nominal and TIPS yields, and expected inflation. This approach is especially useful for the purpose of producing market-based estimates of the inflation risk premium. The TIPS liquidity measure proposed here is based on TIPS yields only and very easy to implement.

We find that the 10-year inflation risk premium varies between -16 and 10 basis points over the full sample depending on the proxy used for expected inflation. In addition, the inflation risk premium is found to be time-varying, and more specifically, negative in the first half of our sample period but positive in the second half. Negative inflation risk premium in the first subperiod appears to be due to a combination of illiquidity of TIPS and deflation scare in 2002-2003. In the second half of the sample period, inflation risk premium is significantly positive and the 10-year premium varies from 14 to 19 basis points, depending on the proxy used for expected inflation. The indexation lag correction increases with yield maturity, from 0.03 basis points for one-year TIPS to 4.2 basis points for 10-year TIPS. We also find that the inflation risk premium is considerably less volatile during the 2004-2008 period. This indicates that the monetary policy of the Fed has been credible in recent years and inflation expectations are well-anchored.

We contribute to the literature by obtaining reasonable estimates of inflation risk premium using a very simple method with data on market prices of TIPS and nominal Treasury bonds. Our empirical results should be of value to anyone interested in assessing inflationary expectations and inflation risk premia at a point in time or in tracking changes in those expectations over time.

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Table 1: Summary statistics

This table reports the summary statistics of the data. Panel A reports the statistics on h-month Treasury Inflation Protected Security (TIPS) yields $y^{IL}(h)$. Panel B reports statistics on h-month nominal Treasury yields $y(h)$. Panel C reports the statistics of realized and expected inflation variables. Realized inflation variables are based on the CPI, the seasonally-unadjusted Consumer Price Index for All Urban Consumers (also denoted CPI-U); and core CPI, the seasonally-adjusted CPI excluding food and energy. We calculate the inflation measure at time t using $log(P_t/P_{t-12})$, where P_t is the inflation index. Expected inflation variables are: (1) one-year ahead forecast based on CPI price deflator from SPF, (2) 10-year ahead forecast based on CPI price deflator from SPF, and (3) one-year ahead forecast from the Blue Chip Economic Indicators. Panel D reports real activity measures: the growth rates of: (1) the Index of Help Wanted Advertising in the Newspapers HELP, (2) civil employment level EMPLOY, (3) industrial production index IP, and (4) unemployment rate UE. The growth rate variables are computed as $log(I_t/I_{t-12})$, where I_t is the corresponding level variable. Source: Federal Reserve Board TIPS and discount bonds data set, Federal Reserve Bank of St. Louis Economic Data Base, Federal Reserve Bank of Philadelphia, Conference Board and Aspen Publishers. The sample period for all variables is 2000:01-2008:09, monthly frequency, except SPF, whose forecasts are quarterly.

	Central Moments				Autocorrelations		
	Mean	Stdev	Skew	Kurt	Lag1	Lag2	Lag3
	Panel A: TIPS Yields (%)						
$y^{IL}(60)$	2.0874	0.9927	0.4779	2.3706	0.9737	0.9494	0.9295
$y^{IL}(84)$	2.3058	0.8912	0.5769	2.3479	0.9777	0.9574	0.9404
$y^{IL}(120)$	2.4930	0.7783	0.6949	2.3478	0.9805	0.9631	0.9482
	Panel B: Nominal Bond Yields (%)						
$y(60)$	4.1299	0.9901	0.5115	2.9097	0.9836	0.9669	0.9516
$y(84)$	4.4499	0.8128	0.6931	3.1858	0.9848	0.9698	0.9563
$y(120)$	4.8228	0.6511	0.8180	3.1557	0.9860	0.9727	0.9607
	Panel C: Inflation Variables (%)						
CPI	2.8864	0.9428	0.2205	2.7029	0.9744	0.9409	0.9113
Core CPI	2.1984	0.4144	-0.9322	3.3338	0.9888	0.9770	0.9639
PPI	3.2346	2.5647	-0.3752	3.4683	0.9511	0.8930	0.8468
SPF, CPI 1yr forecast	2.3534	0.2356	-0.9290	4.2152	0.9649	0.9289	0.8945
SPF, CPI 10yr forecast	2.4857	0.0394	-2.0119	6.5477	0.9710	0.9421	0.9131
Blue Chips, CPI 1yr forecast	2.5179	0.4504	-0.0791	2.4284	0.9859	0.9694	0.9522
	Panel D: Real Activity Variables (%)						
EMPLOY	1.0171	1.0126	-0.2887	2.4476	0.9529	0.9183	0.8762
IP	1.2457	2.7200	-1.1736	3.8939	0.9121	0.8505	0.7794
HELP	-17.7050	16.0619	-0.4332	2.2716	0.9491	0.9163	0.8854
UE	5.0743	0.6780	-0.0905	1.8605	0.9897	0.9795	0.970

Table 2: TIPS indexation lag correction

This table reports estimates of $\gamma_t(\tau)$ computed as

$$\gamma_t(\tau) = i_1' \left[\sum_{i=1}^{\tau} A^{\tau-i} \left(\sum_{j=1}^{i} A^{i-j} V(e_{t+j}|z_t) A^{i-j'} \right) \right] i_2,$$

where i_1 is the selection vector such that $\Delta p_t = i_1' z_t$ and $q_t(l) = i_2' z_t$. This equation shows how the covariance between $\Delta^\tau p_{t+\tau}$ and $q_{t+\tau}(l)$ conditioned on z_t relates to the dynamics of VAR(1) through the coefficient matrix A, and the innovation variances, $V(e_{t+j}|z_t)$. $\Delta^\tau p_{t+\tau}$ is the log change in the price level from time t to time $t+\tau$. $q_{t+\tau}(l)$ is the log price at time $t+\tau$ for a nominal bond maturing in l months. For each t $\gamma_t \tau$ estimates are based on VAR(1) estimated using 10 years of data prior to date t. Sample average $\gamma_t \tau$ are reported in the table. Annualized negative $\gamma_t(\tau)$ represents the correction to the real yields.

Maturity τ	Correction to the real yields (in %) due to the 3-month indexation lag of TIPS	
(month)	$\gamma(\tau)$ (monthly)	$-\gamma(\tau)$ (annualized)
12	-0.0000	0.0003
24	-0.0000	0.0012
36	-0.0001	0.0027
57	-0.0003	0.0070
60	-0.0004	0.0078
81	-0.0010	0.0154
84	-0.0012	0.0168
117	-0.0038	0.0390
120	-0.0042	0.0418

Table 3: Estimated real yields

This table reports summary statistics for estimated real yields and also for TIPS yields for comparison. Statistics is reported for both the whole sample and two subsamples. The real yield on a τ-month zero-coupon bond, $y^R(\tau)$, is estimated using the following formula:

$$y^R(\tau) = \frac{h}{\tau} y_t^{IL}(h) - \frac{l}{\tau} f_t(\tau, l) + \frac{1}{\tau}\gamma_t(\tau),\ \tau = h - l,$$

where $y_t^{IL}(h)$ is the yield of a TIPS with h months to maturity, f_t log nominal forward rates, and $\gamma_t(\cdot)$ the adjustment due to an indexation lag of $l = 3$ months. Estimates of $\gamma_t(\tau)$ reported in Table 2 are used here. Sample period: 2000:01 to 2008:09, monthly frequency.

Sample	Horizon τ	TIPS yields (%)				Estimated real yields (%)			
period	(month)	Mean	Stdev	Skew	Kurt	Mean	Stdev	Skew	Kurt
2000:01-2008:09									
	57	2.087	0.993	0.478	2.371	1.928	1.018	0.460	2.363
	81	2.306	0.891	0.577	2.348	2.173	0.910	0.572	2.371
	117	2.493	0.778	0.695	2.348	2.367	0.790	0.740	2.465
2000:01-2004:05									
	57	2.518	1.105	-0.070	1.693	2.352	1.141	-0.064	1.691
	81	2.783	0.946	-0.127	1.680	2.639	0.983	-0.112	1.676
	117	2.973	0.787	-0.112	1.681	2.817	0.840	-0.064	1.680
2004:06-2008:09									
	57	1.648	0.613	-0.295	2.004	1.495	0.639	-0.302	1.986
	81	1.819	0.478	-0.286	2.107	1.698	0.498	-0.308	2.119
	117	2.004	0.348	-0.151	2.104	1.908	0.360	-0.181	2.122

Table 4: Expected inflation based on historical average

This table reports the estimates of the expected inflation based on historical average. $E_t\pi_{t+\tau}(\tau)$ is the expected rate of inflation computed as $T-$year historical average of $\pi_{t+\tau}(\tau)$, $\tau-$period realized inflation, computed as

$$E_t\pi_{t+\tau}(\tau) = \frac{1}{T}\sum_{k=1}^{T}\frac{1}{\tau}(p_{t-k} - p_{t-k-\tau}).$$

Panel A reports expected inflation based on CPI-U. Panel B reports expected inflation based on historical average of core CPI. Standard deviations are reported in parentheses below the estimates. Estimation period is 1980:01 to 2008:09, monthly frequency.

Horizon τ (month)	Estimation period T (year)				
	1	3	5	7	10
	Panel A: Based on CPI (%)				
57	2.514	2.463	2.469	2.528	2.722
	(0.196)	(0.112)	(0.083)	(0.140)	(0.284)
81	2.498	2.484	2.526	2.635	2.839
	(0.153)	(0.104)	(0.139)	(0.237)	(0.306)
117	2.551	2.612	2.718	2.837	3.028
	(0.133)	(0.207)	(0.283)	(0.305)	(0.299)
	Panel B: Based on Core CPI (%)				
57	2.181	2.241	2.335	2.470	2.741
	(0.144)	(0.168)	(0.212)	(0.298)	(0.420)
81	2.268	2.343	2.469	2.634	2.913
	(0.163)	(0.211)	(0.297)	(0.378)	(0.439)
117	2.443	2.576	2.738	2.911	3.181
	(0.288)	(0.366)	(0.418)	(0.439)	(0.439)

Table 5: Accuracy of proxies for expected inflation

This table reports the forecasting errors in percentages for the following forecasts of inflation: (1) one-year historical-based forecasts of CPI and core inflation, (2) VAR-based forecasts of CPI and core inflation, and (3) forecasts by the Survey of Professional Forecasters (SPF) and Blue Chip Economic Indicators of seasonally-unadjusted CPI. One-year historical-based forecasts are computed using the formula (17) and VAR-based forecasts are computed using the formula (20). Seasonally-unadjusted CPI and core inflation are used as the benchmark. If $\hat{I}_t$ is the benchmark inflation and I_t is the forecast series in question, then the root of the mean squared error (RMSE) is given by:

$$RMSE_{I,T} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(I_t - \hat{I}_t)^2}$$

where T is the sample size. We report quarterly estimates in the case of SPF and monthly estimates in all other cases. Sample period: 2000:01 to 2008:09.

Proxy for	Horizon τ	RMSE (%) against	
Expected Inflation	(month)	CPI	Core CPI
Historical mean:			
	57	0.1779	0.0657
	81	0.1401	0.0508
	117	0.0991	0.0760
VAR-based forecast:			
	57	0.0047	0.0036
	81	0.0064	0.0041
	117	0.0062	0.0059
Forecast from surveys:			
SPF	12	0.5583	
SPF	120	0.4260	
Blue Chip	12	0.3685	

Table 6: Inflation risk premium

This table reports average estimates for the inflation risk premium in percentages based on the following forecasts of inflation: (1) one-year historical-based forecasts of CPI and core inflation, (2) VAR-based forecasts of CPI and core inflation, and (3) forecasts by the Survey of Professional Forecasters (SPF) and Blue Chip Economic Indicators (BCF) of seasonally-unadjusted CPI. Sample period is January 2000-September 2008. We report quarterly estimates in the case of SPF and monthly estimates in all other cases. Statistics is reported for various subsamples. Estimates at the 1% level of statistical significance are reported in bold, while estimates at the 5% (10%) level of statistical significance are marked with ** (*).

	Historical-based		VAR-based		Survey-based (CPI only)		
Horizon τ	CPI	Core	CPI	Core	SPF		BCF
(month)	1yr	1yr	1yr	1yr	1yr	10yr	1yr
Panel A (over 2000:01-2008:09)							
57	**-0.357**	-0.024	**-0.514**	0.015	-0.238**	**-0.370**	**-0.361**
81	**-0.259**	-0.029	**-0.313**	0.107	-0.153*	**-0.285**	**-0.279**
117	**-0.123**	-0.014	**-0.218**	**0.325**	0.042	-0.090*	-0.089*
Panel B (over 2000:01-2004:05)							
57	**-0.543**	**-0.463**	**-0.850**	**-0.357**	**-0.465**	**-0.678**	**-0.464**
81	**-0.432**	**-0.417**	**-0.563**	-0.172	**-0.327**	**-0.541**	**-0.322**
117	**-0.323**	**-0.406**	**-0.462**	0.155	-0.041	**-0.254**	-0.038
Panel C (over 2004:06-2008:09)							
57	**-0.168**	**0.423**	-0.171**	**0.396**	0.002	-0.044	**-0.256**
81	-0.082*	**0.366**	-0.059	**0.392**	0.031	-0.015	**-0.235**
117	**0.082**	**0.385**	0.031	**0.499**	0.129*	0.083	**-0.141**

Table 7: Liquidity correction

This table reports descriptive statistics for the liquidity premium correction defined as a root mean squared error between the market yields y_t^i and model-implied yields $y_t^{i,m}$:

$$y_t^L(\tau) = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}[y_t^i(\tau) - y_t^{i,m}(\tau)]^2},$$

where N_t is the number of existing TIPS or nominal bonds on date t. τ refers to maturities of the individual bonds, 3 to 10 years, used to compute the liquidity adjustment. Model-implied yields are based on Nelson-Siegel-Svensson functional form. Source: Federal Reserve Board TIPS data set. Individual bond prices are from Advance Datastream 4.0. Sample period is January 2000-September 2008. The results are reported in basis points for daily and monthly frequency.

	daily	monthly
Panel A (over 2000:01 - 2008:09)		
mean	4.7191	5.5951
st. dev.	3.3261	4.3352
maximum	35.1184	29.3706
Panel B (over 2000:01 - 2004:05)		
mean	4.5933	5.5104
st. dev.	3.4894	4.6716
maximum	35.1184	29.3706
Panel C (over 2004:06 - 2008:09)		
mean	4.8448	5.6486
st. dev.	3.1510	4.0546
maximum	24.3400	24.3400

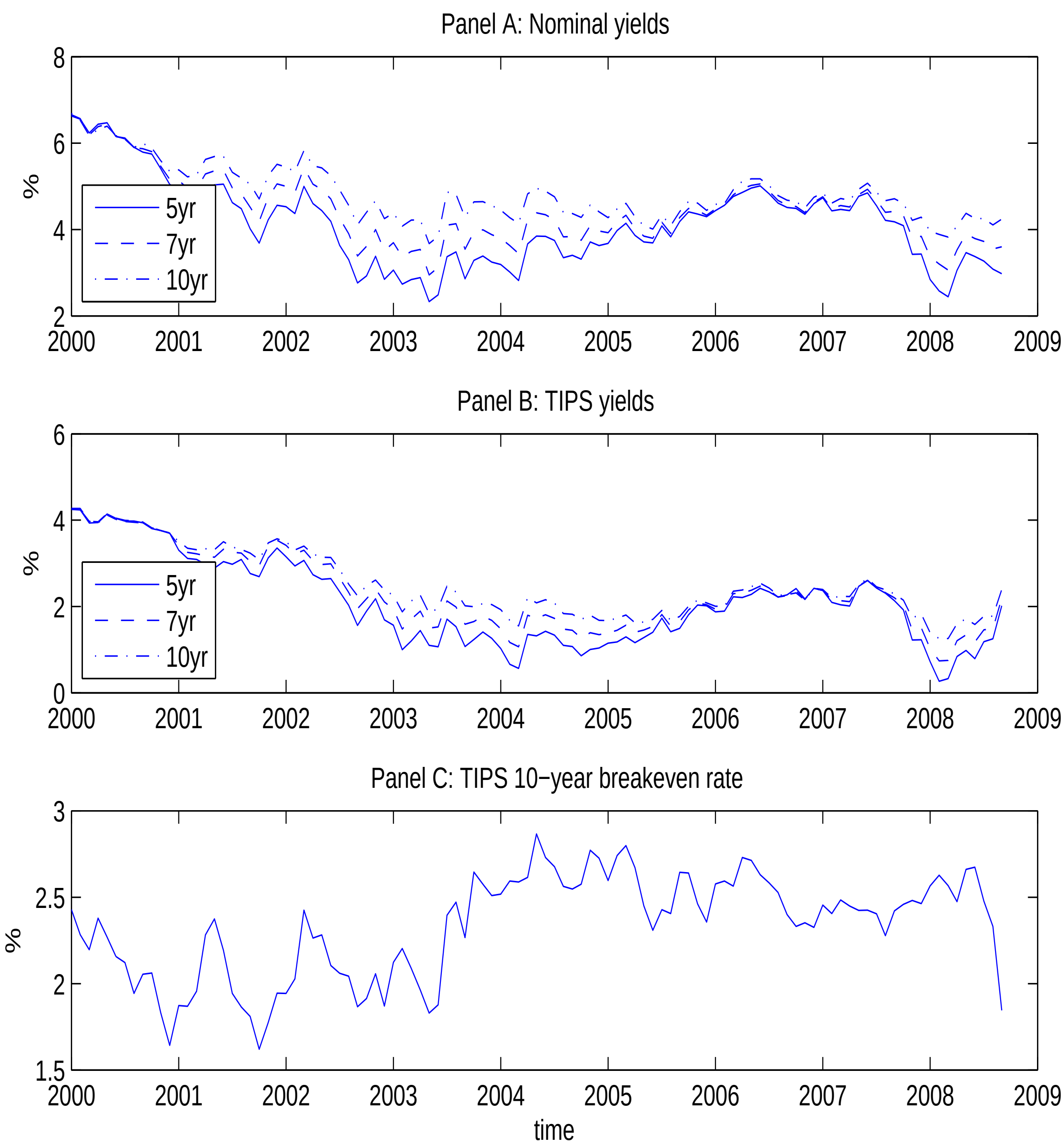

Figure 1: Zero-coupon nominal and TIPS yields, and the 10-year TIPS breakeven rate.

This figure plots zero-coupon nominal (Panel A) and TIPS yields (Panel B) of 5-, 7-, and 10-year maturities, and the 10-year (zero-coupon) TIPS breakeven rate (the zero-coupon nominal-TIPS yield spread) over the period January 2000 - September 2008.

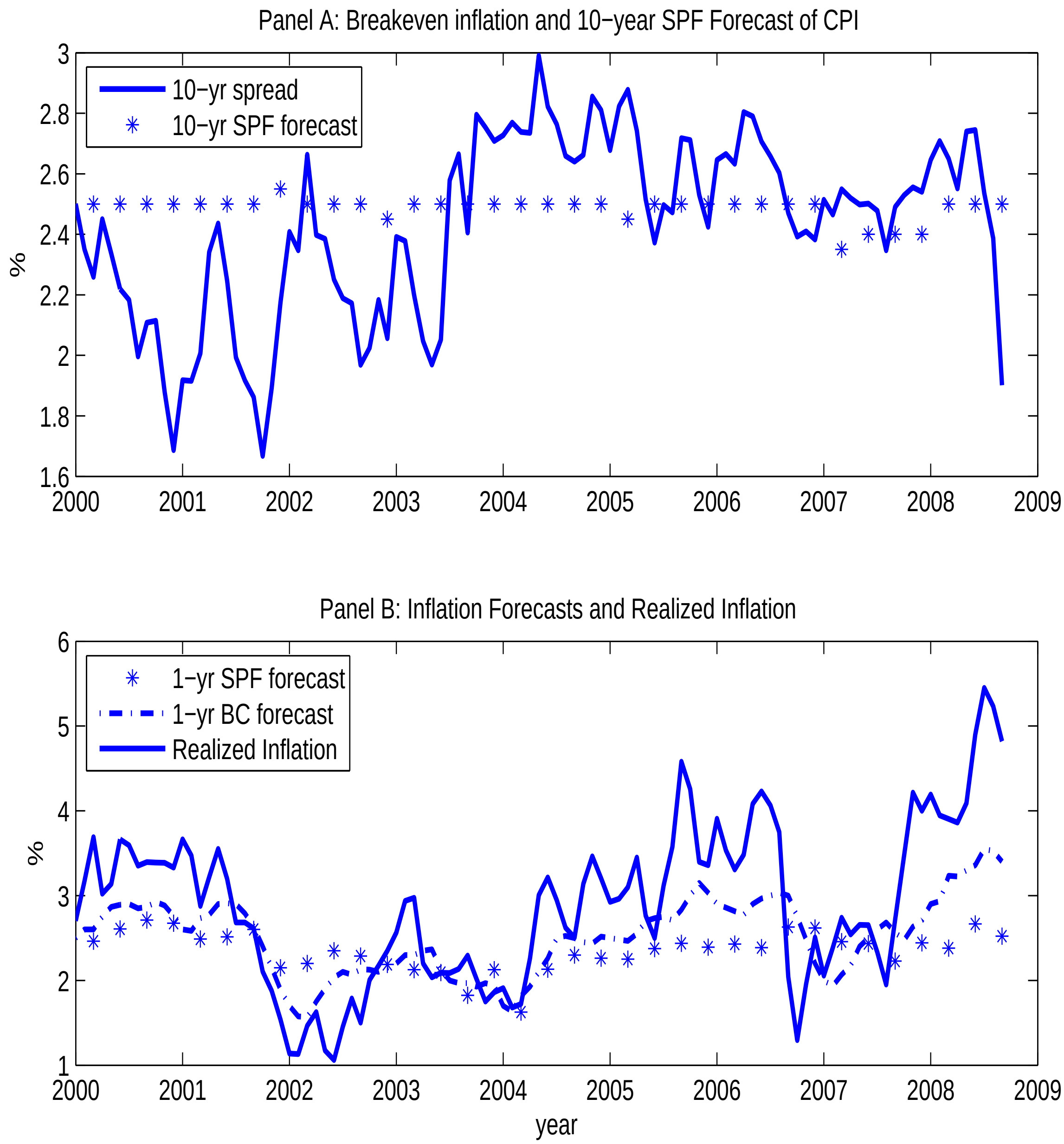

Figure 2: The 10-year breakeven inflation rate, inflation forecasts based on surveys, and realized one-year inflation rates.

Panel A shows the 10-year breakeven inflation rate (the 10-year nominal-real yield spread) and the Survey of Professional Forecasters 10-year ahead (CPI) inflation forecast. Panel B plots one-year ahead CPI forecasts by the Survey of Professional Forecasters and Blue Chip Forecasters, and realized one-year CPI inflation. The sample period is January 2000 - September 2008.

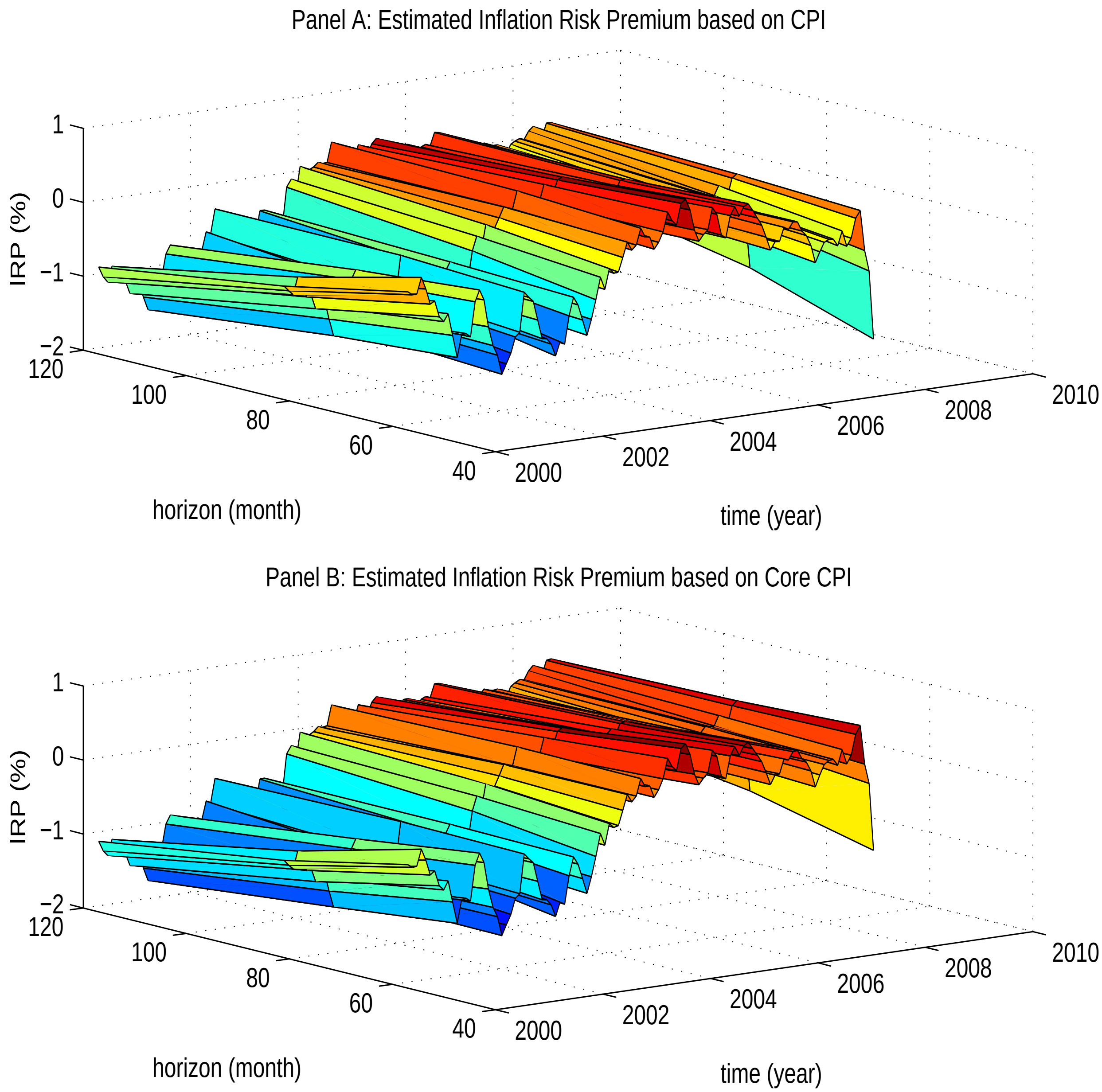

Figure 3: The term structure of the inflation risk premium

This figure displays the term structure of the inflation risk premium estimated using the historical-based inflation forecast reported in Table 4. Estimation period of inflation forecast used is five years. Panel A shows the inflation risk premium based on the CPI (more precisely, CPI-U). Panel B plots the inflation risk premium based on the seasonally adjusted core CPI (that excludes food and energy prices). Sample period is January 2000 - September 2008, monthly frequency.

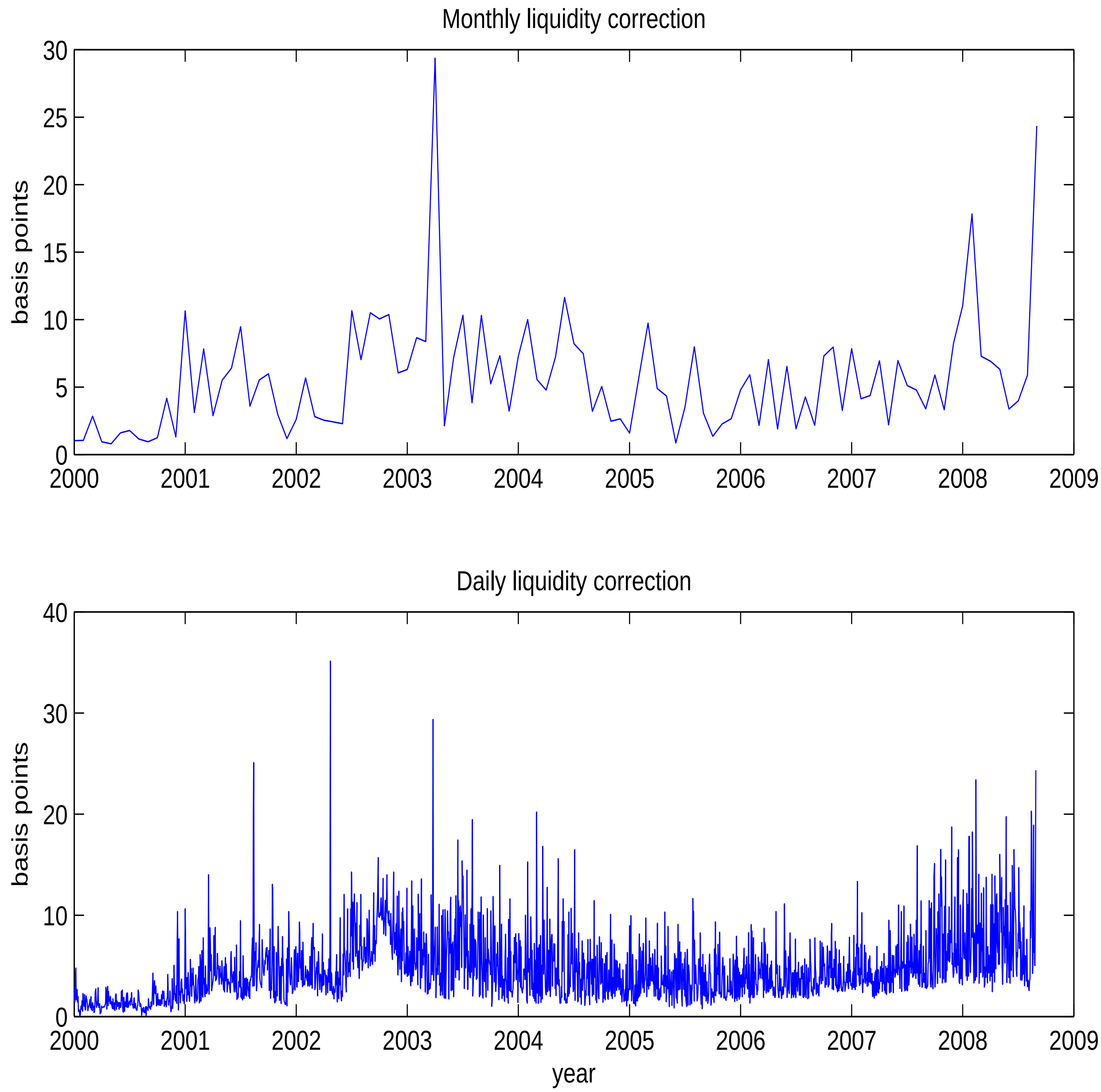

Figure 4: Liquidity component of TIPS yields

This figure plots liquidity correction embedded in the TIPS yields. Panels A and B display this correction at monthly and daily frequency in basis points, respectively. Liquidity correction is the root mean square error between observed TIPS yields of individual securities and Svensson (1994) model implied TIPS yields of maturities 3 to 10 years. Sample period is January 2000 - September 2008.

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The TIPS Yield Curve and Inflation Compensation†

By Refet S. Gürkaynak, Brian Sack, and Jonathan H. Wright*

For over ten years, the Treasury has issued index-linked debt. This paper describes the methodology for fitting a smoothed yield curve to these securities that is used at the Federal Reserve Board every day, and makes the estimates public. Comparison with the corresponding nominal yield curve allows measures of inflation compensation to be computed. We discuss the interpretation of inflation compensation, and provide evidence that it is not a pure measure of inflation expectations being distorted by inflation risk premium and liquidity premium components. We attempt to estimate the TIPS liquidity premium and to extract underlying inflation expectations. (*JEL* E31, E43, H63)

For over ten years, the US Treasury has issued Treasury Inflation-Protected Securities (TIPS)—debt securities for which the coupon and principal payments are indexed to the consumer price index (CPI)—in addition to conventional nominal bonds. However, for nominal securities and TIPS, the Treasury issues only securities with particular maturities and coupon rates. Thus, it is not possible to directly observe the nominal or real discount factors from these issues.

In a previous paper (Gürkaynak, Sack, and Wright 2007), we estimated a smoothed nominal Treasury yield curve from the outstanding off-the-run nominal Treasury notes and bonds. The results allowed us to compute the nominal discount factor, as well as to compute nominal Treasury yields and forward rates at any horizon. The first part of this paper is the sequel to Gürkaynak, Sack, and Wright (2007) that fits a similar yield curve to outstanding TIPS. The results allow us to recover the real discount function, as well as real Treasury yields and forward rates, at a daily frequency going back to 1999. These data are available in an online Appendix at www.federalreserve.gov/econresdata/researchdata.htm and are updated periodically.

A comparison of the nominal and TIPS smoothed yield curves allows us to compute measures of inflation compensation—the rate of inflation that would give an

* Gürkaynak: Department of Economics, Bilkent University, 06800 Ankara, Turkey (e-mail: refet@bilkent.edu.tr); Sack: Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10038 (e-mail: Brian.Sack@ny.frb.org); Wright: Department of Economics, Johns Hopkins University, Baltimore, MD 21202 (e-mail: wrightj@jhu.edu). We are grateful to Stefania D'Amico, Jennifer Roush, Michelle Steinberg, Min Wei, and an anonymous referee. We are also grateful to Katherine Femia for excellent research assistance. Gürkaynak gratefully acknowledges the research support of the Turkish Academy of Sciences via a TÜBA-GEBIP fellowship. All of the authors were involved in real yield curve and inflation compensation estimation at the Federal Reserve Board when working at that institution. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other employee of the Federal Reserve System.

† To comment on this article in the online discussion forum, or to view additional materials, visit the articles page at: http://www.aeaweb.org/articles.php?doi=10.1257/mac.2.1.70.

investor the same return on a nominal security and an indexed security at maturity. These measures are also known as breakeven inflation rates among financial market participants. These yield curves (nominal, TIPS, and inflation compensation) can be expressed in terms of zero-coupon yields, par yields, instantaneous forward rates, or n-by-m forward rates (that is, the m-year rate beginning n years ahead) for any n and m.

After describing how we fit the real yield curve, we provide a discussion of how to interpret the resulting measures. We pay particular attention to the measures of inflation compensation in this regard. These measures are often thought of as being driven by investors' expectations of inflation. However, we argue that high-frequency movements in inflation compensation are considerably too volatile to represent revisions to rational expectations of inflation alone. Inflation compensation provides information about agents' inflation expectations, but its interpretation is complicated by inflation risk premia and the differential liquidity premia between TIPS and nominal securities. We provide support for this view by analyzing the time series properties of inflation compensation and actual inflation, and by comparing inflation compensation to survey respondents' inflation forecasts. Among other results, we show that inflation compensation is related to the dispersion of survey forecasts, more than to the level of those forecasts, consistent with a view that a risk premium reflecting inflation uncertainty is an important element of inflation compensation.

Section I describes the mechanics of TIPS and briefly discusses the operation of the TIPS market. Section II describes the yield curve fitting exercise. Section III shows the results of our estimation, including an assessment of the fit of the TIPS curve. Section IV provides empirical evidence indicating that inflation compensation is not a pure measure of inflation expectations. Section V delves deeper into the interpretation of inflation compensation by providing a decomposition into its components: the liquidity premium, the inflation risk premium, and inflation expectations. Section VI offers some concluding thoughts. The yield curve data described here are updated daily and posted on the Federal Reserve Board's Web site (www.federalreserve.gov/econresdata/researchdata.htm).

I. The TIPS Market

A nominal Treasury security pays the holder a coupon twice a year and the principal value at maturity. The coupon and principal value are fixed in nominal terms, and their real value will be eroded over time by inflation. For TIPS, the principal payment is multiplied by the ratio of the reference CPI on the date of maturity to the reference CPI on the date of issue.[1] If the maturity or issue date falls on day d_t of a month with d_n days, then the reference CPI is

$$CPI(-2)\frac{d_t - 1}{d_n} + CPI(-3)\frac{d_n - d_t + 1}{d_n},$$

[1] Unless this ratio is less than one, in which case no adjustment is made. This consideration became important for newly issued bonds during the deflation scare in 2003 and again in 2008.

where $CPI(-2)$ and $CPI(-3)$ denote the nonseasonally adjusted US City Average All Items Consumer Price Index for the second and third months prior to the month in which the maturity or issue date falls, respectively. The reason for the indexation lag is that the Bureau of Labor Statistics publishes these data with a lag, with the index for a given month released in the middle of the subsequent month.[2] Coupons are indexed in precisely the same way.[3] In effect, this gives TIPS an indexation lag of about two-and-a-half months.

The first TIPS were issued in 1997. The Treasury initially sold 5-, 10-, and 30-year TIPS. The 5-year TIPS were dropped in September 1998, and the 30-year TIPS were dropped in October 2001. Subsequently, the 5-year TIPS were reintroduced, and 20-year TIPS were added in May 2004. As of the time of this writing, there are 27 outstanding TIPS with maturity dates ranging from 2009 to 2032.

Liquidity in TIPS was initially poor, and investor participation in the market was limited, either due to lack of familiarity with the asset class or, in some cases, institutional rules preventing these securities from being held. Another important factor shaping the market was that, for a time, the long-term future of TIPS was unclear. For example, in May 2001, the Treasury Advisory Committee of the Bond Market Association recommended that the TIPS program be discontinued. However, the Treasury subsequently reaffirmed its commitment to the program, and liquidity improved substantially. TIPS now represent about 10 percent of the outstanding supply of Treasury coupon securities.[4] It is now the largest sovereign index-linked market in the world, measured in terms of the par value of outstanding issuance. More detail on the history and liquidity of the TIPS market is provided by Sack and Elsasser (2004).

II. Yield Curve Fitting

We begin this section by reviewing the fundamental concepts of the yield curve, including the necessary "bond math" for determining both nominal and TIPS yields. Then, we describe the specific estimation method employed in this paper.

A. *Discount Function and Zero-Coupon Yields: Nominal and Real*

The starting point for pricing any nominal fixed-income asset is the *nominal discount function*, or the price of a nominal zero-coupon bond. This represents the value today to an investor of a \$1 nominal payment n years hence. We denote this

[2] David G. Barr and John Y. Campbell (1997) discuss the indexation lag for UK index-linked bonds, which was eight months for bonds issued at the time they wrote the paper.

[3] Except that the constraint that the adjustment factor cannot be less than one does not apply to the indexation of coupons. Thus, a period of deflation could lower the coupon payments, but the cumulative adjustment to the principal can never be negative.

[4] According to an informal survey of dealers conducted by the Federal Reserve Bank of New York in 2007, typical TIPS bid-ask spreads at maturities of five years or less were one-half to one tick (a tick is roughly one-thirty-second of a percentage point of the price of the security). At maturities around ten years, the spread is one to two ticks. At longer maturities, the spread is four to ten ticks. These spreads are a bit tighter than those observed in 2003, as discussed by Brian Sack and Robert Elsasser (2004).

as $P_t^{nom}(n)$. The continuously compounded yield on this nominal zero-coupon bond can be written as

$$y_t^{nom}(n) = -\ln(P_t^{nom}(n))/n, \tag{1}$$

and, conversely, the zero-coupon bond price can be written in terms of the yield as

$$P_t^{nom}(n) = \exp(-y_t^{nom}(n)n). \tag{2}$$

Here, and throughout, yields and coupon rates are expressed in percentage points. For example, 1 percent is written 0.01.

In the same way, we consider a *real discount function*, or the price of a real zero-coupon bond. We denote this as $P_t^{real}(n)$. This represents the value today to an investor of a $\$Q_{t+n}/Q_t$ payment n years hence, where Q_t denotes the price index at time t.[5] The continuously compounded nominal yield on this bond is $\ln(Q_{t+n}/Q_t P_t^{real}(n))/n$. The continuously compounded real yield on this bond can be written as $y_t^{real}(n) = -\ln(P_t^{real}(n))/n$. Throughout this paper, we discuss real bonds in terms of their real yields and nominal bonds in terms of their nominal yields.

B. *Par Yields and Forward Rates*

There are a number of ways to express the information in the nominal yield curve in addition to continuously compounded zero-coupon yields. One way is to solve for the coupon rate, which ensures that the price of the bond today will equal its maturity price. This is known as the par yield, and it is the market convention used to describe bond yields. Par yields are quoted with semiannual compounding because coupons on US Treasury securities are paid twice per year. An alternative way of describing the yield curve is in terms of forward rates. We can solve for continuously compounded instantaneous forward rates at all horizons. Or, we can solve for m-year forward rates beginning n-years hence.[6]

All of these concepts apply to TIPS and nominal securities, giving us two parallel sets of yields. In this paper, let $f_t^{nom}(n)$ and $f_t^{real}(n)$ denote the n-period ahead nominal and real instantaneous forward rates, and let $f_t^{nom}(n,m)$ and $f_t^{real}(n,m)$ denote the m-year nominal and real forward rates beginning n years hence, respectively. In addition, we will use $y_t^{p,nom}(n)$ and $y_t^{p,real}(n)$ to denote the n-year nominal and real par yields, respectively.

C. *The Nelson-Siegel-Svensson Yield Curve*

When fitting yield curves, one faces a tradeoff between the goodness of fit and smoothness of the curve. Spline-based nonparametric curves can fit the yields of individual securities arbitrarily closely, but at the cost of being quite jagged. The

[5] In this discussion, we are abstracting from the indexation lag.

[6] To further confuse matters, the m-year forward rates can be expressed as either zero-coupon forward rates or par forward rates.

choice, in this dimension, depends on the purpose that the yield curve is intended to serve. For example, John H. Cochrane and Monika Piazzesi (2008) argue that the fourth and fifth principal components of the nominal yield curve (that explain a tiny share of the variation in yields) are, nonetheless, very useful for forecasting excess returns. If so, in forecasting excess returns, using a smoothed curve could lose the information in the fourth and fifth principal components. On the other hand, if the purpose of the yield curve is to understand its fundamental macroeconomic determinants, a spline-based curve may produce implausibly jagged yields, and especially forward rates, that will not be very useful in macroeconomic analysis. Our TIPS yield curve is designed primarily for macroeconomic interpretation and policy analysis. Thus, rather than fitting a spline-based curve, we impose some structure on the shape by imposing a parametric form that fits the TIPS yields remarkably well. The benefit of the parametric approach is that it smoothes through the idiosyncratic movements in yields of individual securities and accurately represents the underlying shape of the (real) discount function.

The yield curves that we fit assume that the instantaneous forward rates (whether real or nominal) follow the functional form

$$(3)\qquad f_t(n) = \beta_0 + \beta_1 \exp(-n/\tau_1) + \beta_2(n/\tau_1)\exp(-n/\tau_1) + \beta_3(n/\tau_2)\exp(-n/\tau_2).$$

This structure was proposed by Lars E. O. Svensson (1994) and is an extension of the functional form used earlier by Charles R. Nelson and Andrew F. Siegel (1987). We refer to it as the NSS (Nelson-Siegel-Svensson) functional form. The original Nelson-Siegel functional form is a special case of (4) in which $\beta_3 = 0$. Integrating these forward rates gives us the corresponding zero-coupon yields:

$$(4)\qquad y_t(n) = \beta_0 + \beta_1\frac{1-\exp(-\frac{n}{\tau_1})}{\frac{n}{\tau_1}} + \beta_2\left[\frac{1-\exp(-\frac{n}{\tau_1})}{\frac{n}{\tau_1}} - \exp(-\frac{n}{\tau_1})\right]$$

$$+ \beta_3\left[\frac{1-\exp(-\frac{n}{\tau_2})}{\frac{n}{\tau_2}} - \exp(-\frac{n}{\tau_2})\right].$$

The assumed functional form of the forward rates (and, hence, yields) has some intuitive characteristics. As discussed in more detail in Gürkaynak, Sack, and Wright (2007), it allows the forward rate curve the flexibility to start and end at estimated parameters, and to have a hump-shaped pattern in between. The Nelson-Siegel functional form effectively allows for only one hump, whereas the Svensson curve allows for two humps, which is important to capture convexity effects at longer horizons. The estimated parameters will determine the magnitude and location of these humps.

Given any candidate set of parameters, we can use (4) to solve for the nominal and real discount factors. With these discount factors, we can construct a predicted price

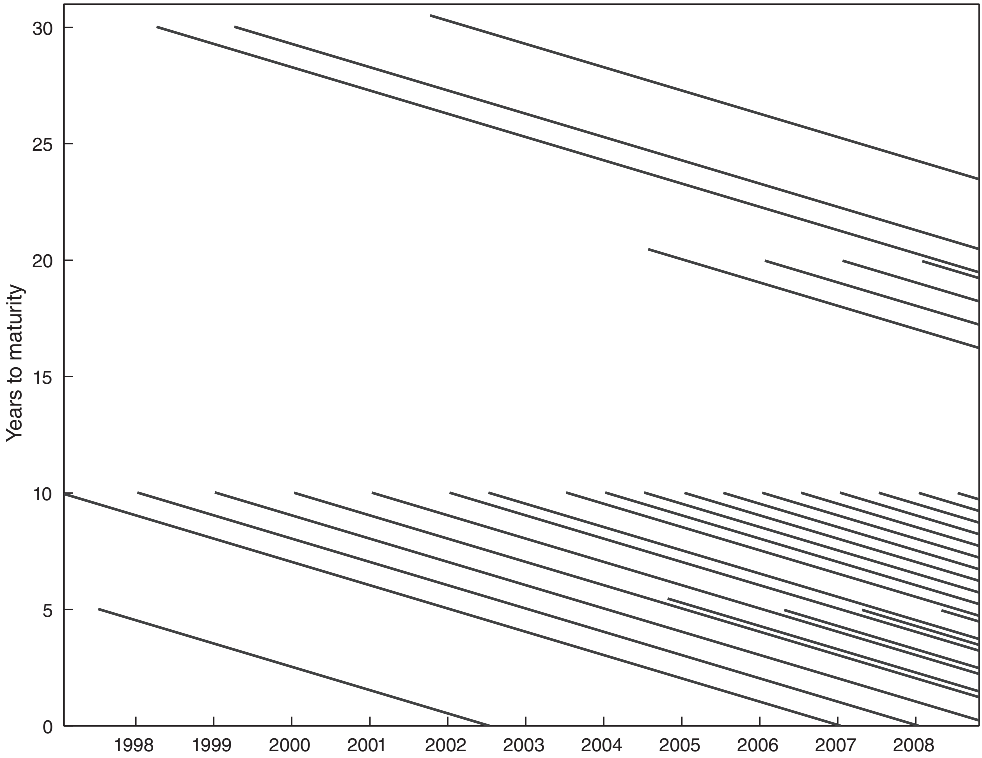

Figure 1. Outstanding TIPS Securities

for any Treasury security (nominal or real) with a given maturity date and coupon rate by considering it to be a bundle of zero-coupon securities, one corresponding to each payment on the security, with the value of each payment determined by the appropriate discount factor. We estimate the nominal and TIPS yield curves by numerically choosing the set of parameters so as to minimize the weighted sum of squared deviations between actual and predicted prices. The weights are the inverse of the durations of each individual security.[7]

The ranges of maturities available for estimation over our sample are shown graphically in Figure 1, which takes the same form as a figure reported by Robert R. Bliss (1996). The date is shown on the horizontal axis, the remaining maturity is shown on the vertical axis, and each outstanding TIPS security is represented by a line plotting its remaining years to maturity against the date.

As noted before, the Svensson curve allows for two humps, while the original Nelson-Siegel functional form allows for just one hump. The second hump is, however, not well identified unless we have enough long-term securities. For the nominal yield curve, we used the restricted functional form up until 1980, then switched to the Svensson parameterization because more long-term nominal Treasury securities

[7] Weighting price by inverse duration converts the pricing errors into yield fitting errors, to a first approximation. Fitting inverse-duration-weighted prices, rather than yields, is preferable because it is computationally much faster and delivers essentially the same yield curve.

became available to estimate the shape of more distant forward rates. Following similar reasoning, and given the maturities available, as shown in Figure 1, for the TIPS yield curve, we used the more restricted functional form through the end of 2003, and then we switch to the Svensson parameterization as the issuance of 20-year TIPS helped the estimation.

TIPS with less than 18 months to maturity are dropped from the estimation of the TIPS yield curve because the effect of the indexation lag makes the prices of these securities erratic. TIPS with remaining maturity between 18 and 24 months are downweighted linearly for smooth behavior of the short-end of the curve over time. All other TIPS are included in estimation of the TIPS yield curve.

D. *Inflation Compensation*

Having computed nominal and TIPS yields, it is straightforward to solve for rates of inflation compensation. These rates are defined as the inflation rates which, if realized, would leave an investor indifferent between holding a TIPS and a nominal Treasury security.

The formula is simplest for the continuously compounded zero-coupon inflation compensation rate at maturity n:

$$\pi_t(n) = y_t^{nom}(n) - y_t^{real}(n).$$

It simply states that the cumulative amount of inflation needed to equalize the return on nominal and real zero-coupon securities, expressed as an annual inflation rate on a continuously compounded basis, is given by the difference in the nominal and real yields. Similarly, the continuously compounded instantaneous forward inflation compensation rate is

$$\pi_t^f(n) = f_t^{nom}(n) - f_t^{real}(n).$$

For par securities, the semi-annually compounded inflation compensation rate is given by:

$$\pi_t^p(n) = 2\left(\frac{1 + \frac{y_t^{p,nom}(n)}{2}}{1 + \frac{y_t^{p,real}(n)}{2}} - 1\right).$$

III. Yield Curve Results

Using the methodology described above, we estimate the US TIPS yield curve using daily data from January 1999 to the present (the data used in the paper are through October 21, 2008). Our underlying quotes on individual TIPS were provided to us by Barclays Capital Markets.[8] The quotes are the averages of bid and ask prices.

[8] We are not permitted to release the underlying data. However, the estimated yield curve is publicly available and regularly updated, as described in the text.

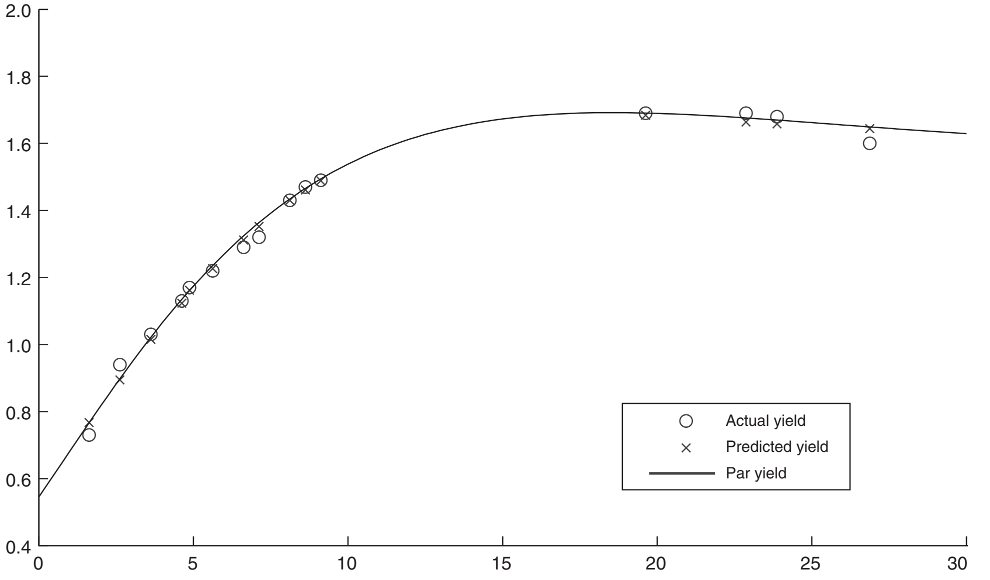

Figure 2. Par TIPS Yield Curve on June 1, 2005

As an example of the results, Figure 2 shows the estimated TIPS yield curve on June 1, 2005. The solid line is the continuously compounded par yield curve, the circles are the actual quotes on all outstanding coupon securities included in the estimation, and the crosses are the predicted yields for these issues.[9]

As can be seen, the yield curve does an impressive job fitting the entire cross-section of TIPS issues with a function of only six parameters. The success at fitting TIPS yields on this date is repeated throughout the sample. Figure 3 shows the average absolute yield prediction error in different maturity buckets over time. As can be seen, all of the errors are quite small over the entire sample. The largest fitting errors tend to be seen in the very shortest (2–5 year) and longest (20–30 year) maturity buckets, and even there, the typical errors are only a few basis points.

Figure 4 returns to the specific date considered in Figure 3, only now it shows the zero-coupon TIPS yield curve and the instantaneous forward rates at all horizons, as well as the corresponding measures for inflation compensation. In June 2005, the Federal Reserve was in the middle of a tightening cycle. The TIPS yield curve sloped up at that time, reflecting expectations for the continued removal of monetary policy accommodation and, perhaps, a real interest rate risk premium that was increasing in maturity. Because of convexity effects, the upward slope of the zero-coupon TIPS yield curve tapers off at long horizons, and eventually turns down. Accordingly, the forward rates turn down earlier and much more sharply. Inflation compensation slopes down at short to intermediate maturities, perhaps reflecting expectations for a moderation in headline inflation, but then slopes up at intermediate and longer

[9] That is, the crosses are consistent with the par yields shown in the line. They are not exactly on the par curve because the outstanding securities are not trading precisely at par.

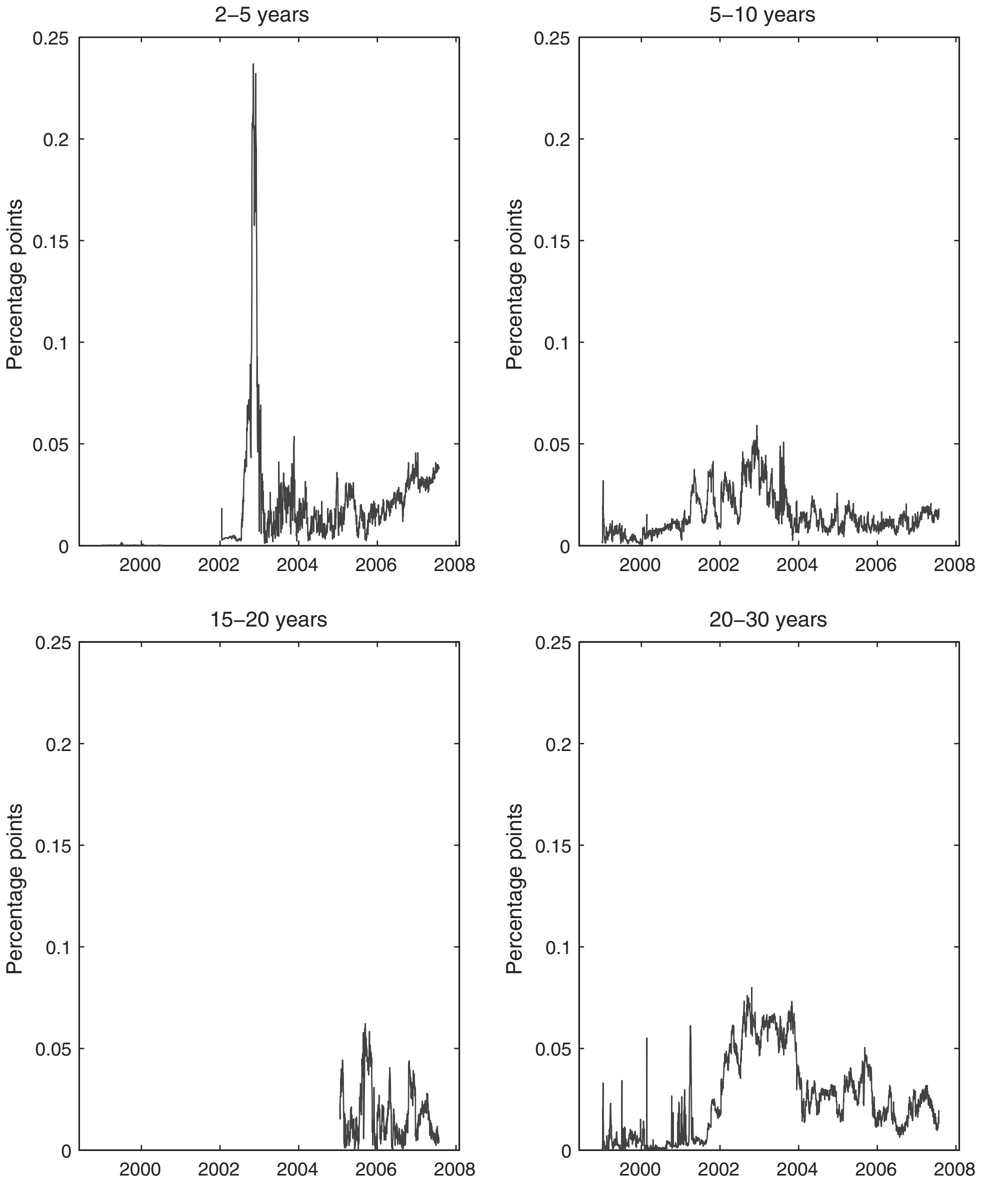

FIGURE 3. AVERAGE ABSOLUTE YIELD PREDICTION ERRORS BY INDICATED MATURITY BIN

maturities, presumably owing, in part, to an inflation risk premium that is increasing in maturity.

The history of 5- and 10-year zero-coupon nominal and TIPS yields is shown in Figure 5. In 1999, TIPS yields were high, reflecting, in part, the premium that investors demanded to induce them to hold these assets that were then quite illiquid. TIPS yields subsequently declined sharply as liquidity improved and the FOMC eased monetary policy to combat the 2001 recession. The FOMC began to tighten monetary policy again in the middle of 2004. Five-year zero-coupon nominal and

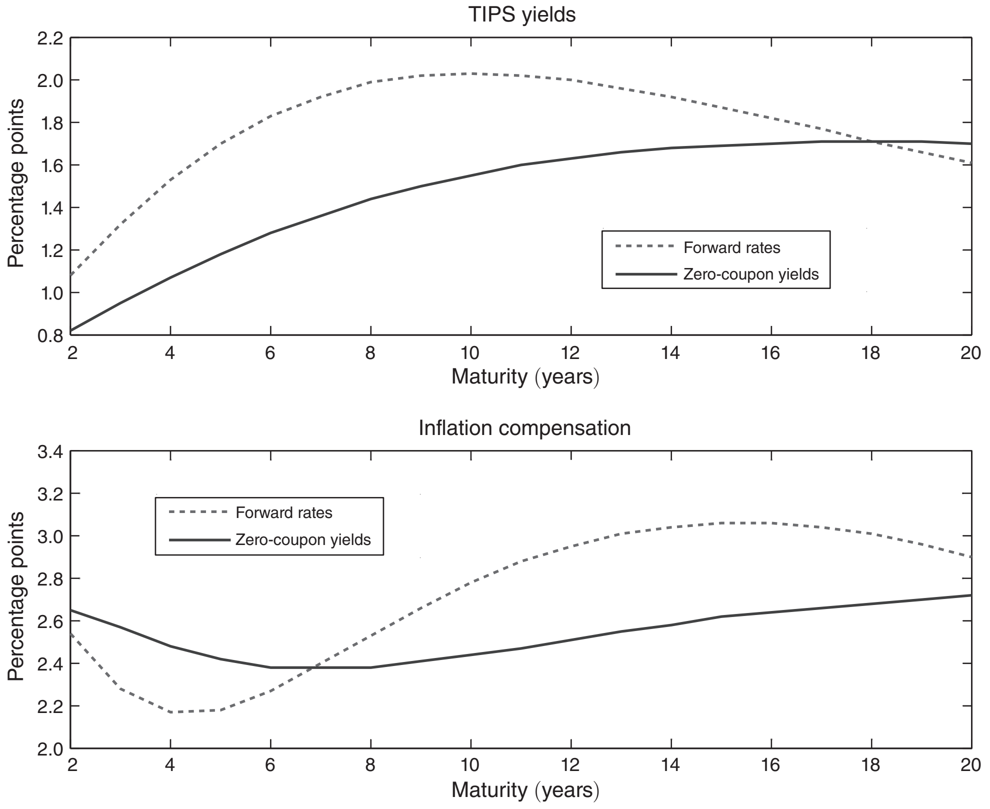

Figure 4. Zero-Coupon and Forward Rates on June 1, 2005

TIPS yields began to rise, as expected, but ten-year yields fell for a while, a phenomenon called the "conundrum" by former Federal Reserve Chairman Alan Greenspan and discussed in Don H. Kim and Wright (2005) and David K. Backus and Wright (2007).

The second half of 2007 and early 2008 were marked by the onset of turmoil in financial markets, and monetary policy was eased sharply to support economic growth. Accordingly, real rates plunged, with the five-year TIPS yield falling close to zero, and, indeed, shorter-term TIPS yields were negative. TIPS yields can and do fall below zero.[10] However, real yields rebounded starting in late 2008, as financial market conditions continued to deteriorate, even though monetary policy was eased further. This could reflect expectations for greater bond issuance caused by the "bailout" of financial institutions. Also, it could reflect the greater premium that investors demanded to hold relatively less liquid TIPS securities at a time of financial market stress.

[10] The Treasury Department has issued rules on how a TIPS auction would be conducted in a negative real rate environment. The coupon would be set to zero, and TIPS would sell for below par value, at a price determined at auction. However, our fitted TIPS yields have never fallen below zero at the maturities at which the Treasury Department conducts auctions, and there has never been a negative-yield TIPS auction.

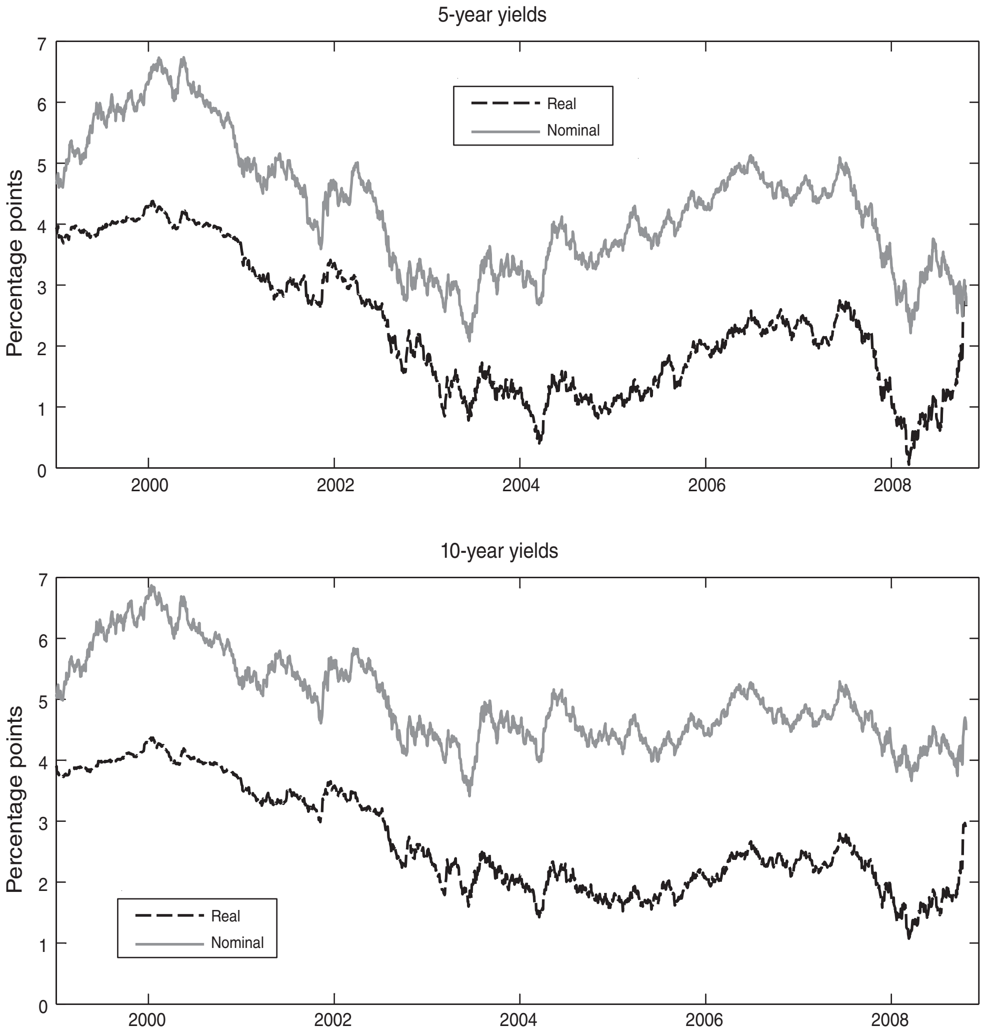

Figure 5. Zero-Coupon Yields: TIPS and Nominal

The behaviors of 5- and 10-year zero-coupon and instantaneous forward inflation compensation over the sample are shown in Figure 6. Inflation compensation was quite low in 1999, reflecting the poor liquidity of TIPS relative to nominal securities (the counterpart of the high TIPS yields at that time). Breakeven inflation rates tended to drift higher through 2003, in part because of the improvement in TIPS liquidity. In addition, investors may have become more concerned about upside inflation risks by early 2004, in light of the updrift in realized inflation, the rebound in growth, and the continued accommodative stance of monetary policy.

At the very end of the sample period, five- and ten-year inflation compensation plummeted, presumably reflecting expectations for economic weakness to restrain inflation, and also, a further spike in the compensation that investors demand for the relatively low liquidity of TIPS. Distant-horizon forward measures of inflation

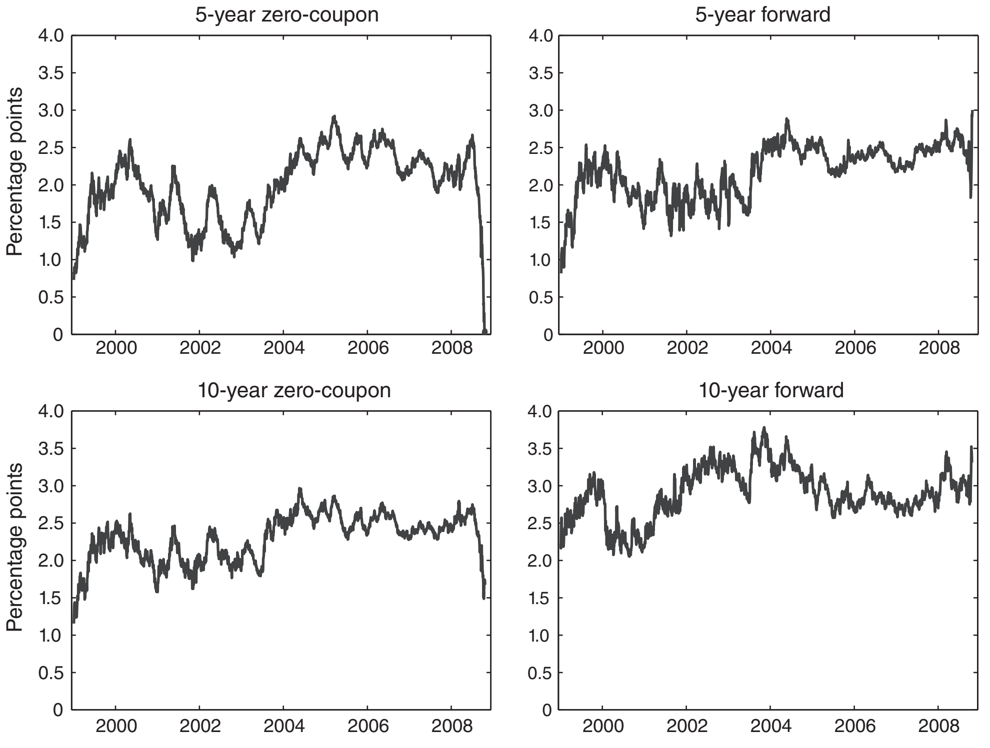

Figure 6. Inflation Compensation

compensation, however, increased somewhat, which could reflect a concern that the exceptional policy actions being undertaken in response to the credit crisis may lead to higher inflation in the long run.

One inflation compensation measure that is of particular interest is the five-year forward five-year rate (also known as the five-year five-year forward breakeven inflation rate), because it has been explicitly mentioned in speeches by a number of Fed policymakers. The behavior of this measure is often taken as a gauge of the Fed's inflation-fighting credibility. Policymakers seem to look to this measure to help judge whether near-term inflation pressures are working their way into long-term expectations. The concern is that such leakage would create a more persistent inflation problem that would be costly to reverse. If the Fed maintains its credibility, then the forward inflation compensation measure should be relatively unresponsive to information about the near-term outlook.[11] This measure, which can be derived from our yield curves as a par forward rate over a five-year horizon, is shown in Figure 7. It shares many of the same properties of the instantaneous forward rates discussed previously.

[11] The view that forward inflation compensation rates cannot be read as pure inflation expectations because of the presence of an inflation risk premium and a liquidity premium provides some room for the measure to vary without raising concerns among policymakers. However, risks to the inflation outlook are also important, and a large enough rise would be concerning to a central bank, regardless of whether it was driven by inflation expectations or investors' assessment of considerable upside inflation risks.

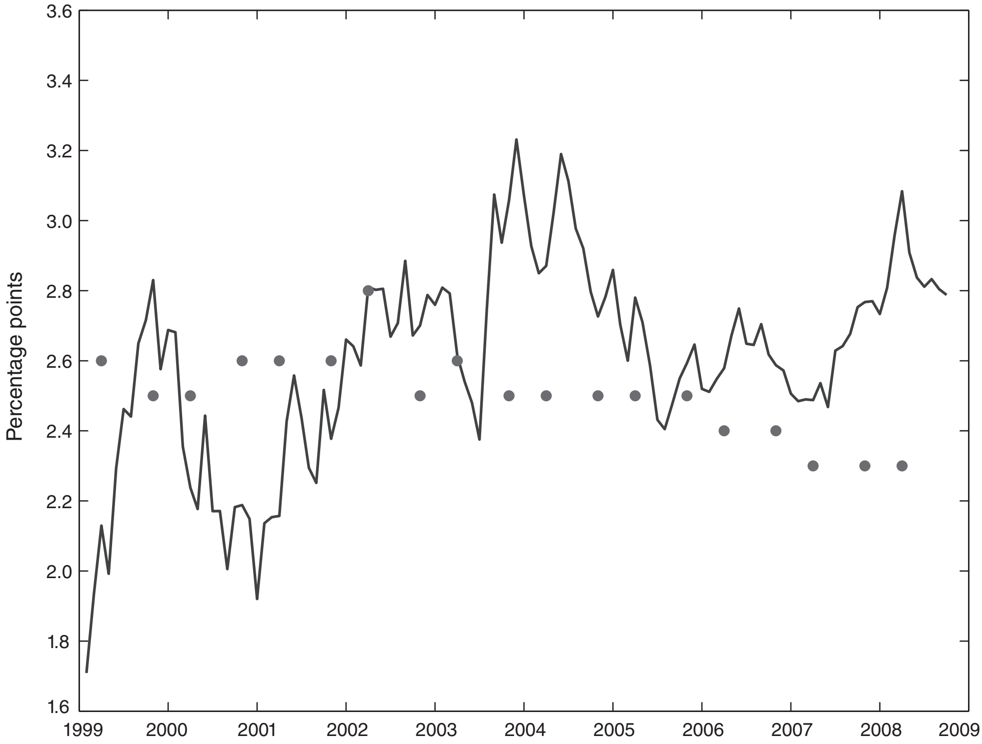

Figure 7. Five-to-Ten Year Forward Inflation Compensation and Blue Chip Forecasts

Notes: The solid line gives forward par inflation compensation. The dots are the Blue Chip survey inflation expectations.

The yield curve estimated above is intended to be flexible enough to capture the general shape of TIPS yields while smoothing through some of the factors that might affect individual securities. One such factor is the seasonality of CPI.[12] Because TIPS are indexed to nonseasonally adjusted CPI, the yield on an individual security will reflect the expected seasonal change in the index ratio between the quote date (or more specifically the settlement date) and the maturity date of the security. This has two effects. It causes some variation in yields over time, as the seasonality of the quote date changes. And, it causes some variation across individual securities. For example, TIPS securities that mature in April tend to have higher yields and lower breakeven rates than those maturing in January because the CPI seasonal factor corresponding to the April maturity is much lower than that corresponding to the January maturity (reducing the price of the April TIPS and raising their yield). At longer maturities, the impact of the seasonal pattern gets amortized over a longer period, and is negligible, but it can be important at shorter horizons. The NSS yield curve, however, smoothes through this variation across maturity months. This

[12] Jacob Ejsing, Juan Angel Garcia, and Thomas Werner (2007) study the seasonal effect in euro area inflation compensation and show that for very short maturities the magnitudes involved are nontrivial.

Table 1—Description of the Series in the Data Appendix

Series	Compounding convention	Mnemonics	Maturities reported (max)
TIPS yields			
Zero-coupon	Continuously comp.	TIPSYXX	All integers 2–20
Par	Coupon-equivalent	TIPSPYXX	All integers 2–20
Instantaneous forward	Continuously comp.	TIPSFXX	All integers 2–20
One-year forward	Coupon-equivalent	TIPS1FXX	4 and 9
Five-to-ten-year forward	Coupon-equvalent	TIPS5F5	
Parameters	N/A	BETA0 to TAU2	N/A
Inflation compensation			
Zero-coupon	Continuously comp.	BKEVENYXX	All integers 2–20
Par	Coupon-equivalent	BKEVENXX	All integers 2–20
Instantaneous forward	Continuously comp.	BKEVENFXX	All integers 2–20
One-year forward	Coupon-equivalent	BKEVEN1FXX	4 and 9
Five-to-ten-year forward	Coupon-equivalent	BKEVEN5F5	

Notes: XX in each case denotes the maturity in years. For example, TIPSY10 denotes the ten-year zero-coupon yield. The one-year forward rates in XX years denote the one-year forward rates *beginning* XX years hence. For example, TIPS1F09 is the one-year forward rate from nine to ten years hence. The parameters are labeled BETA0, BETA1, BETA2, BETA3, TAU1, and TAU2, corresponding to the equations in the text. Note that the parameters BETA3 and TAU2 are restricted to zero in the earlier part of the sample, as discussed in the text.

feature is desirable for our curve, as it is designed to extract information about macroeconomic expectations and risks.[13]

The Appendix on the Federal Reserve Web site www.federalreserve.gov/econresdata/researchdata.htm provides data on zero-coupon yields (continuously compounded), instantaneous forward rates (continuously compounded), and par yields (coupon-equivalent) for TIPS securities at a range of maturities, as well as the five-year forward par five-year TIPS yield (coupon-equivalent). The maturities included span 5–20 years for the period through 2004, and 2–20 years since 2004 (when we use the more flexible specification, as discussed above). Yields at maturities below five years are not reported before the end of 2004 because, as can be seen in Figure 1, this would, at times, have entailed extrapolating the TIPS yield curve outside of the range of maturities that were actually outstanding. Meanwhile, yields for maturities below two years are never reported because the shortest maturity TIPS are excluded from our smoothed yield curve due to the effects of the indexation lag and seasonality in the CPI.

The data are daily and are available back to January 4, 1999. The online Appendix also includes estimates of the six parameters of the NSS TIPS yield curve and the zero-coupon, instantaneous forward and par rates of inflation compensation, and the five-year forward five-year rate of inflation compensation. This Appendix uses mnemonics described in Table 1. The data will be updated regularly as a resource for academic researchers and financial market practitioners.

[13] One might design a different curve, or append this one with additional analysis, if the main purpose is to gauge the relative value of specific securities.

IV. Inflation Compensation and Inflation Expectations

Inflation compensation is a mechanical calculation of the level of inflation which, if realized, would give investors the same return on TIPS and nominal Treasury securities. It is often used as a measure of inflation expectations, but this is correct only if investors are risk neutral, and there is no liquidity premium. Our interpretation of movements in inflation compensation has stressed the existence of factors other than inflation expectations. In this section, we provide some further analysis supporting the view that variation in the inflation risk premium and the liquidity premium are also part of the behavior of inflation compensation. Inflation compensation is inflation expectations *plus* an inflation risk premium *minus* a liquidity premium that investors demand to hold comparatively less liquid TIPS securities.

A. *The Volatility of Forward Inflation Compensation Rates*

In this subsection, we address whether distant-horizon forward rates of inflation compensation can be viewed simply as measures of the long-run expected level of inflation, or the implicit inflation target of the central bank. If a ten-year forward rate of inflation compensation really is the rational long-run expectation of inflation, then it should be a martingale. Otherwise, the expectation of the long-run expectation of inflation tomorrow would differ from the long-run expectation of inflation today, which is impossible under rational expectations by the law of iterated expectations.

More precisely, let $\pi_t^f(10)$ and $\pi_t^f(10-)$ denote the ten-year and ten-year-less-one-day forward rates of inflation compensation.[14] If the forward rates of inflation compensation represent inflation expectations, then $E_t(\pi_{t+1}^f(10-) - \pi_t^f(10)) = 0$, and $x_t = \pi_{t+1}^f(10-) - \pi_t^f(10)$ is a martingale difference sequence. This hypothesis can be tested by a variance ratio test. Table 2 shows the standard deviation of x_t and $\sum_{j=1}^k x_{t+j}$, where k is 22, 66, or 132, corresponding to 1, 3 and 6 months, respectively. The standard deviation of a one-day change in forward inflation compensation is a bit less than five basis points. If x_t is a martingale difference sequence, then the variance of $\sum_{j=1}^k x_{t+j}$ must be k times the variance of x_t. Table 2 reports variance ratio statistics testing this hypothesis. The test statistic is $z^*(q)$ in the notation of Andrew W. Lo and A. Craig Mackinlay (1988), which means that it is the variance ratio statistic that allows for time-varying conditional heteroskedasticity. Under the martingale hypothesis, this test statistic has a standard normal asymptotic distribution. However, in Table 2, we see that the test rejects in the left tail, meaning that the volatility of longer term changes in inflation compensation is too small relative to the volatility of daily changes for inflation compensation to be a martingale.[15] This, in turn, means there is some tendency to mean reversion in forward inflation compensation. When it is high, it subsequently falls, and vice-versa.

[14] The ten-year-less-one-day rate of inflation compensation can be obtained from our parametric yield curves, assuming 260 business days in a year.

[15] It is well-known that the distribution of this test statistic can be quite far from being standard normal in small sizes (Lo and Mackinlay 1988; Matthew Richardson and James H. Stock 1989). However, those papers find that the left-tail percentiles of the small sample distribution are above their asymptotic counterparts. Under these circumstances, the fact that we reject in the left tail is all the stronger evidence against the martingale hypothesis.

Table 2—Volatility of Changes in Ten-Year Forward Inflation Compensation at Selected Horizons

Horizons	Standard deviation (basis points)	Variance ratio statistic
One day	5.6	
One month	18.8	−3.67**
Three months	26.7	−2.86**
Six months	32.6	−2.35**

Notes: This table shows the standard deviation of one-day and one-, three-, and six-month cumulative values of $x_t = \pi^f_{t+1}(10-) - \pi^f_t(10)$. They are computed assuming 22 days per month. The variance ratio statistic is the heteroskedasticity robust test statistic of Lo and MacKinlay (1988), and has a standard normal asymptotic distribution. The number of daily observations is 2,449.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Stock and Mark W. Watson (2007) find that an unobserved components model with stochastic volatility provides good forecasts for inflation. The model is a univariate model in which inflation is the sum of a martingale permanent component and a martingale difference sequence transitory component. The variance of the innovations to both components is allowed to be time-varying. At any point in time, the forecast of future inflation at any horizon is equal to the estimated permanent component. And the volatility of that forecast is the volatility of the permanent component. Stock and Watson (2007) find the volatility of the permanent component was high in the early 1980s, but has fallen since. Estimating this model on headline CPI has averaged 20 basis points per quarter since the start of 1999. The standard deviation of one-day changes in ten-year inflation compensation is 5.6 basis points. So, if we interpret ten-year inflation compensation as a long-run inflation measure, and appeal to the martingale property that this implies, then the volatility of quarterly changes in long-run inflation expectations should be 45 basis points per quarter, which is more than twice as big as the time-series estimate. Again, it appears that inflation compensation is too volatile at high frequency to represent inflation expectations alone.

B. *Comparison to Surveys of Inflation Expectations*

Twice a year, in March and October, Blue Chip Economic Indicators collects long-range forecasts of CPI inflation, five to ten years hence, from a large number of professional forecasters. It seems worthwhile to compare the survey results with average five-to-ten year forward inflation compensation in each of the survey months. After all, at least at shorter horizons, surveys have been remarkably accurate predictors of future inflation (Andrew Ang, Geert Bekaert, and Min Wei 2007).

Figure 7 shows the time series of the mean survey forecast, in addition to five-to-ten year forward inflation compensation. Inflation compensation has been far more volatile than survey expectations, and the two have no consistent relationship with each other. Since 2002, survey expectations have been consistently below inflation compensation, suggesting that the inflation risk premium (which pushes inflation compensation up) now outweighs the TIPS liquidity premium (which pushes inflation compensation down).[16, 17]

It is also of interest to study the association between inflation compensation and investors' uncertainty about inflation. Macroeconomic uncertainty is very hard to measure, and we are not aware of any survey asking respondents for density forecasts at long horizons. But, the dispersion of long-horizon survey responses may serve as a crude proxy for uncertainty.[18] The Blue Chip surveys report a simple dispersion measure for their long-horizon survey questions, which is the difference between the average of the ten highest forecasts and the average of the ten lowest forecasts. Figure 8 plots the time series of this dispersion measure for CPI and five-to-ten year forward inflation compensation. There is a remarkable, positive association between these two variables. In fact, the correlation between the survey dispersion and five-to-ten year forward inflation compensation in the survey months is 0.71, which seems reasonable if inflation compensation represents, in part, a risk premium that compensates investors for uncertainty about future inflation.

V. Decomposing Inflation Compensation

The previous section showed evidence that inflation compensation is not a pure measure of inflation expectations. In this section, we attempt to decompose inflation compensation into its components: inflation expectations, the liquidity premium, and the inflation risk premium.

A. *The Liquidity Premium*

We estimate the TIPS liquidity premium by regressing inflation compensation on measures of liquidity, following authors such as Long Chen, David A. Lesmond, and Jason Wei (2007), who estimated the effects of liquidity on corporate yield spreads in this way.[19] We use two measures of the relative liquidity of the nominal and index-linked bond markets.[20] The first is the trading volume among primary dealers in TIPS, expressed as a share of total Treasury trading volume, from the FR-2004 survey of primary dealers conducted by the Federal Reserve Bank of New York. This share rose from about 0.5 percent in 1999 to about 2 percent in 2006, as

[16] Our nominal yield curve does not include on-the-run issues, and, so, our inflation compensation numbers are not distorted by the large and time-varying liquidity premia associated with these securities. Nonetheless, to the extent that TIPS are still less liquid than off-the-run nominal securities, inflation compensation may be pushed down by a premium to compensate investors for the differential liquidity of nominal and TIPS securities.

[17] This pattern has implications for the cost of TIPS issuance. In the early years of the TIPS program, TIPS were more expensive than nominal Treasury securities, in terms of their expected servicing cost to the Treasury, as argued by Sack and Elsasser (2004). However, with breakevens moving above expected inflation, the relative costs have been reversed for securities issued more recently, as pointed out by Jennifer E. Roush (2007).

[18] Gürkaynak and Justin Wolfers (2007) show that for several macroeconomic data releases the uncertainty and heterogeneity of beliefs are positively correlated, but that these correlations are not very high. The dispersion of survey answers is likely to capture some element of underlying uncertainty, but is an imperfect measure.

[19] Chen, Lesmond, and Wei (2007) control for measures of default risk. But since both the bonds we are considering are issued by the Treasury, there is no need to control for default risk.

[20] Ideally, we would use bid-ask spreads in the TIPS market, but, unfortunately, we do not have access to such data.

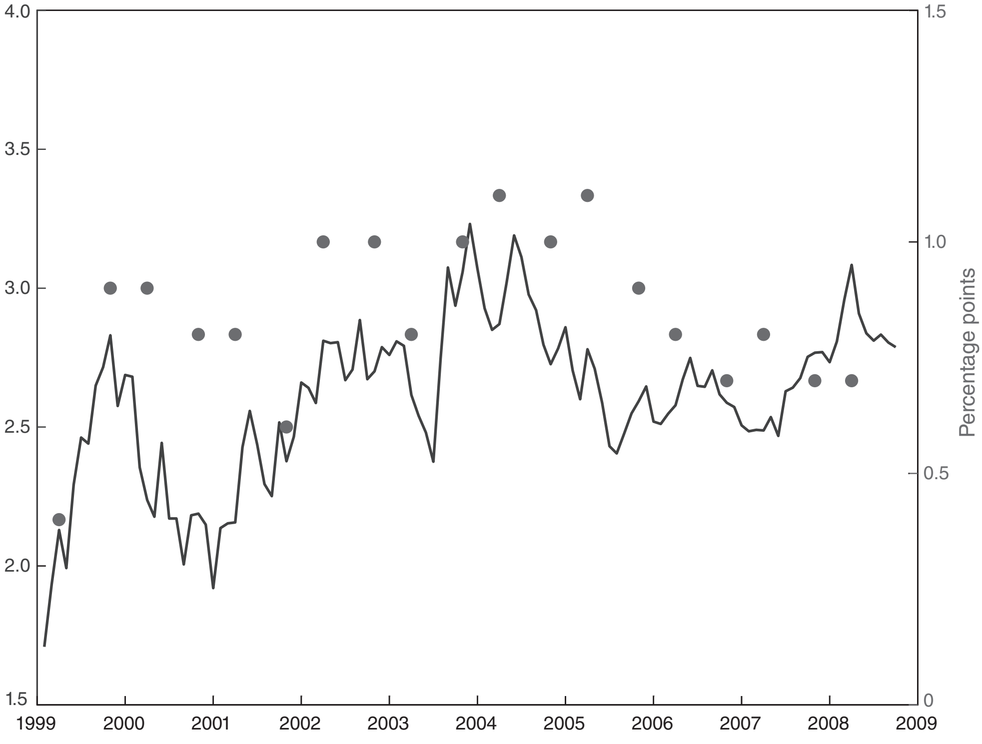

Figure 8. Five-to-Ten Year Forward Inflation Compensation and Blue Chip Forecast Dispersion

Notes: The solid line gives forward par inflation compensation (scale on the left). The dots are the dispersion of forecasts from the Blue Chip survey (scale on the right).

the TIPS market developed, but it remains small.[21] The second is the spread between Resolution Funding Corporation (Refcorp) strips and Treasury strips. Refcorp issued bonds to finance the resolution of the Savings and Loan crisis. These bonds are guaranteed by the Treasury and have the same credit risk as Treasury securities, but they are considerably less liquid than Treasuries.[22] Thus, the spread between Refcorp and Treasury strips is a very direct indicator of the liquidity premium in the Treasury market, and has been used as such by Francis A. Longstaff (2004). Of course, this measures the liquidity premium that investors demand to hold Refcorp bonds rather than nominal Treasury securities, which need not necessarily be the same as the liquidity premium that they demand to hold TIPS. Nonetheless, it seems reasonable to suppose that the Refcorp spread and TIPS liquidity premium should be highly correlated, as authors such as Tarun Chordia, Asani Sarkar, and Avanidhar Subrahmanyam (2005) have argued that there is considerable commonality in liquidity premia, even across quite different markets (including stock and bond

[21] TIPS constitute about 10 percent of Treasury issues outstanding, so their share in trading volume is well below their share in total supply of Treasury securities.

[22] To be precise, they have principal payments that are fully collateralized by nonmarketable Treasury securities and coupon payments that are explicitly guaranteed by the Treasury. Also, they have the same tax treatment as Treasuries (subject to Federal tax and exempt from state and local tax).

Table 3—Regression Results for Estimating Liquidity Premia in Five- and Ten-Year Inflation Compensation

Predictor	Five-year	Ten-year
TIPS relative volume	0.51	0.40
	(0.09)	(0.06)
Refcorp spread	−1.67	−0.78
	(0.64)	(0.34)
R^2	0.422	0.424

Notes: This table reports the results from regressions of five- and ten-year inflation compensation (in percentage points) onto the TIPS volume, as a share of total Treasury Primary Dealer trading volume (in percentage points), and the spread of 20-year Refcorp strips over their Treasury counterparts (in percentage points). Newey-West standard errors with a lag truncation parameter of 20 are shown in parentheses. The number of observations is 2,450.

markets). Note that while our first measure (relative trading volumes) captures a physical measure of trading intensity, the second measure captures possibly time-varying prices of illiquidity as well.

We regressed five- and ten-year inflation compensation on these two liquidity measures jointly. The regression results are shown in Table 3. Both are significant with the expected sign at the five- and ten-year horizons. Rising TIPS volumes boost inflation compensation, while an increase in the Refcorp spread lowers inflation compensation. The fitted values from this regression represent our measure of the time-varying effect of liquidity on inflation compensation. It does not, however, identify the level of the liquidity effect. We normalize this to zero in April 2005, meaning that we are measuring the liquidity premium *relative* to its value at that time (which was the period when the TIPS liquidity premium was estimated to be the lowest in our sample). The estimated liquidity premium on five- and ten-year TIPS is shown in Figure 9. In this figure, the sign of the liquidity premium has been flipped so that it measures the extra yield that investors demand to hold TIPS rather than nominal securities. A high liquidity premium drives inflation compensation down.

The estimated liquidity premium in yield terms is larger at the five- than at the ten-year horizon. The liquidity premium was high in the early years of the TIPS program, but fell fairly steadily between 1999 and 2005. During the recent period of financial market turmoil, the liquidity premium rose considerably, and it soared in September 2008, reaching about the same level as in 1999 when the TIPS market was small and still relatively new.

B. *Extracting Inflation Expectations*

We finally aim to construct a series of inflation expectations purged, to the extent possible, of liquidity and risk effects. This is a challenging task given the short sample period, but we attempt to do so using a state-space model in which survey expectations are treated as noisy measures of inflation expectations.

Concretely, we take the inflation compensation series at either the five- or ten-year horizon, adjusted by the liquidity premium as estimated in subsection V(A), π_t^{ADJ}, and assume that this represents the sum of inflation expectations and an inflation risk premium:

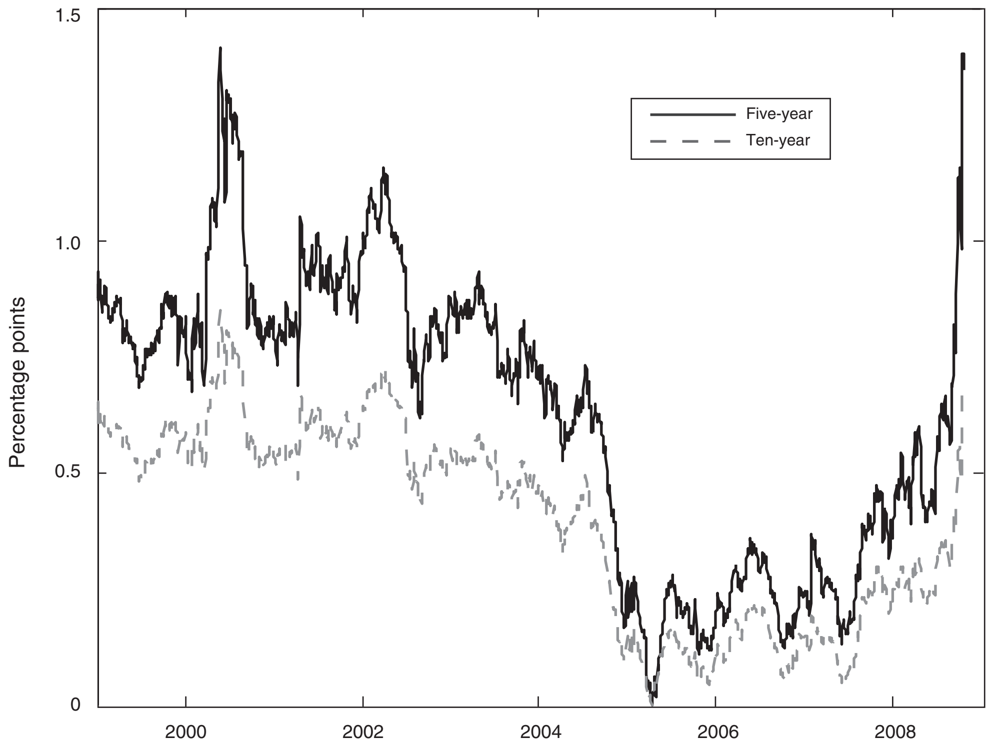

FIGURE 9. ESTIMATED TIPS LIQUIDITY PREMIUM

Notes: Regression-based estimates of the liquidity premium for holding TIPS, relative to that for nominal securities, constructed as described in the text, normalized to zero in April 2005. The regression coefficient estimates are shown in Table 3.

$$\pi_t^{ADJ} = \pi_t^{EXP} + \pi_t^{RP}. \tag{5}$$

Both the Survey of Professional Forecasters (SPF) and Blue Chip periodically ask respondents to forecast inflation over the next five and ten years. We assume that on the days of SPF surveys,[23] the survey expectation of inflation at the five- or ten year horizon, π_t^{SPF}, can be written as a noisy measure of latent inflation expectations:

$$\pi_t^{SPF} = \pi_t^{EXP} + u_t^{SPF}, \tag{6}$$

where u_t^{SPF} is an independently and identically distributed measurement error. Likewise, on the days of long-horizon Blue Chip surveys, the survey expectation of inflation, π_t^{BC}, is assumed to be

$$\pi_t^{BC} = \pi_t^{EXP} + u_t^{BC}, \tag{7}$$

[23] The SPF is conducted around the start of each February, May, August, and November. We treat the first business day of each month as the survey date. Likewise, the long-horizon Blue Chip surveys are conducted around the start of each March and October, and we treat the first business day of each month as the survey date.

where u_t^{BC} is an independently and identically distributed measurement error with a separate variance. The combination of equations (5), (6), and (7) gives us the measurement equations for a system in state space form, where $(\pi_t^{EXP}, \pi_t^{RP})'$ is the state vector. On most days, the survey expectations are treated as missing data. The transition equation assumes that long-run inflation expectations can be approximated by a random walk (motivated by the model of Stock and Watson 2007), while the inflation risk premium is an AR(1), so that the transition equation is

$$(8) \qquad \begin{pmatrix} \pi_t^{EXP} \\ \pi_t^{RP} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & \varphi \end{pmatrix} \begin{pmatrix} \pi_{t-1}^{EXP} \\ \pi_{t-1}^{RP} \end{pmatrix} + \begin{pmatrix} v_{1t} \\ v_{2t} \end{pmatrix},$$

where v_{1t} and v_{2t} are independently and identically distributed, mutually uncorrelated random variables with mean zero and variances σ_1^2 and σ_2^2, respectively. We set σ_1^2 to its estimated average value since 1999 from fitting the model of Stock and Watson to actual CPI inflation data. The Kalman filter can be used to estimate the remaining model parameters by maximum likelihood, and smoothed estimates of inflation expectations can be extracted.[24]

Figure 10 shows the five- and ten-year inflation expectations obtained in this way. Our estimates of inflation expectations generally moved in a fairly narrow range over this period. Inflation expectations were low at the start of the sample, which may partly owe to a difficulty in fully adjusting for the effects of poor liquidity at that time. Inflation expectations fell in 2003, at the time of the "deflation scare," before rebounding as the economy grew. Expected inflation also rose during most of the recent period of financial market turmoil, which is consistent with a view that the FOMC was focusing on supporting growth at the expense of its inflation objective. However, at the end of the sample, our measure of inflation expectations fell sharply. Extracting macroeconomic expectations implicit in asset prices is particularly challenging in the fall 2008, but this could be because agents expect a severe and long-lasting recession to restrain aggregate demand and inflation going forward—a view also echoed by policymakers.

VI. Conclusion

In this paper, we have estimated the US TIPS yield curve using an approach that is simple and parsimonious. The methodology is quite effective at capturing the general shape of the yield curve while smoothing through idiosyncratic variation in the yields of individual inflation-protected securities. The estimated yield curve can be expressed in a variety of ways, including zero-coupon yields, par yields, and

[24] The inflation risk premium can also be extracted, though this is only identified up to a constant because the liquidity premium has only been identified up to a constant. Meanwhile, the assumption that the surveys measure inflation expectations correctly, on average, identifies the level of inflation expectations.

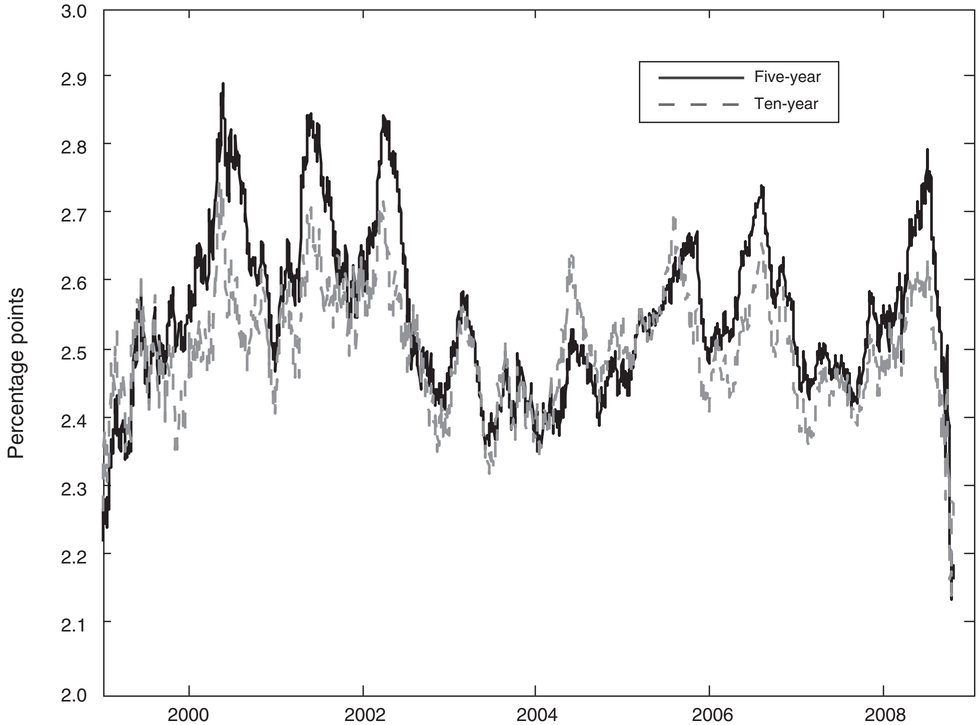

Figure 10. Estimated Inflation Expectations

Note: Estimates of inflation expectations at five- and ten-year horizons obtained from the Kalman smoother applied to the inflation compensation series adjusted for liquidity effects.

forward rates. And, it can be compared to the corresponding nominal yield curve to obtain estimates of inflation compensation.

Having the real yield curve should provide tremendous benefits to our efforts to better understand the behavior of nominal yields. It allows us to parse nominal yields and forward rates into their real rate component and their inflation compensation component. These two components may behave quite differently, in which case, simply looking at a nominal yield might mask important information. Inflation compensation is a useful measure, because it is the only high frequency measure of the market's concerns about inflation. Nonetheless, we argue that it embodies nontrivial and time-varying liquidity and inflation risk premia. Thus, research on understanding not only the mean, but the distribution of perceived future inflation outcomes, and the prices of risk associated with these, is an important part of understanding the behavior of inflation compensation and the nominal yield curve. We have taken a step in that direction by showing one way to decompose inflation compensation into its inflation expectations, inflation risk premium, and liquidity premium components.

We hope that our TIPS yield curve will be useful to researchers in further work that combines macroeconomics and finance. It is to this end that we have made the full dataset available to be downloaded at www.federalreserve.gov/econresdata/researchdata.htm. These data will be updated periodically.

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Return Predictability in the Treasury Market: Real Rates, Inflation, and Liquidity

Carolin E. Pflueger and Luis M. Viceira[1]

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[1]Pflueger: University of British Columbia, Vancouver BC V6T 1Z2, Canada. Email carolin.pflueger@sauder.ubc.ca. Viceira: Harvard Business School, Boston MA 02163 and NBER. Email lviceira@hbs.edu. We thank Tom Powers, Haibo Jiang, Shuangyi Cao and Uyseok Lee for excellent research assistance. We are grateful to John Campbell, Kent Daniel, Graig Fantuzzi, Peter Feldhutter, Michael Fleming, Josh Gottlieb, Robin Greenwood, Arvind Krishnamurthy, George Pennacchi, Michael Pond, Matthew Richardson, Josephine Smith, Jeremy Stein, to seminar participants at the NBER Summer Institute 2011, the Econometric Society Winter Meeting 2011, the Federal Reserve Board, the European Central Bank, the New York Federal Reserve, the Foster School of Business at the U. of Washington, the HBS-Harvard Economics Finance Lunch and the HBS Finance Research Day for helpful comments and suggestions. We are also grateful to Martin Duffell, Anna Christie, and Henry Luckhoo from the U.K. Debt Management Office for their help providing us with U.K. bond data. This material is based upon work supported by the Harvard Business School Research Funding. This paper was previously circulated under the title "An Empirical Decomposition of Risk and Liquidity in Nominal and Inflation-Indexed Government Bonds".

Return Predictability in the Treasury Market: Real Rates, Inflation, and Liquidity

Abstract

Estimating the liquidity differential between inflation-indexed and nominal bond yields, we separately test for time-varying real rate risk premia, inflation risk premia, and liquidity premia in U.S. and U.K. bond markets. We find strong, model independent evidence that real rate risk premia and inflation risk premia contribute to nominal bond excess return predictability to quantitatively similar degrees. The estimated liquidity premium between U.S. inflation-indexed and nominal yields is systematic, ranges from 40 bps in 2014 to over 200 bps during 2008-2009, and contributes to return predictability in inflation-indexed bonds.

I Introduction

There is wide consensus among financial economists that returns on nominal U.S. Treasury bonds in excess of Treasury bills are predictable at different investment horizons or, equivalently, that the expected excess return on nominal goverment bonds is time varying. Predictor variables include forward rates (Fama and Bliss, 1987), the slope of the yield curve (Campbell and Shiller, 1991), and a linear combination of forward rates (Cochrane and Piazzesi, 2005).

However, the question of whether the expected excess returns on inflation-indexed bonds is time varying remains relatively unexplored. This is partly due to the short history of inflation-indexed bonds in the U.S. and in other countries (Campbell, Shiller, and Viceira, 2009). Answering this question is important on its own, since inflation-indexed bonds are widely used by institutional and retail investors and a significant source of government funding.

It is also important because it can help understand the economic determinants of predictability in nominal bond excess returns (Campbell, Pflueger, and Viceira, 2014). Research in financial economics has proposed several theories to explain predictability in excess nominal bond returns. One hypothesis is that excess return predictability results from time variation in the aggregate price of risk. Building on the habit preferences model of Campbell and Cochrane (1999), Wachter (2006) shows that a model with time-varying real interest rates can generate nominal bond excess return predictability.

Another hypothesis is that excess return predictability could result from time variation in expected aggregate consumption growth or its volatility. The long-run consumption risk model of Bansal and Yaron (2004) and Bansal, Kiku, and Yaron (2010) emphasizes this possibility. Bansal and Shaliastovich (2013) show that this, combined with time-varying inflation volatility, can explain nominal bond predictability.

If excess bond return predictability is entirely due to time-varying habit or long-run consumption risk, then excess returns of real bonds should be predictable, since prices of both real and nominal government bonds change with the economy-wide real interest rate. Prices of nominal, but not real, government bonds also vary with expected inflation, so excess returns on nominal bonds over real bonds should not be predictable.

A third hypothesis is that the nominal nature of bonds is an important source of time-varying risk premia. In this case, the wedge between nominal and real bond returns should be predictable. Time-varying inflation risk premia are an important source of bond risks in Buraschi and Jiltsov (2005), Piazzesi and Schneider (2007), Gabaix (2012), Bansal and Shaliastovich (2013), Campbell, Sunderam, and Viceira (2013), and Campbell, Pflueger, and Viceira (2014).

We present in this chapter a joint empirical analysis of the sources of excess bond return predictability in nominal and inflation-indexed bonds in the U.S. and the U.K. This analysis establishes four main stylized facts or empirical findings. The first fact is that the yields of inflation-indexed bonds incorporate an economically significant time-varying liquidity premium with respect to the yields of nominal bonds of similar maturity. The second fact is that, adjusting yields and returns for this liquidity premium, inflation-indexed bonds exhibit excess return predictability which we can attribute to a time-varying real interest rate risk premium. The third fact is that both a time-varying real interest rate risk premium and a time-varying inflation risk premium are quantitatively important in explaining time variation in excess returns on nominal bonds.

The fourth fact is that the liquidity component in the yield differential between nominal and inflation-indexed bonds of similar maturity–also known as breakeven inflation–also predicts the return differential between nominal and inflation-indexed bonds. The estimated U.S. return differential due to liquidity exhibits a significantly positive stock market CAPM beta, suggesting that investors in U.S. inflation-indexed bonds (Treasury Inflation Protected Securities or TIPS) bear systematic liquidity risk and should be compensated in terms of a positive return premium. While the return differential due to liquidity is not directly tradable, this result is relevant to investors who may differ in terms of their exposure to liquidity crises.

The analysis starts by proposing an empirically flexible approach to estimate the liquidity differential between inflation-indexed and nominal bond yields. This approach consists in regressing breakeven inflation onto bond market liquidity proxies while controlling for inflation expectation proxies. Liquidity proxies explain almost as much variation in U.S. breakeven as do inflation expectation proxies. We estimate that the sample average ten year U.S. TIPS yield would have been 64 basis points (bps) lower if TIPS had been as liquid as nominal Treasury bonds. Liquidity variables have smaller, but still significant, explanatory power for U.K. breakeven. We find no evidence that residuals from liquidity regressions are non-stationary, alleviating concerns that results might be spurious.

Conditional on estimates of liquidity-adjusted returns, we find strong evidence that returns on nominal bonds in excess of real bonds are predictable from the breakeven term spread. We find that real bond excess returns are predictable from the real term spread. Time-varying liquidity risk contributes statistically and economically significantly to predictability in inflation-indexed bond excess returns. Our results suggest that a well specified model of bond return predictability should match substantial predictability in liquidity-adjusted real bond excess returns and in the liquidity-adjusted differential between nominal and real bond excess returns.

Interpreting expected real bond excess returns as real rate risk premia and expected returns on nominal bonds in excess of real bonds as inflation risk premia, we find that both are similarly variable and strongly correlated with the nominal term spread. Therefore, both inflation and real rate risk appear quantitatively important in explaining the predictability of nominal bond excess returns documented by Campbell and Shiller (1991). Moreover, we find that real rate risk premia and inflation risk premia can contribute either positively or negatively to expected nominal bond excess returns. These empirical findings are consistent across the U.S. and the U.K.

II Brief Literature Review

There is a limited body of academic research that explores excess return predictability in inflation-indexed bonds. Early work includes the studies of Barr and Campbell (1997) and Evans (1998) for the U.K., one of the first countries to issue inflation-indexed bonds in modern times (Campbell, Shiller, and Viceira, 2009). The study of Barr and Campbell (1997) tests for the expectations hypothesis of the term structure of interest rates in inflation-indexed bonds, or equivalently the hypothesis that the expected excess return on inflation-indexed bonds is constant, and it does not reject the hypothesis at short horizons. By contrast, Evans (1998) finds evidence of predictability at long horizons.

Recent work by Pflueger and Viceira (2011) shows that the slope of the real term structure forecasts positively excess returns on inflation-indexed bonds in both the U.K. and the U.S., consistent with the existing evidence of excess return predictability for nominal bonds (Campbell and Shiller 1991). The study also shows evidence that breakeven inflation forecasts positively the return differential between nominal and inflation-indexed bonds in both markets. Huang and Shi (2012) show that macroeconomic indicators also forecast inflation-indexed bond excess returns.

None of these studies controls for the impact of liquidity on the pricing of inflation-indexed bonds. Yet Campbell, Shiller, and Viceira (2009) and Gurkaynak, Sack, and Wright (2010) suggest that historically the market for TIPS has not been as liquid as the market for nominal Treasury bonds.[2] Liquidity could potentially explain part or all of the estimated predictability of excess returns on inflation-indexed bonds or the return differential between nominal and inflation-indexed bonds,[3] complicating interpretations of this predictability in terms of time-varying risk premia related to fundamentals such as real interest rate risk or inflation risk.

[2] For additional evidence of relatively lower liquidity in U.S. TIPS, see Fleming and Krishnan (2009), Dudley, Roush, and Steinberg Ezer (2009), or Christensen and Gillan (2011).

[3] For example, the study of Fontaine and Garcia (2012) shows that liquidity predicts excess returns on nominal bonds, although it does not provide evidence on inflation-indexed bonds.

The question of what explains bond excess return predictability also arises in the context of the literature in fixed income that investigates the determinants of interest rates. This literature specifies no-arbitrage models of the term structure of interest rates to decompose nominal bond yields into components due to expected inflation, expected real rates, and risk premia related to fundamentals. Before pricing data on inflation-indexed bonds was rich enough to be of use in empirical research, studies estimated the models using nominal bond yield data combined with macroeconomic data on variables such as realized inflation or survey measures of expected inflation (Campbell and Shiller, 1996, Campbell and Viceira, 2001, Ang, Bekaert and Wei, 2008). Model estimates were then used to back out the unobserved term structure of real interest rates conditional on the specific parameterization of the model.

As the data on U.S. TIPS have become richer in both the time series dimension and in the cross-sectional dimension (Gurkaynak, Sack, and Wright, 2010), studies of the term structure of interest rates have started to make use of such data for model estimation and testing. Some examples include Chen, Liu, and Cheng (2010), Christensen, Lopez, and Rudebusch (2010), D'Amico, Kim, and Wei (2010), and Campbell, Sunderam, and Viceira (2013). With the exception of Campbell, Sunderam, and Viceira (2013), these studies do not focus explicitly on bond return predictability. But they produce estimates of the time series of real interest and inflation risk premia implied by their models.

A potential issue with these studies is that model-implied estimates of expected inflation, real interest rates, and real interest rate and inflation risk premia can be distorted if liquidity is an important determinant of bond yields and the model does not account for that possibility. D'Amico, Kim, and Wei (2010) is the only study that allows for the potential existence of a liquidity premium in inflation-indexed bond yields and shows that indeed model-implied estimates of the inflation risk premium and inflation expectations change significantly after accounting for such premium. Along these lines, Haubrich, Pennacchi, and Ritchken (2012) use nominal bond yields and inflation swap rates instead of TIPS yields to estimate a model of the nominal and real term structure of interest rates arguing that the inflation swap market is more liquid than the TIPS market. Fleckenstein, Longstaff, and Lustig (2013) show evidence of price discrepancies between U.S. inflation swap and TIPS markets which they attribute to mispricing of TIPS. We are not aware of any prior estimates of liquidity differentials between U.K. inflation-indexed and nominal bond markets.

This handbook chapter proposes a decomposition of nominal bond risk premia that does not rely on a specific parameterization of the stochastic discount factor. Thus it can provide guidance for a much wider range of asset pricing models. This chapter also uses a well-developed array of tools to address identification concerns in the presence of persistent variables, which can plague both ordinary least squares and affine term structure models (Bauer, Rudebusch, and Wu, 2012).

III Bond Data and Definitions

A Bond Notation and Definitions

Let $y_{n,t}^{\$}$ and $y_{n,t}^{TIPS}$denote nominal and inflation-indexed log (or continuously compounded) yields with maturity n. We use the superscript $TIPS$ for both U.S. and U.K. inflation-indexed bonds. Breakeven inflation is the difference between nominal and inflation-indexed bond yields:

$$b_{n,t} = y_{n,t}^{\$} - y_{n,t}^{TIPS}. \tag{1}$$

Log excess returns on nominal and inflation-indexed zero-coupon n-period bonds held for one period before maturity are given by:[4]

$$xr^{\$}_{n,t+1} = ny^{\$}_{n,t} - (n-1)\, y^{\$}_{n-1,t+1} - y^{\$}_{1,t}, \tag{2}$$

$$xr^{TIPS}_{n,t+1} = ny^{TIPS}_{n,t} - (n-1)\, y^{TIPS}_{n-1,t+1} - y^{TIPS}_{1,t}. \tag{3}$$

Inflation-indexed bonds are commonly quoted in terms of *real* yields, but since $xr^{TIPS}_{n,t+1}$ is an excess return over the *real* short rate it can be interpreted as a real or nominal excess return.

We define the log excess one-period breakeven return as the log return on a portfolio long one nominal bond and short one inflation-indexed bond with maturity n. This portfolio will have positive returns when breakeven inflation declines:

$$xr^{b}_{n,t+1} = xr^{\$}_{n,t+1} - xr^{TIPS}_{n,t+1}. \tag{4}$$

The yield spread is the difference between a long-term yield and a short-term yield:

$$s^{\$}_{n,t} = y^{\$}_{n,t} - y^{\$}_{1,t}, \tag{5}$$

$$s^{TIPS}_{n,t} = y^{TIPS}_{n,t} - y^{TIPS}_{1,t}, \tag{6}$$

$$s^{b}_{n,t} = b_{n,t} - b_{1,t}. \tag{7}$$

B Yield Data

We obtain zero-coupon off-the-run U.S. yields from the smoothed yield curves by Gurkaynak, Sack, and Wright (2007) and Gurkaynak, Sack, and Wright (2010, GSW henceforth). Using yields derived

[4] These expressions follow directly from the fact that the log return on a one-period bill is given by its log yield $y_{1,t}$, and that the one-period log return on an n-period zeron coupon bond is given by the change in its log price, $p_{n-1,t+1} - p_{n,t}$, where $p_{n,t} = -ny_{n,t}$ by definition. See Campbell, Lo, and Mackinlay (1997), Chapter 10, p. 298.

from a smoothed yield curve is likely to reduce non-fundamental fluctuations in yields and therefore to bias downward the volatility of the estimated liquidity premium. We focus on 10-year nominal and real yields, because this maturity has the longest sample period. We compute quarterly log returns by substituting 10-year and 9.75-year zero coupon log yields into (2) and (3). Our sample period is 1999.3-2014.12 for yields and 1999.6-2014.12 for quarterly excess returns. We measure U.S. inflation with the all-urban seasonally adjusted Consumer Price Index (CPI), computed by the Bureau of Labor Statistics. The U.S. 3-month nominal interest rate is from the Fama-Bliss riskless interest rate file available on CRSP and Bloomberg.[5]

We use U.K. constant-maturity zero-coupon yield curves from the Bank of England, which are estimated with spline-based techniques (Anderson and Sleath, 2001). We use 20-year yields because those have the longest history. We compute quarterly log returns on 20-year nominal and real bonds using 20-year and 19.75-year zero coupon log yields.[6] Our sample covers 1999.11-2014.12 for U.K. yields and 2000.2-2014.12 for U.K. quarterly excess returns because liquidity variables only become available at the end of 1999. We use the non seasonally adjusted Retail Price Index, which is also used to calculate inflation-indexed bond payouts. U.K. three month Treasury bill rates are from the Bank of England (IUMAJNB).

The nominal principal value of U.S. TIPS adjusts with the CPI, but it can never fall below its original nominal face value. Consequently, a recently issued TIPS whose nominal face value is close to its original nominal face value contains a potentially valuable deflation option (Wright, 2010, Grishchenko, Vanden, and Zhang, 2011). The 10-year TIPS yield used for our empirical analysis is based on off-the-run TIPS issuances, which typically have high nominal face values relative to the deflation floor. Our empirical measure of the 10-year TIPS yield therefore likely does not contain

[5] We use the CRSP 3-month T-bill for 1999.3-2013.12. We extend the data using month-end T-bill rates from Bloomberg (USGG3M) for 2014.1-2014.12. Monthly 3-month T-bill rates from CRSP and Bloomberg are 99.99% correlated for the period 1999.3-2013.12.

[6] The Bank of England only publishes 19.5 and 20-year zero coupon yields. We approximate the 19.75-year zero coupon log yield with the arithmetic average of 19.5 and 20-year log yields.

a significant deflation option. U.K. inflation-indexed bonds do not contain a deflation option.[7]

Since neither the U.S. nor the U.K. governments issue inflation-indexed bills, we build a hypothetical short-term real interest rate following Campbell and Shiller (1996) as the predicted real return on the nominal three month T-bill.[8] We use this real rate to construct excess returns on inflation-indexed bonds. Finally, although our yield data is available monthly, we focus on quarterly overlapping bond returns to reduce the influence of high-frequency noise in observed inflation and short-term nominal interest rate volatility in our tests.

IV Estimating the Liquidity Differential Between Inflation-Indexed and Nominal Bond Yields

Breakeven inflation should reflect investors' inflation expectations plus any compensation for bearing inflation risk. However, if the inflation-indexed bond market is not as liquid as the nominal bond market, inflation-indexed bond prices might reflect a liquidity discount relative to nominal bonds, or equivalently a liquidity premium in yields. This liquidity differential will impact breakeven inflation negatively.

We pursue an empirical approach to identify the liquidity differential between inflation-indexed and nominal bond markets in the U.S. and the U.K. We estimate the liquidity differential by regressing breakeven inflation on measures of liquidity as in D'Amico, Kim, and Wei (2008) and Gurkaynak, Sack, and Wright (2010), while controlling for inflation expectation proxies. We capture different notions of liquidity through three different liquidity proxies: the nominal off-the-run

[7] There are further details such as in inflation lags in principal updating and tax treatment of the coupons that slightly complicate the pricing of these bonds. More details on TIPS can be found in Viceira (2001), Roll (2004), Campbell, Shiller, and Viceira (2009) and Gurkaynak, Sack, and Wright (2010). Campbell and Shiller (1996) offer a discussion of the taxation of inflation-indexed bonds.

[8] We predict the real return on a nominal T-bill using the lagged real return on the nominal three month T-bill, the lagged nominal T-bill, and lagged four quarter inflation over the sample 1982.1-2014.12. For simplicity we assume a zero liquidity premium on one-quarter real bonds.

spread, relative transaction volume of inflation-indexed bonds and nominal bonds, and proxies for the cost of funding a levered investment in inflation-indexed bonds.

Time-varying market-wide desire to hold only the most liquid securities, such as "flight to liquidity" episodes, might drive part of the liquidity differential between nominal and inflation-indexed bonds. We capture this notion of liquidity by the nominal U.S. off-the-run spread. The Treasury regularly issues new 10 year nominal notes and the newest "on-the-run" note is considered the most liquidly traded security in the Treasury bond market. The older "off-the-run" bond typically trades at a discount – i.e., at a higher yield – despite offering almost identical cash flows (Krishnamurthy, 2002).[9] The U.K. Treasury market does not have on-the-run and off-the-run bonds in a strict sense, since the Treasury typically reopens existing bonds to issue additional debt. We capture liquidity in the U.K. nominal government bond market with the difference between a fitted par yield and the yield on the most recently issued 10 year nominal bond, similarly to Hu, Pan, and Wang (2013). Hu, Pan, and Wang (2013) argue that such a measure captures market-wide liquidity and the availability of arbitrage capital. We refer to this U.K. measure as the "off-the-run spread" for simplicity.

Liquidity developments specific to inflation-indexed bond markets might also generate liquidity premia. When U.S. TIPS were first issued in 1997, investors might have had to learn about them and the TIPS market might have taken time to get established. More generally, following Duffie, Garleanu and Pedersen (2005, 2007) and Weill (2008), one can think of the transaction volume of inflation-indexed bonds as a measure of illiquidity due to search frictions.[10] We proxy for this idea with the transaction volume of inflation-indexed bonds relative to nominal bonds for the U.S. and the U.K., a measure previously used by Gurkaynak, Sack, and Wright (2010) for U.S. TIPS.

[9] In the search model with partially segmented markets of Vayanos and Wang (2007) short-horizon traders endogenously concentrate in one asset, making it more liquid. Vayanos (2004) presents a model of financial intermediaries and exogenous transaction costs, where preference for liquidity is time-varying and increasing with volatility.

[10] See Duffie, Garleanu, and Pedersen (2005, 2007) and Weill (2008) for models of over-the-counter markets, in which traders need to search for counter parties and incur opportunity or other costs while doing so.

Fleming and Krishnan (2009) also provide evidence that trading activity is a good measure of cross-sectional TIPS liquidity.

Finally, we want to capture the cost of arbitraging between inflation-indexed and nominal bond markets for levered investors, and more generally the availability of arbitrage capital and the shadow cost of capital (Garleanu and Pedersen, 2011). In the U.S. and the U.K., a non-levered investor who perceives inflation-indexed bonds to be under priced relative to nominal bonds can enter a zero price portfolio long one dollar of inflation-indexed bonds and short one dollar of nominal bonds. If held to maturity, this position will effectively pay the investor cumulative inflation over the remaining life of the bonds, in exchange for paying breakeven inflation—or the yield differential between the nominal and inflation-indexed bonds—plus any funding costs of the position. The investor can effectively fund the long position in inflation-indexed bonds by borrowing against his nominal bond in the repo market.

A levered investor with no nominal bonds to borrow against in the repo market can replicate this position by entering into an inflation swap. A zero-coupon inflation swap is a contract where at maturity one party pays cumulative CPI inflation in exchange for a pre-determined fixed rate. The fixed rate is often referred to as synthetic breakeven inflation. A zero-coupon inflation swap does not require any initial capital. An inflation-swap position paying fixed and receiving floating is functionally equivalent to being long inflation-indexed bonds and short nominal bonds.

In practice, synthetic breakeven inflation and cash breakeven inflation are not equal, and the difference between the two varies over time reflecting variation in funding costs, or the cost of arbitraging between the cash market and the inflation-swap market (Viceira, 2011). The synthetic-cash breakeven inflation spread and the off-the-run spread in the U.S. are likely related to specialness of nominal Treasuries in the repo market and the lack of specialness of TIPS, which can vary over time.[11] Differences in specialness might be the result of variation in the relative liquidity of

[11] A Treasury instrument is considered "on special" when its holders can use it as collateral to borrow at rates

securities, which make some securities easier to liquidate and hence more attractive to hold than others.

The spread between synthetic and cash breakeven inflation could potentially reflect mispricing or arbitrage opportunities between the two markets (Fleckenstein, Longstaff, and Lustig, 2013). When inflation-indexed bonds and inflation derivatives are not traded by the same marginal investor and investors face borrowing constraints, derivatives may not reflect all non-fundamental related fluctuations in inflation-indexed bond prices. However, the spread has historically tracked very closely the funding differentials between Treasury bonds and TIPS. We therefore control for investors' ability to finance a levered bond position, as reflected by mispricing between derivatives and bond markets, as an important but not the only potential source of non-payoff related fluctuations. We use the cash-synthetic breakeven inflation spread as our benchmark variable in the U.S., since it most closely captures the relative financing cost and specialness of TIPS over nominal Treasuries.

U.K. inflation swap data is not available. We use the LIBOR-general collateral (GC) repo interest-rate spread, as suggested by Garleanu and Pedersen (2011), to proxy for arbitrageurs' shadow cost of capital. In contrast to the cash-synthetic breakeven inflation spread, this measure cannot capture time-varying margin requirements of inflation-indexed bonds relative to nominal bonds.[12]

The estimated liquidity premium likely represents a combination of current ease of trading and

significantly below prevailing market rates in the market for repurchase (or "repo") agreements. The prices of Treasury bonds "on special" tend to be larger than the prices of comparable bonds, reflecting their ability to produce interest rate savings when used in collateralized repo loans (Duffie, 1996, Buraschi and Menini, 2002). The repo "specialness" is the difference between the repo rate quoted for Treasury bonds that are not "on special" and the repo rate quoted for bonds that are "on special." In private email conversations Michael Fleming and Neel Krishnan report that for the period Feb. 4, 2004 to the end of 2010 average repo specialness was as follows. On-the-run coupon securities: 35 bps; off-the-run coupon securities: 6 bps; T-Bills: 13 bps; TIPS: 0 bps.

[12] We obtain the 3-month London Interbank Offered Rate (LIBOR), based on British Pound from the St. Louis Fed Fred data base http://research.stlouisfed.org/fred2/series/GBP3MTD156N. The General Collateral (GC) 3-month repo rate is from the Bank of England (IUDGR3M).

the risk that liquidity might deteriorate: If the liquidity of inflation-indexed bonds deteriorates during periods when investors would like to sell, as in "flight to liquidity" episodes, risk averse investors will demand a liquidity risk premium (Amihud, Mendelson, and Pedersen, 2005, Acharya and Pedersen, 2005). While the relative transaction volume of inflation-indexed bonds likely only captures the current ease of trading, the off-the-run spread, the smoothness of the nominal yield curve, the asset-swap spread and the LIBOR-GC spread are likely to represent both current liquidity and liquidity risk.

A Estimation Strategy

Let $b_{n,t}$ be breakeven inflation, X_t a vector of liquidity proxies, and π_t^e a vector of inflation expectation proxies. We estimate:

$$b_{n,t} = a_1 + a_2 X_t + a_3 \pi_t^e + \varepsilon_t, \tag{8}$$

Let $\hat{a}_2$ denote the vector of slope estimates in (8). The estimated liquidity premium in inflation-indexed yields over nominal yields is the negative of the variation in $b_{n,t}$ explained by the liquidity variables:

$$\hat{L}_{n,t} = -\hat{a}_2 X_t. \tag{9}$$

Variables indicating less liquidity in the inflation-indexed bond market, such as the off-the-run spread, the smoothness of the nominal yield curve, the asset-swap spread, and the LIBOR-GC spread, should enter negatively in (8). The relative transaction volume of the inflation-indexed bonds should enter positively.

We normalize liquidity variables to equal zero in a world of perfect liquidity. With perfect liquidity, the off-the-run spread, the smoothness of the nominal yield curve, the asset-swap spread, and the LIBOR-GC spread should be zero. U.S. and U.K. relative transaction volumes are normalized to a maximum of zero. This assumption might bias the estimated liquidity differential downward and does not affect the liquidity differential's estimated variability.

In order to obtain consistent liquidity estimates, the regression residual ε_t needs to be uncorrelated with liquidity proxies, controlling for inflation expectations. We do not include inflation risk proxies in the liquidity estimation (8) so as not to not preclude the outcome of our analysis. Not controlling for inflation risk premia is conservative in the following sense: If the estimated liquidity premium also happens to pick up on inflation risk premia in nominal bonds, then this should bias us against finding predictability in liquidity-adjusted breakeven returns.

If our liquidity proxies contain information on inflation expectations not already captured by included inflation variables, our estimate of the liquidity premium may be biased. We think that this is unlikely given that we control comprehensively for inflation expectations. In any case, changes in inflation expectations are not predictable if agents are rational. In that case, even if our estimate of the liquidity premium is correlated with inflation expectations, this type of potential mis-estimation will not introduce return predictability in either liquidity or liquidity-adjusted bond returns.

While our liquidity estimate most likely reflects liquidity fluctuations in both nominal bonds and in inflation-indexed bonds, we have to make an assumption in computing liquidity-adjusted inflation-indexed bond yields. We could assume that all of the liquidity premium is in nominal bonds, in which case we would not need to correct inflation-indexed bond yields. Here, we make the alternative assumption and adjust inflation-indexed assuming that the relative liquidity premium is entirely attributable to inflation-indexed bond illiquidity.[13] We refer to the following variables

[13] See Pflueger and Viceira (2011) for evidence on predictability of TIPS excess returns with no liquidity adjustment.

as liquidity-adjusted inflation-indexed bond yields and liquidity-adjusted breakeven:

$$y_{n,t}^{TIPS,adj} = y_{n,t}^{TIPS} - \hat{L}_{n,t}, \tag{10}$$

$$b_{n,t}^{adj} = b_{n,t} + \hat{L}_{n,t}. \tag{11}$$

B Data on Liquidity and Inflation Expectation Proxies

The U.S. off-the-run spread is the difference between the 10 year GSW off-the-run par yield and the 10 year on-the-run nominal bond yield from Bloomberg (USGG10YR). For the U.K., we use the difference between the fitted 10 year nominal par yield available from the Bank of England (IUMMNPY) and the 10 year nominal on-the-run yield from Bloomberg.

We calculate U.S. and U.K. relative transaction volume as $\log\left(Trans_t^{TIPS}/Trans_t^{\$}\right)$ smoothed over the past three months. Here, $Trans_t^{TIPS}$ and $Trans_t^{\$}$ denote average monthly transaction volume for inflation-indexed and long-term nominal bonds. We use transaction volume for long-term nominal coupon bonds to capture the liquidity differential between inflation-indexed and equivalent maturity nominal bonds.[14]

[FIGURE 1 ABOUT HERE]

Data on 10 year zero-coupon inflation swaps are available from Bloomberg (USDSW10Y) from July 2004 onwards. The U.K. LIBOR-GC spread is the difference between three month British Pound LIBOR and three month British Pound GC rates.

[14] For the U.S., we use Primary Dealers' transaction volumes from the New York Federal Reserve FR-2004 survey. We are grateful to the U.K. Debt Management Office for providing us with U.K. turnover data. In 2001 the Federal Reserve changed the maturity cutoffs. Before 6/28/2001 we use the transaction volume of Treasuries with 6 or more years to maturity while starting 6/28/2001 we use the transaction volume of Treasuries with 7 or more years to maturity. The series after the break is scaled so that the growth in $Trans^{\$}$ from 6/21/2001 to 6/28/2001 is equal to the growth in transaction volume of all government coupon securities.

Figures 1A and 1B plot the time series of the U.S. and U.K. liquidity variables. The U.S. off-the-run spread was high during the late 1990s, declined during 2005-2007, jumped to over 50 bps during the financial crisis, and continued its decline afterwards. U.S. relative transaction volume rises linearly through 2004 and then stabilizes.[15] The differential between synthetic and cash breakeven inflation varies within a relatively narrow range of 15 to 45 bps during our sample period excluding the financial crisis period. Therefore, during our sample period it has always been more expensive to finance a long position in TIPS than in nominal Treasury bonds. This cost differential rose sharply during the financial crisis, reaching 113 bps in December 2008. Campbell, Shiller, and Viceira (2009) argue that the Lehman bankruptcy significantly affected TIPS liquidity because Lehman Brothers had been very active in the TIPS market. The unwinding of its large TIPS inventory, combined with a sudden increase in the cost of financing long positions in TIPS appears to have induced unexpected downward price pressure in the TIPS market.

Figure 1B shows a steady increase in the U.K. relative transaction volume. Greenwood and Vayanos (2010) argue that the U.K. pension reform of 2004, which required pension funds to discount future liabilities at long-term real rates, increased demand for inflation-indexed gilts and it seems plausible that the same reform also increased trading volume. Figure 1B shows that the LIBOR-GC spread peaked during the financial crisis, consistent with the notion that arbitrageurs' capital was scarce during this period. The smoother U.K. off-the-run spread might indicate that during flight-to-liquidity episodes investors have a preference for U.S. on-the-run nominal Treasuries.

We proxy for U.S. inflation expectations with the median 10 year CPI inflation forecast from the Survey of Professional Forecasters (SPF), consistent with bond maturities. We also include the Chicago Fed National Activity Index (CFNAI) to account for the possibility that shorter-term

[15] Interestingly, the U.S. Treasury's renewed commitment to the TIPS issuance program (Bitsberger, 2003) and the development of synthetic markets occurred at a similar time.

inflation expectations enter into breakeven (Stock and Watson, 1999).[16] We proxy for U.K. inflation expectations using the median response to the question "How much would you expect prices in the shops generally to change over the next 12 months?" from the Bank of England Public Attitudes survey. Unfortunately, no longer forecasting horizon is available for our sample.

[TABLE I ABOUT HERE]

Summary statistics in Table I suggest that there was a substantial liquidity premium in U.S. TIPS yields relative to nominal yields, or a substantial negative inflation risk premium in nominal yields. Over our sample, U.S. average breakeven was 2.25% per annum (p.a.), average TIPS yields were 1.87% p.a., and average U.S. survey inflation was 2.43% p.a. If breakeven exclusively reflected investors' inflation expectations, the negative gap between U.S. breakeven and survey inflation would be surprising, especially given that the SPF tends to under predict inflation in low inflation environments (Ang, Bekaert, and Wei, 2007). In contrast, average U.K. breakeven exceeded survey inflation over the similar period 1999.11-2014.12.

Table I shows that realized log excess returns on U.S. Treasury bonds averaged 5.57% p.a. and exceeded average log excess returns on U.S. TIPS by 71 bps over our sample. This differential reverses in the U.K. At 4.14% p.a., average log excess returns on U.K. inflation-indexed bonds exceeded U.K. nominal log excess returns by 82 bps p.a.

C Estimating Differential Liquidity

Table IIA and IIB estimate the relation (8) for the U.S. and the U.K., respectively. We add liquidity proxies one at a time. For both panels, column (4) presents our benchmark estimate with

[16] SPF survey expectations are available at a quarterly frequency and are released towards the end of the middle month of the quarter. We create a monthly series by using the most recently released inflation forecast.

all liquidity proxies and inflation expectation controls. The last two columns verify that results are robust to excluding the financial crisis.

[TABLE II ABOUT HERE]

Table IIA column (1) shows that inflation expectation proxies jointly explain 31% of the variability in U.S. breakeven. CFNAI enters positively and significantly, suggesting that short-run inflation expectations influence investors' long-run inflation expectations. Table I shows that SPF inflation expectations exhibit very little time variation. Table II suggests that this variation is unrelated to breakeven, after controlling for liquidity proxies and CFNAI.

Panel A shows that liquidity measures explain significant variation in U.S. breakeven inflation. The regression R^2 increases with the inclusion of every additional liquidity variable and reaches 59% in column (4). Column (2) shows that the off-the-run spread alone increases the regression R^2 by 17 percentage points. Column (5) adds a time trend to the regression, which enters significantly but does not impact the magnitude and statistical significance of the other variables, suggesting that our estimates of liquidity are not driven by a time trend, particularly in relative TIPS trading volume.

The coefficients in Table IIA are consistent with intuition and they are statistically significant. Breakeven inflation decreases in the off-the-run spread, suggesting that TIPS yields reflect a strong market-wide liquidity component. A one standard deviation move in the off-the-run spread of 12 bps tends to go along with a decrease in breakeven of 11.2 bps in our benchmark estimation (0.93×12 bps). These magnitudes are substantial relative to average breakeven of 225 bps. This empirical finding indicates that during flight-to-liquidity episodes, investors prefer nominal on-the-run U.S. Treasuries over U.S. TIPS, even though both types of bonds are fully backed by the U.S. Treasury.

Relative TIPS trading volume enters positively and significantly, indicating that search frictions impacted inflation-indexed bond prices during the early period of inflation-indexed bond issuance. As TIPS trading volume relative to nominal Treasury trading volume increased, TIPS yields fell relative to nominal bond yields. Our empirical estimates suggest that an increase in relative trading volume from its minimum in 1999 to its maximum in 2014 was associated with a decrease in the TIPS liquidity premium of 29 bps.

When the marginal investor in TIPS is levered, we would expect breakeven to fall one for one with the synthetic minus cash breakeven inflation spread. The estimated slope on the synthetic-cash breakeven inflation spread is at -1.32 just one standard deviation away of the theoretical value of -1. This slope estimate suggests that disruptions to securities markets and constraints on levered investors were important in explaining the sharp fall in breakeven during the financial crisis, when the synthetic-cash breakeven inflation differential spikes up.

We also find a strong relation between breakeven and liquidity proxies during the pre-crisis period. Column (6) in Panel A shows that before 2007, proxies for inflation expectations explain 28% of the variability of breakeven inflation. Column (7) shows that adding liquidity proxies more than doubles the regression R^2 to 58% and that the off-the-run spread enters with a strongly negative and significant coefficient.

Since some liquidity variables are persistent, one might be concerned about spuriousness. If there is no slope vector so that the regression residuals are stationary, Ordinary Least Squares is quite likely to produce artificially large R^2s and t-statistics (Granger and Newbold, 1974, Phillips, 1986, Hamilton, 1994). Table II shows that the augmented Dickey-Fuller test rejects the presence of a unit root in regression residuals for all regression specifications at conventional significance levels, including those specifications that include a time trend.

Table IIB shows that U.K. survey inflation explains a significant 46% of the variability in U.K.

breakeven inflation. Liquidity proxies enter with the predicted signs and increase the regression R^2 substantially to 61%. However, column (5) shows that introducing a time trend in the regression reduces both the magnitude and statistical significance of the coefficients survey inflation expectations and relative transaction volume, while it has the opposite effect on the LIBOR-GC spread, suggesting that market-wide liquidity conditions are an important determinant of high frequency variation in the yield differential between nominal and inflation-indexed bonds in the in U.K.

Columns (6) and (7) show that prior to the financial crisis, liquidity variables have somewhat greater explanatory power of the variability in U.K. breakeven inflation. In the pre-2007 sample, including the liquidity variables increases the regression R^2 to 67%. Interestingly, while in the full sample only relative transaction volume is individually statistically significant, in the pre-2007 sample the smoothness of the nominal yield curve also becomes statistically significant. Again, the augmented Dickey-Fuller tests reject the presence of a unit root for all regression specifications in the panel. Overall these results suggest that liquidity factors are important for understanding the time series variability of breakeven inflation both in the U.S. and the U.K.

[FIGURES 2A AND 2B ABOUT HERE]

Figures 2A and 2B plot estimated U.S. and U.K. liquidity premia from Table IIA (4) and Table IIB (4). The estimated U.S. liquidity premium averages 64 bps with a standard deviation of 26 bps over our sample. This high average reflects periods of very low liquidity in this market. Figure 2A shows a high liquidity premium in the early 2000's (about 70-100 bps), but a much lower liquidity premium between 2004 and 2007 (35-70 bps). The premium shoots up again beyond 200 bps during the crisis, and finally comes down to 40 bps at the end of our sample.

The estimated U.S. liquidity time series is consistent with previous estimates (D'Amico, Kim, and Wei (2008), Dudley, Roush, and Steinberg Ezer (2009), Gurkaynak, Sack, Wright (2010), Christensen and Gillan (2011), Haubrich, Pennacchi, and Ritchken (2012), Fleckenstein, Longstaff, and Lustig (2013)). However, we consider a more comprehensive set of liquidity proxies and estimate U.S. liquidity over a longer time period. We are not aware of any previous estimates of the liquidity differential between U.K. inflation-indexed and nominal bond yields.

The large liquidity premium in TIPS is puzzling given narrow TIPS bid-ask spreads. Haubrich, Pennacchi, and Ritchken (2012) report TIPS bid-ask spreads of at most 10 bps during the financial crisis. It seems implausible that the liquidity premium in TIPS yields simply serves to amortize transaction costs of a long-term investor.[17] If TIPS are held by buy-and-hold investors, as previously argued, then transaction costs of 10 bps can only justify a 1 bp liquidity premium for 10-year TIPS (Amihud, Mendelson, and Pedersen (2005)).

A simple calculation shows that the estimated liquidity premium in U.S. TIPS, though puzzlingly large when compared to bid-ask spreads, gives rise to liquidity returns in line with those on off-the-run nominal Treasuries. The on-the-run off-the-run liquidity differential converges in 6 months, when the new on-the-run nominal 10-year bond is issued. Thus, an average U.S. off-the-run spread of 17 bps yields an annualized return on the liquidity differential of 340 bps (annualized yield differential, $17\times$ 2 bps, times the maturity of the bonds, 10 years). In contrast, the 10-year U.S. TIPS liquidity premium might take as long as 10 years to converge, yielding an average annualized return on U.S. TIPS liquidity of only 64 bps.

The estimated U.K. liquidity premium has a lower average (50 bps) but a similar standard deviation (25 bps) compared to U.S. liquidity. Figure 2B shows that the estimated U.K. liquidity premium was initially similar to the U.S. liquidity premium (around 100 bps), but declined to 10 bps towards the end of our sample. It even became briefly negative during the financial crisis,

[17] See also Wright (2009).

reflecting extremely high relative transaction volume in U.K. inflation-indexed bonds.

[FIGURE 3 ABOUT HERE]

Figure 3A shows that liquidity-adjusted U.S. breakeven was substantially more stable than raw U.S. breakeven. Estimated liquidity-adjusted U.S. breakeven averaged 2.90% with a standard deviation of 25 bps over our sample. Adjusting breakeven for liquidity suggests that while investors' U.S. long-term inflation expectations fell during the crisis, there was never a period when investors feared substantial long-term deflation in the U.S.

Figure 3B partly attributes the strong upward trend in U.K. breakeven inflation to liquidity. However, even after adjusting for liquidity U.K. breakeven has trended upwards from around 3% to 3.5% over our sample. In contrast to the U.S., U.K. breakeven does not exhibit a pronounced drop during the financial crisis. Both raw and liquidity-adjusted U.K. breakeven become highly volatile during 2008-2010, potentially reflecting inflation uncertainty.

V Bond Excess Return Predictability

This section decomposes government bond excess returns into returns due to real interest rates, changing inflation expectations, and liquidity. We test for predictability in each component separately: Predictability in liquidity-adjusted real bond excess returns would indicate a time-varying real interest rate risk premium, while predictability in liquidity-adjusted breakeven returns would indicate a time-varying inflation risk premium. Predictability in the liquidity component of inflation-indexed returns would indicate a time-varying liquidity risk premium.[18]

[18] Relative supply shocks and market segmentation of the type implied by the preferred habitat hypothesis of Modigliani and Sutch (1966) as formalized by Vayanos and Vila (2009) can also generate bond excess return predictability from the relative supply of inflation-indexed bonds (Greenwood and Vayanos, 2008, Hamilton and Wu, 2012). However, in unreported results we find that relative bond supply measures do not explain variation in breakeven

We adjust inflation-indexed and breakeven excess returns for liquidity and compute inflation-indexed bond returns due to illiquidity:

$$xr^{TIPS-L}_{n,t+1} = ny^{TIPS,adj}_{n,t} - (n-1)\, y^{TIPS,adj}_{n-1,t+1} - y^{TIPS}_{1,t}, \tag{12}$$

$$xr^{b+L}_{n,t+1} = xr^{\$}_{n,t+1} - xr^{TIPS-L}_{n,t+1}, \tag{13}$$

$$r^{L}_{n,t+1} = -(n-1)\, L_{n-1,t+1} + nL_{n,t}. \tag{14}$$

Table III regresses quarterly excess returns (12), (13), and (14) onto the lagged liquidity-adjusted real term spread $\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$, the lagged liquidity-adjusted breakeven term spread $(b_{n,t} + L_{n,t}) - b_{1,t}$, and the lagged estimated liquidity differential between inflation-indexed and nominal yields $L_{n,t}$. Intuitively, the three right-hand-side variables decompose the nominal term spread, used by Campbell and Shiller (1991) to predict nominal bond excess returns, into real term structure, inflation, and liquidity components. The table reports Newey-West standard errors with three lags and one-sided bootstrap p-values accounting for generated regressors.[19]

Ordinary least squares can overstate return-predictability in small samples, when the regressor is persistent and innovations are negatively correlated with returns (Stambaugh, 1999). In contrast, this correlation is typically negative for bond return predictability regressions (Bekaert, Hodrick, and Marshall, 1997). Therefore, the same small sample bias should bias us towards finding no predictability in real bond excess returns and breakeven returns.

[TABLE III ABOUT HERE]

inflation nor predict bond excess returns. Thus we rule out this potential channel of excess return predictability for the remaining analysis.

[19] We use a non-parametric block bootstrap with block length 24 months and 2000 replications. We re-sample the data on inflation-indexed and nominal yields, liquidity variables, and inflation expectation proxies from non-overlapping blocks of length 24 with replacement. See Horowitz (2001) for a survey of bootstrap methods with serially dependent data.

Columns (1) and (2) in Table III show that the real term spread forecasts real bond excess returns positively, even controlling for liquidity, in the U.S. and the U.K. Bootstrap p-values in Columns (1) and (2) in Table III indicate that these positive coefficients are not statistically significant at conventional significance levels, even though Newey-West standard errors would indicate statistical significance. Of course, the relatively short sample may make it hard to detect predictability and bias our results towards finding no predictability. The liquidity-adjusted breakeven term spread and lagged liquidity do not enter significantly in columns (1) or (2) either in the U.S. or the U.K., as one might expect if those variables are unrelated to real interest rate risk.

Columns (3) and (4) in Tables IIIA and IIIB show that liquidity-adjusted breakeven term spreads predict breakeven excess returns with coefficients that are large, statistically significant, and similar across both countries. This empirical finding indicates that that time-varying inflation risk premia are a source of predictability in nominal bond excess returns and that the nominal term spread partly reflects time-varying inflation risk premia.

Remarkably, liquidity does not predict liquidity-adjusted real bond or breakeven excess returns in the U.S. or the U.K. The estimated liquidity differential does not appear related to fundamental bond cash-flow risk, alleviating concerns that estimated liquidity might capture time-varying inflation risk premia as a result of our estimation strategy.

The last two columns in Tables IIIA and IIIB show that liquidity $L_{n,t}$ predicts liquidity returns $r^L_{n,t+1}$ with large positive and highly significant coefficients. Time-varying and predictable liquidity premia are a source of inflation-indexed bond excess return predictability both in the U.S. and the U.K. Equivalently, the liquidity component in breakeven exhibits mean reversion. When liquidity in the inflation-indexed bond market is scarce, inflation-indexed bonds enjoy a higher expected return relatively to nominal bonds, rewarding investors who are willing to invest into a temporarily less liquid market.

A Economic Significance of Bond Risk Premia

[TABLE IV ABOUT HERE]

Table IV evaluates the economic significance of time-varying real rate risk premia, inflation risk premia, and liquidity risk premia. For simplicity we refer to the expected liquidity excess return as a liquidity risk premium, the expected liquidity-adjusted breakeven return as an inflation risk premium and expected liquidity-adjusted TIPS returns as a real rate risk premium. We note that our average return calculations are based on log returns with no variance adjustments for Jensen's inequality.

By construction, the average excess return on inflation-indexed bonds equals the sum of the liquidity risk premium plus the real rate risk premium. Column (1) of Panel A shows that, at 92 bps, the liquidity risk premium accounts for one-fifth of the average realized U.S. TIPS excess return over this period. Although the average estimated inflation risk premium is economically significant at 163 bps, it is substantially smaller than the average real interest rate risk premium of 394 bps over the same time period. Panel B shows that at 156 bps, the average estimated U.K. liquidity risk premium is even more substantial. The estimated inflation risk premium in U.K. nominal bonds is much lower at 74 bps, helping to explain low average log excess returns on nominal U.K. bonds.

Column (2) of Table IVA shows that the CAPM beta on U.S. liquidity-adjusted breakeven excess returns is negative, small, and not significant. But contrast, the CAPM beta on liquidity-adjusted TIPS excess returns is negative, large in absolute value, and and significant, and the CAPM beta on U.S. liquidity returns is positive and significant. The positive liquidity beta implies that TIPS tend to become illiquid relative to nominal Treasury bonds – or conversely, nominal bonds become liquid relative to TIPS – during stock market drops.[20] The strong positive covariation between

[20] We compute CAPM betas using the stock market as the proxy for the wealth portfolio. The U.S. excess stock return is the log total return on the S&P 500 in excess of the log 3-month interest rate. The U.K. excess stock return is the log quarterly total return on the FTSE in excess of the log 3-month interest rate.

U.S. estimated liquidity returns and stock returns suggests that investors should earn a premium on TIPS for bearing systematic variation in liquidity.

In contrast, Table IVB shows that the U.K. liquidity beta is indistinguishable from zero. The CAPM beta of U.K. liquidity-adjusted breakeven returns is large, negative, and statistically significant, indicating pro-cyclical inflation expectations and nominal interest rates during our sample. Both procyclical nominal interest rates and low inflation risk premia are consistent with a view that nominal Treasuries were safe assets and provided investors with sizable diversification benefits over our sample.

The last two columns in Table IV tie our results back to the initial motivation and theory. Column (3) of Table IV reports roughly similar standard deviations for estimated real rate risk premia, inflation risk premia, and liquidity risk premia. The estimated components of bond excess returns therefore contribute quantitatively similarly to the predictability in standard Campbell and Shiller (1991) bond return forecasting regressions.

Column (4) of Table IV shows that the nominal term spread, shown by Campbell and Shiller (1991) to forecast nominal bond excess returns, is highly correlated with estimates of both inflation risk premia and real rate risk premia. The correlations between the nominal term spread and inflation risk premia range from 65% to 71%, while the correlations with real rate risk premia range from 88% to 92%.

[FIGURE 4 ABOUT HERE]

Figure 4 shows predicted 3-month excess returns or real rate risk premia, inflation risk premia, and liquidity risk premia. While magnitudes may appear large, Figure 4 shows predicted 3-month returns in annualized units and not predicted 12-month returns. Figure 4A shows a negative U.S.

inflation risk premium in the early part of the sample which turns positive in 2003. The inflation risk premium became highly positive during the period of high oil prices in 2008 and fell to almost -10% at the beginning of 2009, just when the U.S. real rate risk premium increased sharply.

A large and positive U.S. real interest rate risk premium during the crisis indicates that real bonds were considered risky, so a deepening of the recession was considered likely to go along with high long-term real interest rates. The liquidity risk premium on real bonds relative to nominal bonds spiked in the U.S., but not in the U.K. during the financial crisis. The U.K. liquidity risk premium even declined, suggesting that investors did not consider U.K. real bonds risky due to illiquidity.

U.S. and U.K. inflation risk premia present a contrasting picture during the financial crisis, mirroring contrasting inflation experiences. In contrast to the U.S., the U.K. inflation risk premium shot up during the financial crisis. This high inflation risk premium likely reflected the high level and volatility of U.K. inflation during the financial crisis.

VI Conclusion

This chapter explores the sources of time variation in bond risk premia in nominal and inflation-indexed bonds in the U.S. and the U.K. We find strong empirical evidence in both markets that nominal bond excess return predictability is related to time variation in inflation risk premia. Inflation risk premia exhibit significant time variation, are low on average, and take both positive and negative values in our sample. We find strong evidence in U.K. data that predictability in nominal bond excess returns is also related to time-varying real interest rate risk premia.

We find strong empirical evidence for both time-varying real rate and time-varying liquidity risk premia in inflation-indexed bonds in both markets. Liquidity risk premia in U.S. TIPS account for

92 bps of TIPS excess returns over our sample. Our results suggest that bond investors receive a liquidity discount for holding inflation-indexed bonds. However, this time-varying discount exposes them to systematic risk as measured by a positive and statistically significant CAPM beta.

The estimated liquidity premium in U.S. TIPS yields relative to nominal yields is economically significant and strongly time-varying. We estimate a large premium early in the life of TIPS, a decline after 2004, and a sharp increase to over 200 bps during the height of the financial crisis in the fall of 2008 and winter of 2009. Since then, the premium has declined to much lower levels of 40 to 50 bps. The estimated relative liquidity premium might partly reflect a convenience yield on nominal bonds (Krishnamurthy and Vissing-Jorgensen, 2012), rather than a liquidity discount specific to TIPS. In this case, TIPS are not undervalued securities, but instead investors may be willing to pay a liquidity premium on nominal Treasury bonds.

Estimated inflation risk premia, real rate risk premia and liquidity risk premia are roughly equally quantitatively important as sources of bond excess return predictability. Inflation risk premia and real rate risk premia are strongly correlated with the nominal term spread, while liquidity risk premia are not. The empirical results in this paper have important implications for modeling and understanding predictability in bond excess returns. We find an important role for time-varying real interest rate risk, which can be modeled either in a model of time-varying habit (Wachter, 2006) or in a model of time variation in expected aggregate consumption growth or its volatility (Bansal and Yaron, 2004, Bansal, Kiku, and Yaron, 2010). However, our results indicate that time-varying inflation risk is equally important for understanding the time-varying risks of nominal government bonds. A model that aims to capture predictability in nominal government bond excess returns therefore has to integrate sources of real interest rate risk and inflation risk.

Our results suggest directions for future research. Different classes of investors have different degrees of exposure to time-varying liquidity risk, real interest rate risk and inflation risk. Exposures may vary with shares of real and nominal liabilities and time horizons. Understanding the sources of bond return predictability can therefore have potentially important implications for investors' portfolio management and pension investing.

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Table I: Summary Statistics.

Nominal and inflation-indexed bond yields, excess returns, inflation expectation proxies and liquidity proxies. U.S. 10 year nominal and TIPS yields from Gurkaynak, Sack, and Wright (2010). U.K. 20 year nominal and inflation-indexed yields from Anderson and Sleath (2001). U.S. three-month log excess returns (1999.6-2014.12) and U.K. three-month log excess returns (2000.2-2014.12) are computed using zero-coupon log yields. U.S. survey inflation is the median 10 year CPI inflation forecast from the Survey of Professional Forecasters. The Chicago Fed National Activity Index (CFNAI) is as in Stock and Watson (1999). U.K. survey inflation reflects Bank of England Public Attitudes Survey 12 month inflation expectations. U.S. difference between synthetic and cash breakeven (2004.7-2014.12), and U.K. 3-month GBP LIBOR minus general collateral (GC) spread capture cost of arbitraging between nominal and inflation-indexed bonds. We normalize the maxima of relative transaction volumes to zero. The U.K. off-the-run spread reflects the spread between a fitted 10 year nominal par yield and the generic 10 year nominal U.K. bond yield from Bloomberg. Spreads and zero-coupon yields continously compounded in annualized percent.

Panel A: U.S. (1999.3-2014.12)		Mean	Std	Min	Max
Nominal Yields	$y^{\$}_{n,t}$	4.12	1.26	1.55	6.70
Inflation-Indexed Yields	$y^{TIPS}_{n,t}$	1.87	1.30	-0.79	4.29
Breakeven	$b_{n,t}$	2.25	0.36	0.39	2.87
Nominal Excess Ret.	$xr^{\$}_{n,t+1}$	5.57	8.74	-40.11	58.56
Infl.-Indexed Excess Ret.	$xr^{TIPS}_{n,t+1}$	4.86	7.64	-64.78	58.58
Breakeven Excess Ret.	$xr^{b}_{n,t+1}$	0.71	6.79	-41.26	76.74
Survey Inflation	π^E	2.43	0.10	2.20	2.55
Chicago Fed Nat. Activity	CFNAI	-0.27	0.89	-4.57	1.16
Off-the-Run Spr.		0.17	0.12	-0.01	0.63
Log Transaction Vol.		-0.66	0.47	-1.68	0.00
Synthetic - Cash		0.29	0.15	0.10	1.13

Panel B: U.K. (1999.11-2014.12)		Mean	Std	Min	Max
Nominal Yields	$y^{\$}_{n,t}$	4.14	0.57	2.45	5.01
Inflation-Indexed Yields	$y^{TIPS}_{n,t}$	1.14	0.82	-0.79	2.44
Breakeven	$b_{n,t}$	3.00	0.45	2.14	3.95
Nominal Excess Ret.	$xr^{\$}_{n,t+1}$	3.31	11.32	-49.72	77.67
Infl.-Indexed Excess Ret.	$xr^{TIPS}_{n,t+1}$	4.14	8.93	-67.51	45.25
Breakeven Excess Ret.	$xr^{b}_{n,t+1}$	-0.82	8.48	-49.34	68.35
Survey Inflation	π^E	2.77	0.68	1.50	4.40
Off-the-Run Spr.		0.05	0.06	-0.06	0.32
Log Transaction Vol.		-0.79	0.37	-1.64	0.00
LIBOR-GC Spr.		0.30	0.32	0.04	2.19

Table II: Estimating Differential Liquidity.

We regress the difference between nominal and inflation-indexed bond yields (breakeven inflation) onto liquidity proxies. The variables are as described in Table I. Newey-West standard errors with three lags in parentheses. * and ** denote significance at the 5% and 1% level, respectively.

Panel A: U.S. (1999.3-2014.12)

$y^{\$}_{n,t} - y^{TIPS}_{n,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Off-the-Run Spr.		-1.69**	-1.44**	-0.93**	-0.98**		-1.56**
		(0.29)	(0.28)	(0.32)	(0.30)		(0.44)
Synthetic-Cash			-1.13**	-1.32**	-1.31**		-0.68
			(0.29)	(0.30)	(0.29)		(0.61)
Transaction Vol.				0.17*	0.35**		0.10
				(0.07)	(0.09)		(0.08)
Month$\times 10^{-2}$					-0.25*		
					(0.11)		
Survey Inflation	0.25	1.10**	0.92**	1.06**	0.47	0.77	0.55
	(0.32)	(0.36)	(0.32)	(0.33)	(0.46)	(1.65)	(0.63)
CFNAI	0.23**	0.12**	0.04	0.07*	0.06	0.27**	0.18**
	(0.05)	(0.04)	(0.03)	(0.03)	(0.03)	(0.05)	(0.04)
Adjusted R-squared	0.31	0.48	0.57	0.59	0.60	0.28	0.58
ADF of Residuals	-4.43^{**}	-4.75^{**}	-4.29^{**}	-4.84^{**}	-4.91^{**}	-4.54^{**}	-3.22^{*}
Period	Full	Full	Full	Full	Full	1999.3 − 2006.12	

Panel B: U.K. (1999.11-2014.12)

$y^{\$}_{n,t} - y^{TIPS}_{n,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Off-the-Run Spr.		0.19	0.10	-0.52	0.02		-3.11**
		(0.65)	(0.76)	(0.72)	(0.61)		(0.60)
LIBOR-GC Spr.			0.05	0.19	0.20*		0.32
			(0.15)	(0.14)	(0.10)		(0.31)
Transaction Vol.				0.68**	-0.07		0.47**
				(0.12)	(0.21)		(0.13)
Month$\times 10^{-2}$					0.64**		
					(0.16)		
Survey Inflation	0.45**	0.45**	0.44**	0.20**	0.11	0.54**	0.22**
	(0.06)	(0.07)	(0.07)	(0.06)	(0.09)	(0.12)	(0.08)
Adjusted R-squared	0.46	0.46	0.46	0.61	0.71	0.28	0.64
ADF of Residuals	-2.62	-2.64	-2.66	-3.67^{**}	-3.45^{*}	-2.79^{*}	-3.03^{*}
Period	Full	Full	Full	Full	Full	1999.11 − 2006.12	

Table III: Liquidity-Adjusted Bond Return Predictability.

We predict 3-month overlapping liquidity-adjusted excess log returns of inflation-indexed bonds and of nominal bonds in excess of inflation-indexed bonds using the liquidity-adjusted inflation-indexed term spread, the liquidity-adjusted breakeven term spread, and the liquidity differential $L_{n,t}$. $L_{n,t}$ is estimated as the negative of the variation explained by liquidity variables in Table II(4). $r^L_{n,t+1}$ is the return on inflation-indexed bonds due to illiquidity. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. We show one-sided bootstrap p-values from 2000 replications to account for the fact that liquidity is estimated. We use block bootstrap with block length 24 months.

Panel A: U.S. (1999.6-2014.12)

		(1) $xr^{TIPS-L}_{n,t+1}$	(2) $xr^{TIPS-L}_{n,t+1}$	(3) $xr^{b+L}_{n,t+1}$	(4) $xr^{b+L}_{n,t+1}$	(5) $r^L_{n,t+1}$	(6) $r^L_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$		3.00	2.60		-0.41		0.45
	Newey-West SE	(1.24)	(1.31)		(1.11)		(0.65)
	Bootstrap p-value	7.45%	14.85%		30.40%		42.00%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			1.76	4.14	4.02		-0.49
	Newey-West SE		(2.80)	(1.69)	(1.91)		(1.82)
	Bootstrap p-value		38.75%	0.00%	0.00%		40.00%
$L_{n,t}$			2.59		-3.65	12.60	11.91
	Newey-West SE		(8.79)		(5.91)	(3.51)	(4.26)
	Bootstrap p-value		22.05%		30.75%	0.00%	0.00%
Const.		-0.00	-0.01	-0.00	0.00	-0.02	-0.02
	Newey-West SE	(0.01)	(0.02)	(0.00)	(0.01)	(0.01)	(0.01)
	Bootstrap p-value	74.00%	15.75%	7.30%	46.20%	0.00%	0.25%
p-value		0.02	0.12	0.02	0.04	0.00	0.00
Adjusted R-squared		0.04	0.04	0.06	0.07	0.17	0.16
Sample				$1999.6 - 2014.12$			

Panel B: U.K. (2000.2-2014.12)

		(1) $xr^{TIPS-L}_{n,t+1}$	(2) $xr^{TIPS-L}_{n,t+1}$	(3) $xr^{b+L}_{n,t+1}$	(4) $xr^{b+L}_{n,t+1}$	(5) $r^L_{n,t+1}$	(6) $r^L_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$		4.80	3.32		-0.82		-0.49
	Newey-West SE	(1.72)	(2.43)		(2.62)		(1.23)
	Bootstrap p-value	14.60%	14.70%		28.80%		40.90%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			-3.62	5.46	6.48		3.17
	Newey-West SE		(2.93)	(3.02)	(3.38)		(1.86)
	Bootstrap p-value		6.35%	0.10%	0.05%		11.50%
$L_{n,t}$			-21.04		7.42	13.08	13.64
	Newey-West SE		(13.43)		(15.71)	(4.73)	(6.40)
	Bootstrap p-value		36.40%		35.75%	0.00%	0.00%
Const.		0.00	0.04	-0.01	-0.02	-0.01	-0.02
	Newey-West SE	(0.01)	(0.02)	(0.01)	(0.03)	(0.01)	(0.01)
	Bootstrap p-value	67.50	33.65	2.30%	19.50%	6.70%	6.75%
p-value		0.01	0.00	0.07	0.27	0.00	0.01
Adjusted R-squared		0.08	0.12	0.04	0.04	0.09	0.12
Sample				$2000.2 - 2014.12$			

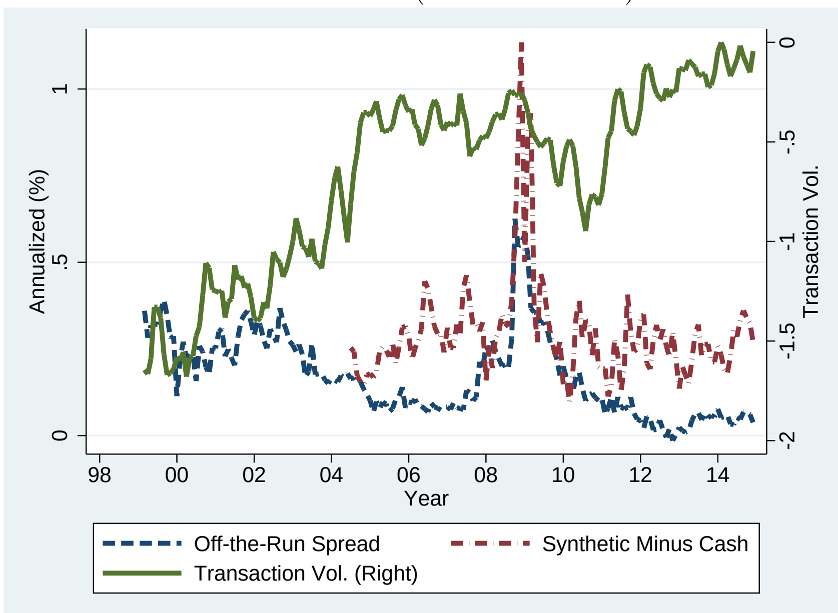
Table IV: Decomposing Bond Risk Premia.

We show statistics for realized and predicted 3-month overlapping log excess returns on real bonds and breakeven, and average log liquidity returns. Realized log excess returns are denoted $xr_{n,t}$, while predicted log excess returns are denoted $E_t\left(xr_{n,t+1}\right)$. We report the average log excess return $\hat{E}\left(xr_{n,t}\right)$, stock market beta $\hat{\beta}\left(xr_{n,t}\right)$, standard deviation of predicted log excess returns $\hat{\sigma}\left(E_t xr_{n,t+1}\right)$, and the correlation between predicted log excess return and the nominal term spread $\widehat{corr}\left(E_t xr_{n,t+1}, y^{\$}_{n,t} - y^{\$}_{1,t}\right)$. Betas are with respect to excess log stock returns on the S&P 500 (U.S.) and the FTSE (U.K.). We obtain predicted excess returns as fitted values from the regressions shown in Tables III(1), III(3) and III(5). Numbers shown are annualized (%). Newey-West standard errors for $\hat{\beta}$ are computed with three lags. * and ** denote significance at the 5% and 1% level for $\hat{\beta}$, respectively.

Panel A: U.S. (1999.6-2014.12)	$\hat{E}\left(xr_{n,t}\right)$	$\hat{\beta}\left(xr_{n,t}\right)$	$\hat{\sigma}\left(E_t xr_{n,t+1}\right)$	$\widehat{corr}\left(E_t xr_{n,t+1}, y^{\$}_{n,t} - y^{\$}_{1,t}\right)$
Liquidity-Adjusted Breakeven	1.63	-0.07	1.33	0.65
Liquidity-Adjusted Inflation-Indexed	3.94	-0.16*	1.52	0.88
Log Return Liquidity	0.92	0.12**	1.62	0.13

Panel B: U.K. (2000.2-2014.12)	$\hat{E}\left(xr_{n,t}\right)$	$\hat{\beta}\left(xr_{n,t}\right)$	$\hat{\sigma}\left(E_t xr_{n,t+1}\right)$	$\widehat{corr}\left(E_t xr_{n,t+1}, y^{\$}_{n,t} - y^{\$}_{1,t}\right)$
Liquidity-Adjusted Breakeven	0.74	-0.27^{**}	2.15	0.71
Liquidity-Adjusted Inflation-Indexed	2.58	0.15	3.32	0.92
Log Return Liquidity	1.56	-0.04	1.60	-0.54

Panel A: U.S. (1999.3-2014.12)



Panel B: U.K. (1999.11-2014.12)

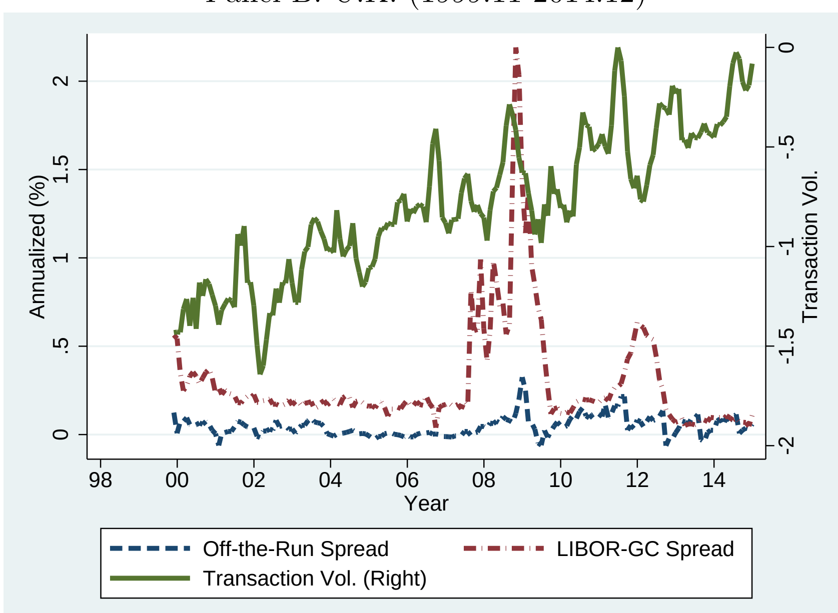
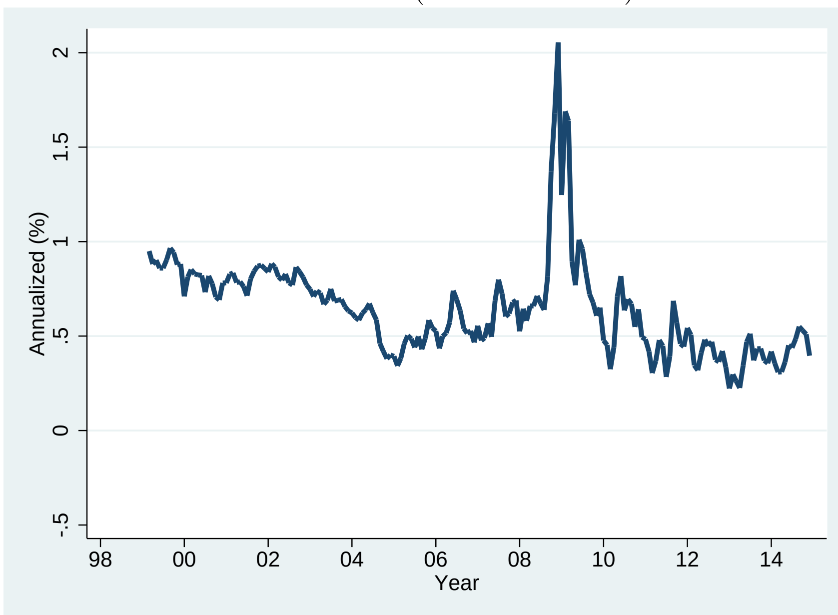


Figure 1: U.S. and U.K. Liquidity Proxies.

We use liquidity proxies to estimate differential liquidity between inflation-indexed and nominal government bonds. For the U.S., we use the spread between off-the-run and on-the-run 10 year nominal bond yields, the relative inflation-indexed bond log transaction volume, the difference between synthetic and cash breakeven. For the U.K., we use the difference between a 10 year nominal fitted par yield and the 10 year nominal generic Bloomberg yield, denoted "off the run". We normalize the maxima of relative transaction volumes to zero. The asset-swap spread differential, synthetic minus cash breakeven, and the GBP three-month LIBOR-GC spread proxy for the cost of funding a levered investment in inflation-indexed bonds.

Panel A: U.S. (1999.3-2014.12)



Panel B: U.K. (1999.11-2014.12)

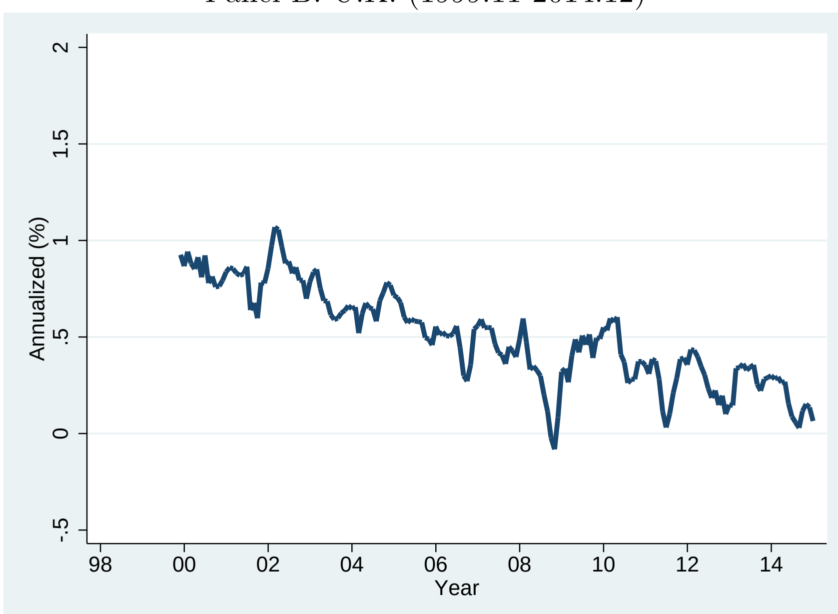
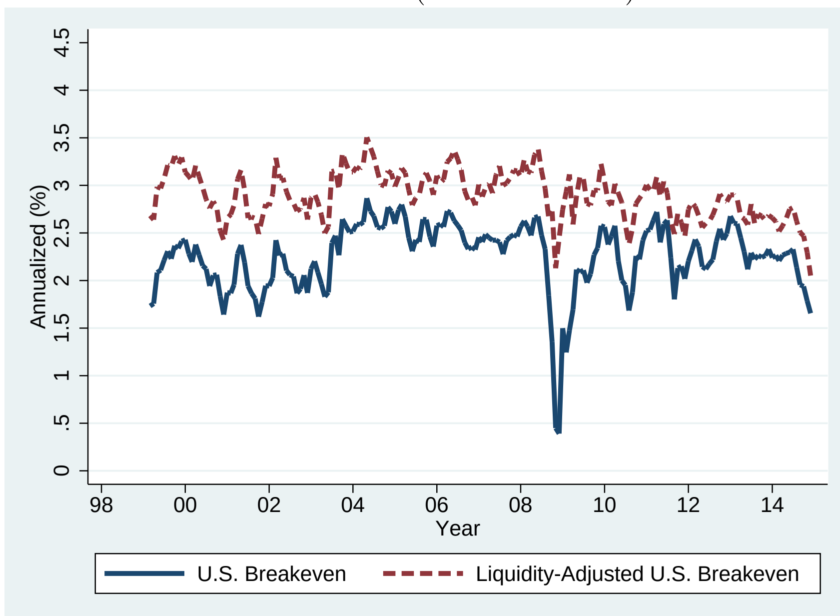


Figure 2: Estimated U.S. and U.K. Liquidity Premia.

We estimate liquidity premia as the negative of the variation in breakeven explained by liquidity proxies. Formally, $\hat{L}_{n,t} = -\hat{a}_2 X_t$, where X_t is the vector of liquidity variables and $\hat{a}_2$ is the vector of corresponding estimated coeffcients in Table II(4), Panels A and B.

Panel A: U.S. (1999.3-2014.12)



Panel B: U.K. (1999.11-2014.12)

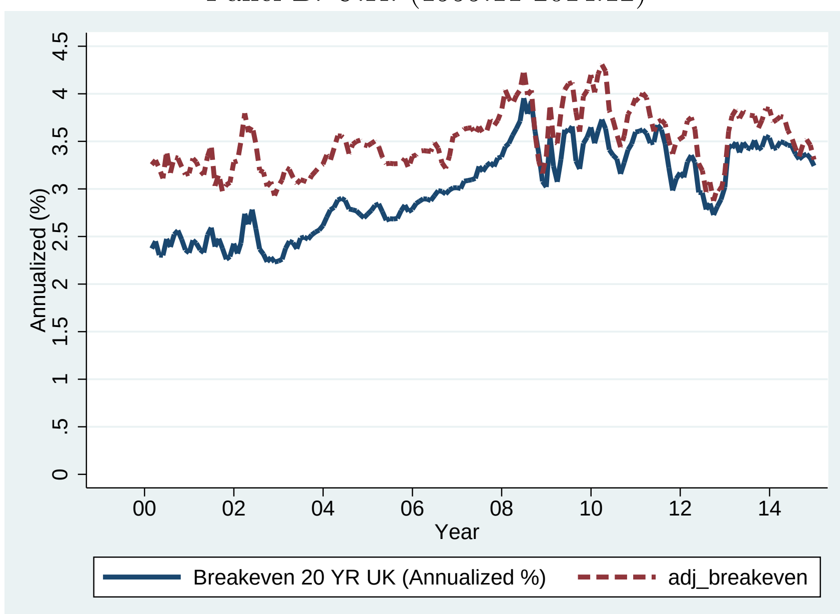
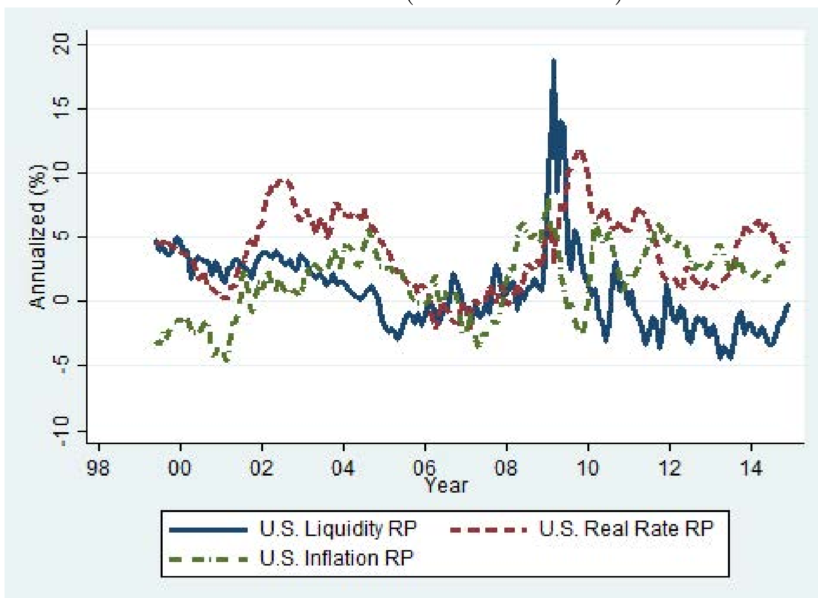


Figure 3: Liquidity-Adjusted U.S. 10 Year Breakeven and U.K. 20 Year Breakeven.

Liquidity-adjusted breakeven equals breakeven plus the liquidity premium shown in Figure 2.

Panel A: U.S. (1999.6-2014.12)



Panel B: U.K. (2000.2-2014.12)

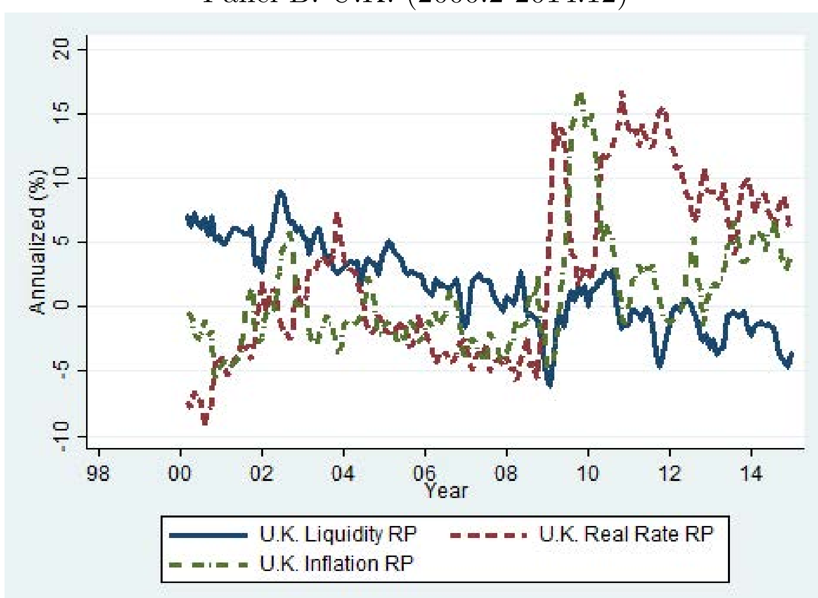


Figure 4: U.S. and U.K. Estimated Risk Premia.

Predicted 3-month excess returns in annualized units, labeled real rate risk premia, inflation risk premia, and liquidity risk premia. We obtain predicted excess returns as fitted values from the regressions shown in Tables III(1), III(3) and III(5), Panels A and B.

On market-based measures of inflation expectations

By Cedric Scholtes of the Bank's Reserves Management, Foreign Exchange Division.

Prices of index-linked financial securities provide market-based measures of inflation expectations and attitudes to inflation risk. In the United Kingdom, 'breakeven' inflation rates derived from index-linked and conventional gilts reflect investors' forecasts of future inflation, and also act as a barometer of monetary policy credibility. Implied breakeven inflation rates are a useful alternative to surveys and econometric forecasts, and are regularly presented to the Bank's Monetary Policy Committee to inform its assessment of economic conditions. This paper outlines the technical and institutional factors that complicate the interpretation of UK breakeven inflation rates. Looking at data, we find that inflation expectations have fallen considerably since the adoption of inflation targeting and that UK monetary policy credibility is considerably stronger since the Bank of England was granted operational independence.

Introduction

Inflation-linked financial securities can be used to infer market-based measures of expectations of future inflation and investors' attitudes to inflation risk. Inflation-linked securities are a useful alternative to surveys and econometric forecasts as a source of information on inflation expectations, with the advantages of being forward-looking, timely, and frequently updated for a range of maturities.

This article discusses how inflation-linked securities are used to derive measures of market expectations of future inflation. The first section briefly outlines the history of the price indexation of financial securities, and looks at the UK inflation-linked debt and swap markets. The second section discusses why investors are concerned about inflation, and outlines suggested criteria for choosing a price index in designing an inflation-proof financial security. The third section explains the concept of 'breakeven' inflation rates. Despite technical and institutional complications, discussed in the following section, breakeven inflation rates contain useful information for policy-makers, and are regularly presented to the Bank's Monetary Policy Committee to inform its assessment of economic conditions. To gauge what incremental information can be extracted from breakeven rates, the next section compares the forecasting performance of breakeven inflation rates with that of Basix inflation surveys. Longer-term breakeven inflation forwards also provide a barometer of monetary policy credibility. We investigate five-year-ahead five-year breakeven forward rates for the United Kingdom since 1985, and find that anti-inflationary credibility is considerably stronger since the Bank was granted operational independence for monetary policy. The last section summarises and concludes.

The UK index-linked gilt market

A brief history of inflation-linked securities

Price indexation of financial contracts is not a new phenomenon. The idea of designing contracts to protect both parties from fluctuations in the price level dates back at least as far as 1780 when the state of Massachusetts issued 'Depreciation Notes' as wages to its soldiers during the American Revolution.(1)

There are four main arguments for debt indexation: to remove the uncertainty about the real cost of borrowing and return on lending (an *ex ante* benefit for both issuers and lenders); to deliver cheaper *ex ante* debt funding (benefiting the issuer); to provide an inflation hedge (expanding investors' investment opportunities

(1) The Massachusetts notes had the following terms: *'Both principal and interest to be paid in the then current Money of said State, in a greater or less sum, according as five bushels of corn, sixty-eight pounds and four-seventh parts of a pound of beef, ten pounds of sheeps wool, and sixteen pounds of sole leather shall then cost more or less than one hundred and thirty pounds current money, at the then current prices of the said articles.'*

and generating general welfare improvements); and to remove the monetary authorities' incentives to reduce the value of government debt through inflationary measures (benefiting bond investors and the general public).

In countries with high inflation, indexed debt may also improve monetary control (by increasing the flexibility of funding), and provide access to and foster the development of long-term capital markets (though it has also been argued that debt indexation can perpetuate the inflationary process by encouraging inflation-linking of other contracts). Since 1980, however, issues of indexed debt have come largely from relatively low inflation countries: the United Kingdom (1981),(1) Australia (1985), Canada (1991), Sweden (1994), the United States (1997) and France (1998).(2)

The UK index-linked gilt market

In 1980, the Chancellor of the Exchequer announced the Government's intention to issue index-linked stock. The index chosen was the general index of retail prices (RPI)—the inflation measure already used for uplifting state pensions. The first index-linked gilt was auctioned in March 1981, and, although initially restricted to pensioners and pension funds, by March 1982 access to the index-linked market was open to all investors. Since then the index-linked gilt (ILG) market has grown steadily: by the end of 2001, the inflation-uplifted amount outstanding, at £70.5 billion, was more than 25% of the size of the total outstanding debt stock (£274.9 billion). Turnover is much lower in the index-linked gilt market, however: in 2001 Q4, ILG turnover by transaction value was only £20.4 billion, around 4.2% of total gilt market turnover by gilt-edged market-makers.(3) Nevertheless, the UK ILG market is special because of its size and range of maturities. The UK market is second only to the United States in terms of absolute size, though it has the most bonds. This is a great advantage as there are enough ILGs distributed sufficiently evenly along the maturity structure to allow a reasonably well-specified yield curve to be fitted.

Given the advantages of issuing index-linked debt, it is perhaps surprising that the private sector sterling index-linked market has only begun to develop in the past two or three years. The corporate and supranational sterling index-linked bond market is currently only around £6.5 billion (uplifted) nominal value in size. This was partly due to previous tax regimes which discouraged corporate issuance of index-linked securities. But another reason must be that for many private issuers, index-linked debt does not help to match liabilities to corporate earnings. Issuing long-term index-linked debt can make little sense to a company with cost and revenue streams that may not be correlated with general inflation, and could merely increase uncertainty in financial planning. One exception (at least in the United Kingdom) are the various utilities sectors whose earnings are directly linked to the RPI through the price-capping formulae used by UK regulators. Indeed, most of the recent private sector index-linked sterling issues by private non-financial companies have been by water companies, electricity generators and gas distribution companies. The non-gilt index-linked market, however, is not sufficiently developed yet to allow comparisons with same-issuer conventional bonds, from which measures of market inflation expectations might be derived.

The UK inflation swap market

In recent years, investor demand has prompted the development of structured financial derivative products designed to deliver a hedge against price inflation. One of these products is the inflation swap, which is a bilateral contractual agreement requiring one party (the 'inflation payer') to make periodic floating-rate payments linked to the RPI in exchange for predetermined fixed-rate 'coupon' payments on the same notional principal from the 'inflation receiver'. Inflation swap contracts are priced directly from the inflation forward rates implied by conventional and index-linked gilts.

Inflation payers are typically institutions with incomes linked to inflation. Examples include utility companies (whose incomes increase with inflation), private finance initiatives (with government-guaranteed cash flows linked to the RPI), and guaranteed return products (which face higher capital gains taxes on indexed gains when inflation is low). Typical inflation receivers are investors with inflation-linked liabilities, such as pension funds, and investors with liabilities on inflation-protected investment products.

(1) Admittedly not a low-inflation country in 1981.
(2) The French Trésor has recently issued a new bond (OATei 3% 25/07/2012) indexed to the eurozone harmonised index of consumer prices minus tobacco.
(3) Source: UK Debt Management Office.

Inflation swaps are generally tailored to the client's particular requirements. Despite being only a fraction of turnover in the index-linked fixed-income market, the use of inflation swaps is growing, and inflation swap activity may enhance the market's liquidity by providing a hedging facility for investors. However, market contacts report that trading is relatively infrequent, and that products are not sufficiently standardised to be able to track and interpret historical prices meaningfully.

Designing inflation-protected debt securities

Why are investors concerned about inflation risk?

Inflation affects the current value of conventional fixed-income securities in two ways. First, *anticipated inflation* determines the expected real value of a fixed nominal income stream. Second, *unanticipated inflation* may further alter the price of a conventional bond—higher-than-anticipated inflation outturns, for example, reduce the real value of a fixed nominal income stream. Hence unanticipated inflation can redistribute wealth between lenders and borrowers. So investors are concerned both about the level and the volatility of price inflation.

We would expect markets to incorporate participants' views of future inflation in prices payable today for conventional fixed-income securities. Investors are ultimately concerned about real returns, and therefore about the likely real value of an asset's payoffs and the risks surrounding those payoffs. For a conventional bond held to maturity, investors will look at the *real yield to maturity*. When the holding period is shorter than the bond's maturity, investors will be interested in *expected real holding period returns*.

If inflation were certain and stable, the nominal yield ($Y_{n,t}$) on a conventional security with a given term of n at time t can be decomposed into a real yield ($R_{n,t}$) and an average inflation component ($\pi_{n,t}$):

$$(1 + Y_{n,t}) = (1 + R_{n,t})(1 + \pi_{n,t})$$

In practice, however, both issuers and purchasers of conventional fixed-income assets are vulnerable to unexpected developments in the general price level. A financial asset that delivers an income stream of known purchasing power may offer a hedge against unpredictable inflation for risk-averse agents, helping to complete the financial markets and generate welfare improvements for both issuers and lenders.(1)

Selecting the reference price index

The choice of reference price index is critical in providing issuers and investors with real value certainty. In principle, bonds could be indexed to any of a number of variables, including price indices, commodity prices, foreign currencies or wage or earnings measures. Price (1997) suggests that the selection of a reference index should be guided by a number of criteria (though these are ideal criteria and may not be achieved in practice):

- The reference index should meet the hedging requirements of both issuer and investor, though in practice these are often unlikely to coincide. Governments, for example, may prefer indexing debt to a broad price measure that is closely correlated with taxation and spending schedules, such as the GDP deflator. Retail investors, on the other hand, may wish to purchase protection against consumer price inflation, while institutional investors (such as pension funds) might want to match liabilities to earnings growth.

- The index should be free of measurement bias. Price indices are subject to measurement and sampling errors and periodic reweighting. In the short to medium term, this may cause consumer price indices to be both an inaccurate and a sometimes upwardly biased reflection of the true cost of living. So index-linked bonds might actually (on average) *overprotect* against inflation risk. Of course, if the biases were known and stable, bond prices could be expected to fully discount for the bias, and the distortion could be negligible. But if index measurement biases were unstable, investors might demand higher real yields on index-linked bonds to compensate.

- The reference price index should be understood, recognised and calculated by a body regarded as independent from the issuer (to avoid any possible conflict of interest). The bond prospectus should describe the index, allocate responsibility for its calculation, and detail the frequency and place of publication. The data behind the index should be reliable and transparent. In addition, the index

(1) A market is complete when, for any possible future state of the world, a security can be purchased that will generate a known payoff in that state and nothing in all other states.

should be free from regular revision, and, should such revisions occur, the procedures for dealing with payment calculations should be outlined in the prospectus. The prospectus should also outline provisions for the index ceasing to exist.

- The indexation lag should be short.(1) For price-indexed bonds to provide complete real value certainty, all cash flows would have to be corrected for changes in purchasing power right up to the moment at which they were due. In practice, however, unavoidable delays between actual movements in prices and adjustment to bond cash flows distort the inflation-proofing properties of indexed securities. Indexation lags produce a period at the end of a bond's life when there is no inflation-proofing, counterbalanced by a period of equal length prior to issue for which inflation compensation is paid. Since inflation in the two periods is unlikely to be the same, the real return on an indexed bond will not be fully invariant to inflation—the longer the lag and the greater the variability of inflation, the poorer the security's inflation-proofing. Because real rates are then distorted, the information content from index-linked bonds will also be affected, with short and medium-term bonds (which may be of particular interest to the monetary authorities) the worst affected.

In practice, most indexed government bonds have been linked to an index of consumer prices. Consumer price indices reflect price developments faced by many bond investors, are generally well understood, widely disseminated, broadly based, rarely revised, and issued with a short time lag (which is important for pricing and trading in the secondary market).

Calculating real interest rates and breakeven inflation rates

Real and nominal yield curves can be derived from conventional and index-linked bond markets. These nominal and real rates can then be used to calculate implied 'breakeven' inflation rates that provide a guide to market inflation expectations. This section describes how index-linked bonds are used to derive real interest rates, from which breakeven inflation rates can be calculated.

Breakeven inflation rates

If conventional and index-linked bond markets are efficient and arbitraged by investors, such that both markets incorporate the same information about real interest rates, then the difference between nominal and real interest rates should contain information about investors' expectations of future inflation. With perfect foresight and no liquidity premia, the difference between nominal and real rates should be equal to the inflation rate over the same period. In practice, however, these are unrealistic assumptions—interest rates and price inflation can be volatile and unpredictable. So implied inflation forward rates are related to, but are not equal to, investors' expectations of future inflation. Implied inflation rates calculated in this way are better referred to as *breakeven* inflation rates.

Calculating a breakeven inflation spot rate for zero-coupon bonds is straightforward.(2) The breakeven inflation zero-coupon rate is the ratio of the zero-coupon yields on two same-maturity conventional and perfectly indexed bonds. Breakeven inflation is the *average* inflation rate that would have to occur over the life of the bonds for the uplifted index-linked bond to generate the same nominal return to maturity as the conventional bond—hence the term 'breakeven'. Another way to think of breakeven inflation rates, however, is as scaling factors applied to future real payments to transform them into future nominal payments of equal present value. Looking at breakeven inflation rates in this way suggests that for coupon bonds, breakeven inflation rates should be calculated by comparing the yields to redemption on same-coupon, same-maturity index-linked and conventional bonds.

Technical complications

Investors prefer to consume wealth today, rather than in the future. Consequently, (zero-coupon) bonds, which promise wealth in the future, trade at a discount, the discount rate for each maturity being the zero-coupon

(1) The minimum indexation lag is determined by two factors: (1) reporting delays, and (2) the method used for calculating accrued interest payments (essential for trading in the secondary market). The indexation lag on US Treasury inflation-indexed securities (more commonly known as TIPS) and Canadian Real Return Bonds is three months, and accrued interest is calculated by interpolating between the three-month lagged CPI and the two-month lagged CPI value. In the United Kingdom, on the other hand, accrued interest is calculated as a linear interpolation to the next coupon payment (which must therefore be known in advance). Consequently, an eight-month lag is required: two months for reporting delays, and six months to calculate the next semi-annual coupon.

(2) A 'zero-coupon' or 'pure discount' bond is a bond that has only one cash flow—the face value (by convention £100)—which is paid at maturity. There are no intermediate cash flows (coupons). Prior to maturity, zero-coupon bonds trade at a discount to face value.

or 'spot' rates. Taken together, spot rates contain implicit forward rates—today's terms for the lending of funds between two dates in the future.(1)

The *expectations hypothesis* of the term structure states that in a world with perfect foresight, expected rates of return on different maturity bonds are equalised only when all forward rates equal expected short-term interest rates. Combined with the *efficient market hypothesis*—which has several forms, all of which require investors to use information efficiently—the pure expectations hypothesis states that market forward rates provide the best forecast of future spot rates.

Of course, in reality, investors do not have perfect foresight. But in a complete and efficient market without distortions, breakeven inflation forward rates should be determined by three factors: (i) inflation expectations; (ii) the convexity adjustments present in conventional and index-linked bonds; and (iii) inflation risk premia. This section considers how convexity biases and risk premia drive a wedge between breakeven inflation forward rates and true inflation expectations.

The convexity adjustment

Interest rate compounding means that bond prices respond asymmetrically to changes in yield—bond prices are more sensitive to reductions in yield than to increases in yield.(2) In other words, bond prices are a convex function of yield. This combination of bond convexity and interest rate volatility raises bond prices, which pushes down forward rates. This effect is known as the convexity bias, and it grows with maturity (as compounding increases) and can vary across time (as yield volatilities change).

Differences in convexity bias between index-linked and conventional bonds mean that breakeven inflation forward rates may differ from actual inflation expectations. For example, if the convexity adjustment for the nominal forward curve was greater than for the real forward curve, perhaps because inflation uncertainty was adding to the volatility of nominal rates, then the net convexity adjustment could be expected to bias long-term breakeven inflation forward rates below actual expectations.

The inflation risk premium

The return to maturity on a conventional bond is fixed in nominal terms, but is uncertain in real terms because of inflation. Investors are interested ultimately in real returns, so may be willing to pay a premium for a security that provides real value certainty. The inflation risk premium will depend on how inflation (and hence the real returns on a conventional bond) varies with the discount factor that the market applies to real wealth in future states of the world. As with the convexity bias, these inflation risk premia may vary over time and maturity.

Fitting breakeven inflation rates

The United Kingdom has a sufficient number of index-linked government bonds to be able to fit a real yield curve.(3) When combined with a nominal yield curve, one can derive breakeven inflation yields. But the breakeven rates obtained will be influenced by the choice of curve-fitting technique, and the differences between techniques will be most pronounced when there are relatively few bond price data.

The Bank aims to use a curve-fitting technique that delivers a relatively *smooth* yield curve, since the aim is to estimate market expectations for monetary policy purposes rather than to fit prices precisely. The ideal technique should also be sufficiently *flexible* to capture movements in, and key features of, the underlying term

(1) If $z(t)$ and $z(T)$ are the annualised zero-coupon rates for t and T years maturity (where $t < T$), then the annualised forward rate at time 0 for lending between t and T is given by:

$$f(0,t,T) = \left(\frac{(1+z(T))^T}{(1+z(t))^t} \right)^{\frac{1}{T-t}} - 1.$$

(2) For example, consider a ten-year zero-coupon bond with face value £100 and initial zero-coupon yield 5%. Its current price is £61.39—since the price at time t of a zero-coupon bond maturing at T with annually compounded yield, $y_{t,T}$, is $P_{t,T} = 1/(1 + y_{t,T})^{T-t}$. Now consider the effect of a 1 percentage point change in yield. If yield rises to 6%, the bond price falls to £55.84 (down £5.55). If yield falls to 4%, the bond price increases to £67.55 (up £6.17). So bond prices are more sensitive to falls in yield than to increases in yield, and will therefore rise as yield volatility increases.

(3) Apart from the UK Treasury, no other major government issuer currently has a sufficient number of outstanding index-linked bonds to permit estimation of a well-specified real yield curve. So for most countries it is not possible to estimate spot or forward breakeven inflation rates, and one is limited to calculating crude breakeven inflation yields from differences in redemption yields on particular conventional and index-linked bonds. However, when comparing index-linked and conventional gilts with similar coupon rates and maturities, this crude approach usually generates breakeven inflation yields that are very close to estimates derived from the difference between fitted real and nominal yields.

structure. Also the yield curves produced should be *stable*, in the sense that fitted yields at one maturity should be robust to small changes in bond data at another maturity. The Bank currently fits yield curves using both smoothed cubic spline (Anderson and Sleath (1999)) and parametric (Svensson (1995)) approaches.(1)

Institutional distortions to breakeven inflation rates

In theory, breakeven inflation rates derived from conventional and index-linked government bonds should reflect rational expectations of future inflation plus an adjustment for inflation convexity biases and risk premia. Under certain conditions, however, the breakeven inflation rates can be distorted. The first of these is the way differences in tax treatment between conventional and index-linked bonds may affect relative prices. The second is institutional factors, which may create price-inelastic demand for gilts. In practice, these technical complications and distortions may limit the usefulness of breakeven inflation rates as a measure of inflation expectations.

Taxation

Investors are concerned about real net-of-tax cash flows, so *differences in tax treatment* between conventional and index-linked bonds could influence relative prices, and therefore breakeven inflation rates. Tax authorities have to decide whether income and capital gains taxes should be applied to nominal or real cash flows—in other words, whether taxes should be levied on the inflation uplift for coupon and principal payments. However, since real value certainty is the most important characteristic of indexed bonds, a tax system that taxes the inflation uplift in effect reintroduces inflation risk. Under such a system, even if pre-tax real yields remained constant, an increase in inflation that raised the nominal yield on indexed bonds would increase the tax liability and lower the post-tax real yield. In the United Kingdom, the inflation uplift on the *principal* is considered a capital gain (and is not taxed). But the uplift on *coupon payments* is treated as income, and taxed accordingly. The implication is that the post-tax real returns on index-linked gilts are not entirely protected from erosion by high inflation, and this will be reflected in prices.

The variety of possible investor tax profiles also complicates the calculation of post-tax yields and breakeven inflation rates for the 'representative' marginal investor. In the United Kingdom, conventional and index-linked gilt stocks are mostly held by largely tax-exempt institutional investors. So if we assume these investors to be the marginal purchasers of gilts, then it is not unreasonable to set aside tax considerations when looking at implied breakeven rates—at least in the United Kingdom.

Other institutional considerations

UK life assurance and pension funds (LAPFs) are estimated to hold a high proportion of the outstanding gilt stock—perhaps more than a half. So the portfolio allocation decisions of these institutions could have significant effects on gilt prices. In the United Kingdom, there are a number of factors that may have helped to generate price-inelastic demand for gilts from LAPFs. In particular, pension funds have raised their holdings of gilts in response to: (i) ageing of the UK population; (ii) the introduction of Minimum Funding Requirement legislation; (iii) the need to hedge old policies with (previously unhedged) guaranteed annuity rates; and (iv) the practice of appraising pension fund and bond portfolio managers' performance against either industry peer group or gilt yield benchmarks, thereby providing an incentive to hold gilts.

In 1997, government legislation came into force designed to ensure that defined benefit pension funds would protect fund members in the event of the employer becoming insolvent. The Minimum Funding Requirement (MFR) was designed to ensure that a scheme would have sufficient assets to be able fully to protect pensions already in payment, and to provide younger members with a transfer value that would give them a reasonable expectation of replicating scheme benefits if they transferred to another pension scheme.

The MFR values a fund's assets at current prices by marking-to-market. However, to ensure that defined benefit schemes hold sufficient assets to meet their liabilities, the MFR applies a set of liability valuation rules linked to yields on a set of gilt indices.(2) Although not actually requiring pension funds to purchase gilts,

(1) For a full description of the Bank of England's yield curve fitting techniques, see Anderson and Sleath (1999) and Deacon and Derry (1994).
(2) In March 2001, the Chancellor of the Exchequer announced that the MFR would be replaced when new legislation could be formulated and passed through Parliament. Note, however, that by June 2003 a new financial reporting standard (FRS17) will come into force. FRS17 will show pension fund net assets or liabilities as an item in the balance sheet of the employer company, and will value defined benefit pension scheme liabilities using the prevailing yield on an AA-rated corporate bond of appropriate maturity.

legislation that requires the use of 15-year conventional gilt and 5-year index-linked gilt indices as discount factors for valuing liabilities also generates strong incentives for defined benefit pension funds to hold these gilts on the asset side. Matching assets and liabilities in this way, by making the same discount rates common to both, reduces the likelihood that fluctuations in financial prices will result in the fund becoming underfunded. Furthermore, work at the Bank has found evidence that the widespread use of FTSE gilt indices can also prompt gilt prices to respond to changes in the composition of the index. By influencing the demand for gilts in this way, it is possible that the MFR and the use of FTSE gilt indices may have distorted (and may continue to distort) implied breakeven inflation rates at certain points along the yield curve.

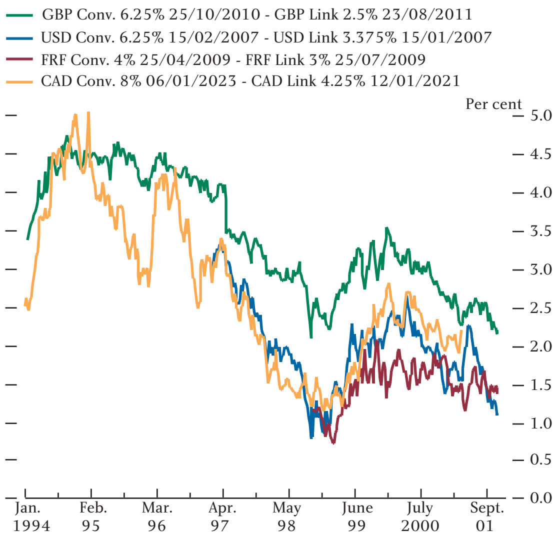
The distortionary impact of price-inelastic demand from the pension fund industry has arguably been aggravated by concerns, in recent years, about the outlook for future new supply and the outstanding stock of government debt. In the United Kingdom, net debt issuance as a percentage of GDP has been shrinking since 1996 Q1, and has been negative since 1997. A diminishing supply of UK government debt, together with a shortage of alternative high-quality long-dated fixed-income sterling securities (such as supranational or high-grade corporate paper) and a strong inelastic-demand from institutional investors may have driven prices out of line with economic fundamentals.

An indication of the impact of institutional factors may be obtained from: (i) comparisons of common currency borrowing rates on government bonds, (ii) comparisons of breakeven inflation rates in different countries, and (iii) breakeven inflation forward curve profiles for sterling.

Using interest rate and currency swaps, it is possible to calculate and compare the common currency costs of borrowing for government bond issuers. For example, on 1 December 1999, the UK Treasury 9% 06/08/2012 gilt could be swapped into a bond paying sterling (GBP) 6-month Libor minus 103 basis points. The French government OAT 8.5% 26/12/2012 bond, on the other hand, could be swapped into GBP 6-month Libor minus 48 basis points. This difference in spreads to GBP 6-month Libor meant that HM Treasury was effectively able to borrow some 55 basis points more cheaply than the French Trésor. Since both issuers are almost identical in terms of credit quality, this difference must have reflected institutional factors, including MFR legislation. But note that relative funding costs also change over time—by February 2002 both the gilt and OAT swap spreads to GBP Libor had narrowed considerably, and the United Kingdom's funding cost advantage had shrunk to around 18 basis points. To the extent that institutional factors have asymmetric effects on the conventional and index-linked markets, one might see an impact on breakeven inflation rates.

Chart 1 provides an international comparison of breakeven inflation rates on selected index-linked government bonds from 1994 to 2001. Given the small absolute size of the differentials, the sterling breakeven inflation yield for the 2011 index-linked gilt was not obviously out of line with breakeven rates for other economies at similar maturities. Furthermore, any divergence could be attributed to economic fundamentals and investor preferences rather than to institutional distortions.

Chart 1
International breakeven inflation yields

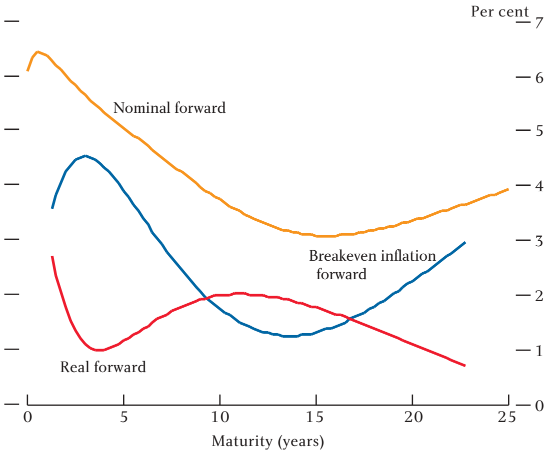


Source: Bloomberg.

However, it is also worth looking at the profile of breakeven inflation forward curves. During the period covered by the MFR, one might expect to see conventional gilts at and around 15 years' maturity trading at relatively expensive levels, driving down nominal spot and forward rates. At the same time, one might also observe episodes with price discontinuities between index-linked gilts either side of the 5-year maturity mark, translating into 'humped' real forward curves. So nominal and real interest rate and breakeven inflation forward profiles such as for 20 December 1999 (see Chart 2) suggest that the MFR was affecting the conventional and index-linked markets.

Chart 2 raises the question of whether investors could really have had sufficient information to foresee inflation following the path indicated. Can we really believe that investors anticipated inflation 15 years ahead to be lower than in 25 years' time? Arguably, breakeven inflation forward curves such as the one shown in Chart 2, taken during a period of low and stable inflation, are difficult to reconcile with investor rationality. More likely, inflation forward profiles such as that for 20 December 1999 reflect the various distortions in the gilt markets, and provide a salutary lesson for those wishing to extract inflation expectations from breakeven inflation rates. The reality is that it is difficult to isolate and quantify the distortions that can affect breakeven inflation rates.

Chart 2
UK forward curves for 20 December 1999



Note: Breakeven inflation, nominal and real one-year forward curves are calculated using the Bank of England's variable roughness penalty spline-based technique (see Anderson and Sleath (1999, 2001)).

Extracting information from breakeven inflation rates

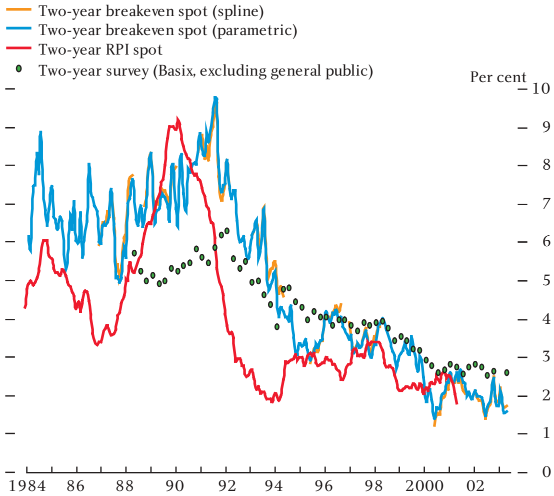
Breakeven inflation rates as forecasts of inflation

Breakeven inflation rates are useful in providing an indication of investors' views of the longer-term inflation outlook that is unavailable elsewhere. But monetary policy makers are also interested in inflation over the short-to-medium term. So it is interesting to compare the forecasting performance of breakeven inflation rates with survey-based measures of inflation expectations.

Breakeven inflation rates can be compared with the Barclays Basix survey of expectations for RPI inflation over the next two years.(1) The survey samples a number of groups, including business economists, investment analysts, academic economists, trade union secretaries and the general public. For this study, we consider only the measure that excludes the general public.(2)

Chart 3 plots the actual (monthly) RPI inflation outturn for the past two years against the zero-coupon breakeven inflation rates and (quarterly) Basix survey inflation forecasts made for those two years. The chart shows a number of interesting features: first, both the survey and breakeven series underpredicted actual RPI inflation outturns during 1989–91 but generally overpredicted inflation after 1991. Second, the two-year breakeven inflation rate tracks two-year-ahead RPI inflation better than survey forecasts. Third, breakeven inflation and survey forecasts have both been falling since 1990, though the adjustment process appears to have been lagged (and slow) compared with actual RPI inflation.(3) Fourth, two-year spot breakeven inflation and survey rates have differed, often quite considerably, during the sample period. Fifth, revisions to survey expectations have been less volatile than those of breakeven inflation rates.

Chart 3
Breakeven inflation and Basix survey two-year spot rates against RPI two-year inflation outturns

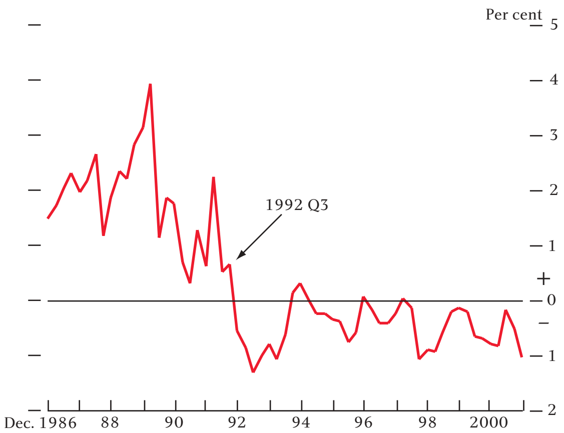


Notes: (1) The two-year annualised spot rate is the average annual rate over the past two years.
(2) Two-year breakeven inflation zero-coupon rates are calculated by the Bank of England (see Anderson and Sleath (2001) and Deacon and Derry (1998)).
(3) The two-year spline-based breakeven inflation series is broken due to occasional absence of sufficiently short index-linked bonds.

(1) Comparisons at shorter-maturity horizons are not possible because the absence of bond data points makes the real yield curve too unreliable at less than two years.
(2) We exclude the general public survey figures because of their consistent positive bias.
(3) This apparent delay in the forecast error correction process is consistent with an overlapping forecast horizon problem.

An important feature of the data is the possible structural break in the differential between the breakeven and survey inflation series—this is shown in Chart 4. The difference between surveys of two-year inflation expectations and the breakeven inflation rate implied from bond prices can be used as a proxy for the inflation risk premium. Prior to 1992 Q3, breakeven inflation rates were consistently above survey expectations (on average by 1.89 percentage points). After this date, however, this differential became negative, though smaller in absolute size (on average -0.42 percentage points), as survey respondents raised their forecasts of two-year inflation after 1992 Q3. This apparent structural break roughly coincides with sterling's exit from the European Exchange Rate Mechanism (ERM).

Chart 4
Difference between two-year breakeven and survey-based inflation expectations



Note: The differential is the two-year breakeven spot rate minus the (quarterly) two-year spot Basix survey (excluding general public).

This break in the breakeven/survey differential series also poses a puzzle, since sterling's ejection from the ERM and the associated loss of policy credibility would have been expected to drive up the inflation risk premium, and so to have widened rather than narrowed the differential, at least until the inflation-targeting framework had become established. An alternative explanation is that the United Kingdom's abandonment of exchange rate targeting in favour of an inflation-targeting policy could have been expected to lower short-term inflation volatility, and therefore to reduce immediately the short-term inflation risk premium. This argument allows for a simultaneous fall in the short-term inflation risk premium and a reduction in long-term policy credibility.

Although short-term breakeven inflation rates are not perfect forecasts of inflation (due to time-varying inflation risk premia and lags in error correction), our analysis does indicate that breakeven inflation rates are better than Basix surveys in terms of forecasting performance, and may therefore be a useful source of information on short-term inflation expectations for policy-makers.

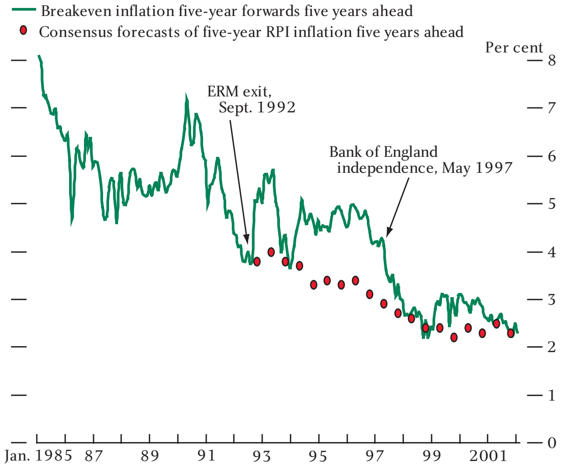
Breakeven inflation rates as a measure of central bank credibility

Investors' longer-term expectations of inflation depend on their confidence in the ability and determination of the monetary authorities to control inflation. Breakeven inflation rates may not be easily decomposed into inflation expectations and inflation risk premia, but these components are linked to investors' views and preferences about the level and volatility of future inflation. As King (1995) notes, 'both the government and private sector have subjective distributions over the possible outturns for inflation at any future date. Credibility is a measure of how close are these two distributions'. The private sector's distribution can be summarised by its mean—the expected inflation rate—and the spread of possible outturns around the mean, as proxied by the inflation risk premium. Since breakeven inflation rates capture both of these components, they are a potentially useful indicator of anti-inflationary credibility.

Forward inflation rates are more informative than spot rates of inflation as an indication of monetary conditions, as they allow policy-makers to assess both the expected average rate of inflation *and* its evolution over time. Implied breakeven forward rates can be used to assess the impact of monetary policy on inflation credibility. To illustrate this, Chart 5 presents annualised breakeven inflation five-year forwards five years ahead since 1985. It is interesting to compare these forward rates with the Consensus economists' expectations of five-year annualised inflation five years ahead. The chart illustrates the impact of two major developments in monetary policy over the period: the United Kingdom's exit from the ERM in September 1992, and the establishment of the RPIX inflation target soon after, followed by the Government's concession of operational independence to the Bank of England and the formation of the Monetary Policy Committee framework in May 1997.

The breakeven inflation forward rates clearly indicate that the United Kingdom's exit from the ERM in 1992 had a dramatic impact on market confidence, driving up breakeven forwards by 125 basis points. This indicates

Chart 5
Long-term breakeven inflation forwards and Consensus expectations



Note: Breakeven inflation forward rates are derived using the Bank of England's variable roughness penalty spline-based technique (see Anderson and Sleath (1999, 2001)).

that the loss of the ERM's external discipline on policy had a serious negative impact on the credibility of UK monetary policy in the financial markets. Although the new inflation-targeting policy became established in late 1992 and early 1993 and economists began gradually to revise downwards Consensus long-term forecasts of RPI inflation, one can see that there continued to be a significant differential between the breakeven forward rates and Consensus forecasts for a number of years. This suggests that although the exchange rate target had been replaced with an inflation target, and the policy process been made more transparent and accountable through the publication of a regular *Inflation Report* by the Bank of England, there was still some 'doubt [about] the United Kingdom's willingness to remove operational decisions on interest rates from the political arena' (King (1999)). In other words, the gap between Consensus forecasts and breakeven inflation forwards was probably pointing to an inflation risk premium stemming from a policy credibility shortfall.

In May 1997, the Chancellor of the Exchequer declared that the Bank of England would be granted operational independence for the conduct of monetary policy, with a clear remit to achieve, on average, 2.5% RPIX inflation. Looking at movements in conventional and index-linked gilt prices, one finds that breakeven inflation forwards fell by 50 basis points at ten years' maturity on the day of the announcement, and by even more thereafter.(1) But credibility generally takes longer to establish than it does to lose, and as the Chancellor, Gordon Brown, stated at the time, 'the ultimate judgement of the success of this measure will not come next week, or indeed in the next year, but in the long term.' Since May 1997, the gap between long-term breakeven inflation forwards and long-term inflation expectations has narrowed considerably. Indeed, breakeven inflation five-year forwards five years ahead have fallen by around 180 basis points, and are currently close to both the Government's 2.5% RPIX inflation target and Consensus RPI inflation forecasts.

Summary and conclusions

This paper has outlined how inflation-linked securities can be used to infer market-based expectations of future inflation. Inflation-linked securities provide an alternative source of information on inflation expectations to surveys and econometric forecasting approaches, with the advantages of being available for a wide range of maturities, entirely forward-looking, timely, and updated every working day.

In the United Kingdom, market inflation expectations can be derived from a comparison of conventional and index-linked gilt prices or (with difficulty) directly from inflation swaps. By fitting real and nominal yield curves to conventional and index-linked gilts, it is possible to infer zero-coupon and forward breakeven inflation rates. These breakeven inflation rates contain information about inflation expectations, though to extract this information one has to allow for both technical complications and the possibility of institutional distortions.

Due to the near-continuous nature of gilt trading activity, breakeven inflation rates can provide policy-makers with an immediate verdict on the market's view of the impact of economic news on the anticipated path of future inflation, and investors' attitudes to inflation risk. To gauge what incremental, policy-relevant information can, in practice, be gained from a comparison of index-linked and conventional gilt prices, we compared the two-year breakeven inflation rates with two-year Basix inflation surveys. Our results indicate that, despite the possible influence of risk premia and institutional distortions, two-year breakeven inflation rates do provide information additional to that already contained in surveys of inflation expectations. Longer-term breakeven inflation rates, meanwhile,

(1) See King (1999). This speech may be found on the Bank's web site at www.bankofengland.co.uk/speeches/speech41.pdf

provide a barometer of inflation credibility. It is interesting, for example, to compare the immediate (negative) impact of September 1992 on UK monetary policy credibility in long-term breakeven forward rates with the gradual gains in credibility accumulated since Bank of England independence.

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Can TIPS Help Identify Long-Term Inflation Expectations?

By Pu Shen and Jonathan Corning

Investors and policymakers have long hoped that Treasury Inflation Protected Securities (TIPS) would provide an accurate measure of long-term market inflation expectations. To make informed decisions and to ensure that inflation does not erode the purchasing power of their assets, investors need to assess the rate of inflation expected by other market participants. Having an accurate measure of market inflation expectations can also help policymakers assess their effectiveness in controlling long-term inflation, as well as their credibility among market participants. Until recently, however, the only sources of information about long-term inflation expectations were surveys and the term structure of interest rates, neither of which were considered highly reliable. With the introduction of TIPS in 1997, it was hoped that a new measure of market inflation expectations—the difference in yields between conventional Treasuries and TIPS—would become available.

The yield difference between conventional Treasuries and TIPS may provide an accurate measure of market inflation expectations because inflation has very different effects on the returns to the two kinds of securities. The yield on a conventional Treasury must compensate the buyer for any expected erosion in purchasing power due to future inflation. In contrast, the buyer of an inflation protected Treasury need not worry about future inflation because the principal and interest payments are both

Pu Shen is an economist at the Federal Reserve Bank of Kansas City. Jonathan Corning is a research associate at the bank. This article is on the bank's web site at www.kc.frb.org.

indexed to inflation. As a result, the yield difference between conventional and inflation protected Treasuries of given maturity should reveal the rate of future inflation expected by market participants.

Not everyone agrees, however, that the yield difference provides an accurate measure of expected inflation. Skeptics point out that the yield difference may depend on other factors, such as the liquidity difference between the two kinds of Treasuries, making it difficult to extract information about market inflation expectations.

This article examines the empirical evidence on the behavior of the yield difference and the liquidity of the TIPS market. The article finds that the yield difference has not provided a good measure of market inflation expectations because of the large and variable liquidity premium on TIPS. Still, the yield difference may become a better measure of market inflation expectations as liquidity conditions in the two kinds of Treasury markets move closer in the future.

The first section of the article explains why the yield difference between conventional Treasuries and TIPS might provide a good measure of market inflation expectations. The second section examines the actual behavior of the yield difference since TIPS were introduced and points out that the yield difference appears to be influenced by factors other than market inflation expectations. The third section investigates the role of market liquidity and concludes that the difference in liquidity between the two types of Treasuries has kept the yield difference from becoming a good measure of expected inflation. The fourth section suggests that the yield difference between conventional and inflation protected Treasuries may approximate market inflation expectations better in the future.

I. WHAT ARE YIELD SPREADS AND MIGHT THEY TRACK MARKET INFLATION EXPECTATIONS?

As TIPS are relatively new to many investors, this section briefly describes their main features. The section then examines the different components of the yield difference, or spread, between conventional and inflation protected Treasuries. The section shows that the expected rate of future inflation is the main component of the yield spread. The section also shows, however, that other components, such as the inflation risk premium and the liquidity premium may also be important, complicating the task of extracting information about market inflation expectations.

What are TIPS?

Since 1997, the U.S. Treasury has been issuing debt instruments, the payoffs of which are tied to the inflation rates during the lives of the instruments. They are called Treasury Inflation Protected Securities, as they protect investors from the risk of unexpected inflation.[1]

The first indexed Treasury was issued in January 1997, with a maturity of ten years. Since then, the U.S. Treasury has regularly issued 10-year TIPS every January and sold additional quantities of the January issue later in the year.[2] The Treasury has also issued TIPS with 5-year and 30-year maturities, but with less regularity.[3] Currently, there are about $135 billion worth of TIPS outstanding, compared with more than $2.8 trillion worth of conventional Treasuries. Thus, TIPS constitute less than 5 percent of the total outstanding value of Treasuries.[4] Within the universe of indexed Treasuries, 10-year TIPS make up more than half of the outstanding total.

The most important feature of TIPS is that investors in these Treasuries are protected from the risk of unexpected inflation. To understand this, first it is helpful to appreciate the inflation risk embedded in conventional Treasuries. In a conventional Treasury security, the coupon rate is fixed at a nominal rate at the auction. Consequently, the nominal return to holding such a Treasury to maturity is fixed at the time of purchase.[5] As what matters to investors is the purchasing power of their investment, investors focus on the *real* return, which is the difference between the nominal return and the inflation rate during the life of the investment. For example, if an investor buys a 10-year conventional Treasury at its par value with a coupon rate of 6 percent, and inflation turns out to average 2 percent for the next ten years, then the real return on this investment is 4 percent. On the other hand, if inflation turns out to be 4 percent, then the *real* return is only 2 percent.[6] In other words, an investor in conventional Treasuries is exposed to inflation risk in the sense that the real return is inversely related to the actual rate of inflation during the life of the security.

In contrast to conventional Treasuries, the real return to investors on a TIPS is fixed at auction time and is unaffected by the actual rate of inflation during the life of the security. This happens because the coupon rate on an indexed Treasury is fixed in real terms, and the dollar value of the principal grows with inflation over the life of the TIPS. For example, in January 2001, the U.S. Treasury issued a 10-year indexed security with a coupon rate of 3.5 percent. If an investor buys this security at par in January and holds it to maturity, and if actual Consumer Price Index (CPI) inflation turns out to average 2.5 percent in the next ten years, the real return to the investor is 3.5 percent even though the average nominal yield is 6 percent.[7] If instead, inflation turns out to average 5 percent, the investor's real return is still 3.5 percent, although the nominal yield is 8.5 percent. In both scenarios the real yield, or the rate of return to the investor in terms of purchasing power, is identical and unaffected by inflation.[8]

Why is expected inflation a component of the yield spread?

The difference between the quoted yields on a conventional and an indexed Treasury security with similar maturity is usually referred to as the yield spread between the two securities. In the bond market, the commonly quoted yield on a conventional Treasury is the nominal yield, while the most commonly quoted yield on an indexed Treasury is the real yield.[9] Therefore, yield spreads are differences between nominal yields and real yields.

In a world where investors are indifferent to risks, only expected real yields matter. In such a world, yield spreads mainly reflect the average rate of future inflation expected by bond market participants, that is, the market inflation expectation, which is sometimes called expected inflation. Investors will always purchase the Treasury with a higher real yield, causing prices to adjust, which results in both nominal and indexed Treasuries ending up with the same expected real yield. In this world, the yield spread is an accurate measure of expected inflation. That is,

$$y^n - y^r = \pi^e ,$$

where y^n is the nominal yield on a 10-year conventional Treasury, y^r is the real yield on a 10-year indexed Treasury, and ^{e} is the average of market participants' expected rates of future inflation for the next ten years.

In this world, the yield spread provides a quick, reliable, and timely measure of expected inflation, which is highly valuable to consumers, investors, as well as policymakers. Accurate measures of market inflation expectation are difficult to come by. Before the existence of the inflation protected Treasuries, the most commonly used measures of expected inflation were forecasts based on survey responses. But survey measures of expected inflation only cover a very small portion of the population and are updated infrequently. Further, such measures may not be completely reliable if survey respondents answer questions casually. In contrast, the yield spread is based on investment decisions of large numbers of investors who risk their own money for such decisions. Further, this information is updated every day when financial markets are open and trading occurs freely. Thus, in a world in which investors care only about expected real yields, yield spreads should be a better measure of market inflation expectations than survey forecasts.[10]

Why the yield spread may have other components

In the real world, other factors may affect yield spreads because investors may care about more than just the expected real yields. In particular, one thing investors may care about besides the expected real yield is *inflation risk*. This is the risk that the real return on a security turns out to be different from what investors expected because inflation turns out to be higher or lower than expected. As noted earlier, TIPS have no inflation risk. In contrast, a conventional Treasury can have considerable inflation risk because the real return on such a security moves inversely with the actual rate of inflation during the life of the security. As a result, a conventional security will generally have to carry a higher expected real yield than an indexed Treasury just to be equally attractive to investors. This additional yield is usually called the *inflation risk premium*, as it is a premium to compensate investors for taking on the risk.

Another thing investors may care about besides the expected real yield is *liquidity risk*. The liquidity risk of an asset is the risk that investors may incur large costs buying or selling the asset in a secondary market. The need to raise cash or make other portfolio adjustments may force an investor to buy or sell a security in the secondary market. As a result, investors need to consider the likely costs associated with such trading. Some of the costs are known, such as brokerage fees and commissions. These kinds of costs are ignored in the discussion, as investors tend to face similar brokerage fees and commissions for trading conventional and indexed Treasuries.[11] Other costs are related to the ease and convenience of trading, which are more uncertain in nature. For example, for less liquid assets, a seller of a large-dollar value of securities may have to accept a lower price to complete the sale in a timely fashion. Since the probability of incurring such costs is inversely related to the liquidity of the asset, the less liquid asset carries higher liquidity risk. Consequently, the less liquid asset needs to carry a higher compensating yield in order to attract investors. This additional yield is commonly referred to as a *liquidity premium*.[12]

Liquidity risk is more relevant to investors in TIPS than to investors in conventional Treasuries. As the market for conventional Treasury securities is the most liquid asset market in the United States, the liquidity risk for conventional Treasuries can be considered to be zero.[13] The market for TIPS, on the other hand, is less liquid. As a result, it is likely that part of the yield on an indexed Treasury is a liquidity premium.

In this more realistic world where investors are concerned about risk, the yield spread between a conventional and an indexed Treasury is no longer an accurate measure of market inflation expectation. The yield spread now equals: (1) the expected inflation rate over the life of the security, plus (2) the inflation risk premium on the conventional Treasury, minus (3) the liquidity premium on the TIPS. More formally, the yield spread is

$$y^n - y^r = \pi^e + p(\pi) - p(l),$$

where $p(\pi)$ is the inflation risk premium on the conventional Treasury, and $p(l)$ is the liquidity premium on the indexed Treasury.[14]

In this world, the yield spread can be higher or lower than expected inflation. If the inflation risk premium exceeds the liquidity premium, the yield spread will be higher than expected inflation. If, on the other hand, the inflation risk premium is smaller than the liquidity premium, the yield spread will be lower than expected inflation. Only when the inflation risk premium is the same size as the liquidity premium will the yield spread equal the expected rate of inflation. Note, however, that if both premia are small relative to expected inflation, their difference will be even smaller, and the yield spread will be a close approximation of expected inflation. Furthermore, even if the yield spread is an inaccurate measure of expected inflation, the change in the spread may still be a good measure of the change in market inflation expectations. This will be the case if both the inflation risk premium and the liquidity premium are roughly constant over time.

II. HOW CLOSELY DO YIELD SPREADS TRACK MARKET INFLATION EXPECTATIONS?

This section examines actual data to show how well the yield spread and the change in the yield spread perform as measures of market inflation expectations. First, examination of the level of yield spread since the inception of TIPS reveals that the level is generally lower than the plausible level of expected inflation. Next, examination of the changes in the yield spread shows that the changes appear to be too volatile to reflect only changes in expected inflation.

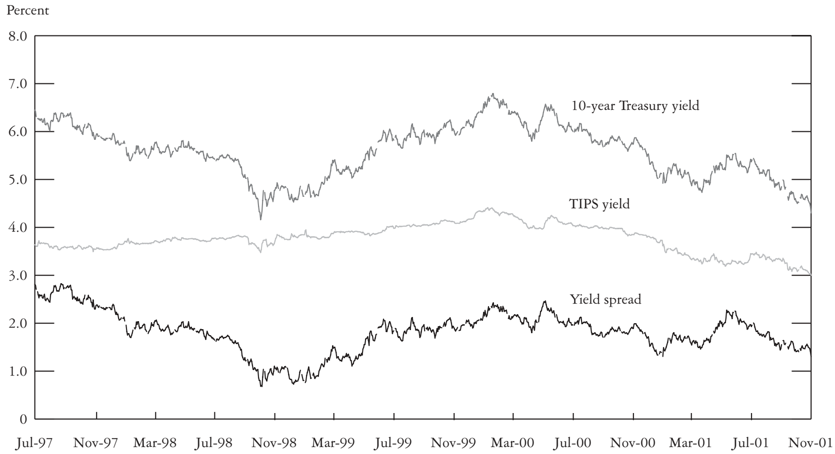
Is the level of the yield spread a good proxy for expected inflation?

To evaluate the yield spread as a measure of inflation expectations, we focus on the yield spread between the most active 10-year conventional and inflation-indexed Treasuries.[15] Ten-year conventional Treasury notes are auctioned regularly by the U.S. Treasury, and the secondary market for those securities is well developed and very liquid. Ten-year indexed Treasury notes are also the most liquid within the universe of TIPS. Chart 1 shows the nominal yield on the 10-year conventional Treasury note, the real yield on the 10-year TIPS, and the yield spread, from July 1997 to November 2001.[16]

Comparison of yield spread with actual inflation. In principle, one way to evaluate how well yield spreads approximate market inflation expectations would be to see how well the spreads forecast actual inflation. The idea is that expected inflation should be a good forecast of actual future inflation. Thus, any proxy for market inflation expectations

Chart 1

YIELDS ON 10-YEAR CONVENTIONAL VS. INDEXED TREASURIES

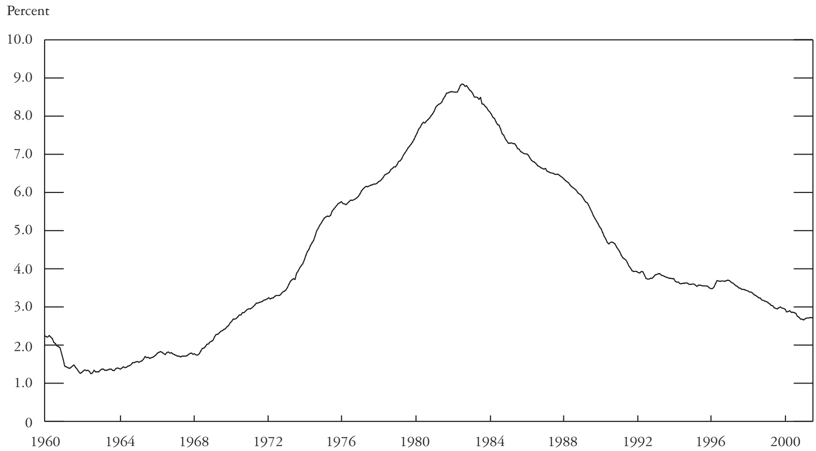


Source: Board of Governors

should also be a good forecast of actual future inflation. Market inflation expectations should be a good forecast of inflation because they are an average of market participants' forecasts. Since investors suffer financial losses when their forecasts err, it seems reasonable to assume that market participants will try to forecast future inflation as accurately as possible. Further, while an individual investor's forecast may deviate widely from the actual outcome, the market average of all individuals' best efforts should produce a reasonably good forecast.[17]

Unfortunately, the short history of TIPS makes it difficult to assess the performance of the spread as a forecast for inflation. If several decades of data were available, it would be a simple matter to look back over the period and statistically compare the ten-year forecast with realized ten-year average inflation. However, with less than a five-year history, we are still more than five years away from knowing the actual average of inflation over the ten-year period starting in 1997. As it stands, the elapsed four-and-a-half-year period is just too short for a meaningful comparison.

Chart 2
10-YEAR AVERAGE CONSUMER PRICE INDEX INFLATION



Source: Bureau of Labor Statistics

There are, however, some alternatives to comparing the yield spread to realized inflation that might be useful in judging the predictive ability of the yield spread. The most obvious approach is to use *past* inflation rates to get a sense of some realistic ranges for *future* inflation. What have the historical averages of CPI inflation been over ten-year periods since 1950?[18] These decade averages are computed monthly and plotted in Chart 2. Each data point in the chart represents the actual average inflation rate for the past ten years ending at that month. For example, the data point for September 1998 is 3.18 percent, which means that the ten-year average CPI inflation rate from October 1988 through September 1998 was 3.18 percent. Over the period of more than 50 years, we can calculate about 500 overlapping monthly averages of actual ten-year inflation rates, with the first average starting at January 1960.

Compared with the experience of the past 50 years, it appears that yield spreads have been predicting exceptionally low inflation for the ten-year period ahead. As shown in Chart 2, the actual ten-year average inflation rate has exceeded 2.5 percent for the last 30 years and has never fallen below 1.0 percent. In stark contrast, the yield spread has been well below 2.5 percent during most of the short history of TIPS. As Chart 1 shows, the yield spread started out quite wide, at slightly lower than 3 percent, but then narrowed rapidly to a low of 0.84 percent at the end of 1998. From there the spread increased but never came close to crossing the 2.5 percent level. In fact, the gap narrowed again to a local low of 1.5 percent in December 2000. Clearly the spread has been predicting much lower rates of inflation than have been experienced over most of the last 50 years.[19]

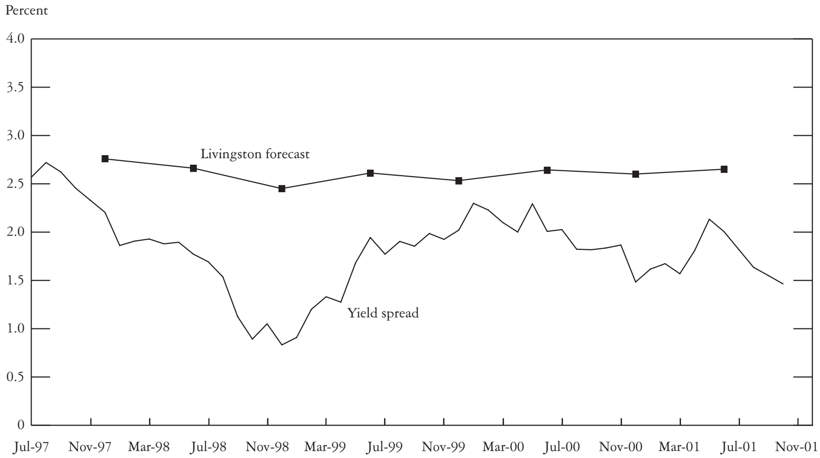
While the forecast of future inflation based on yield spreads appears to be unrealistically low compared with historical experience, the possibility cannot be ruled out that the future inflation outlook may be different from historical averages. For example, market participants may believe that the Federal Reserve has learned from experience, so that inflationary episodes of the past will not recur. An example of such an episode is the late 1970s and early 1980s, when double-digit annual inflation pushed the ten-year averages above 5 percent. Such inflationary episodes have not been repeated, suggesting that they should perhaps be excluded in estimating the most likely range of future inflation.[20]

Comparison of yield spreads with survey forecasts. How does the yield spread as a measure of expected inflation compare with other forward-looking forecasts, such as survey based forecasts? As noted earlier, survey based forecasts are subject to the criticisms that the survey respondents may represent only a small portion of the population, may be surveyed infrequently, and may answer questions casually instead of giving their best efforts. Nevertheless, comparing the yield spread to survey forecasts may provide additional evidence on how reasonable the spread is as a measure of expected inflation.

One widely followed inflation forecast is based on the Livingston Survey of economists in industry, government, banking, and academia, which is maintained by the Federal Reserve Bank of Philadelphia. Twice a year, the participants forecast the ten-year-ahead level of the CPI as well as many other economic variables. The consensus of the Survey forecast for CPI inflation is plotted in Chart 3, as is the level of the yield spread. It is immediately clear that the yield spread bears little relation to the future average inflation rate projected by the consensus of the survey. Throughout the period, the yield spread was consistently lower than the

Chart 3

LIVINGSTON TEN-YEAR INFLATION FORECAST VS. THE YIELD SPREAD



Sources: Federal Reserve Bank of Philadelphia and Board of Governors

rate of inflation predicted by the consensus of the Livingston Survey. The difference ranges from a high of 1.61 percentage points in December 1998 to a low of 0.5 percentage point one year later. For the period as a whole, the survey participants' forecast of ten-year inflation averaged 2.61 percent, while the yield spread averaged only 1.74 percent.

Have changes in the yield spread been good proxies for changes in expected inflation?

As noted at the end of the first section, even if the liquidity premium is much bigger than the inflation risk premium, *changes* in the yield spread may still approximate *changes* in market inflation expectations if both premia are stable over time. In principle, one way to determine if changes in the yield spread reflect changes in expected inflation would be to see if they do a good job of forecasting changes in actual inflation. As was true for the level of the spread, however, TIPS have not been around long enough to perform such an exercise. The best that can be done is to look at changes in the yield spread to see if they have been about the right magnitude—that is, neither too small nor too big to plausibly reflect changes in inflation expectations.

One way to determine if changes in the yield spread are about right is to see whether changes in the yield spread are similar in size to changes in survey forecasts. For the Livingston Survey, the average absolute annual change in the ten-year consensus inflation forecast has been only 0.17 percentage points throughout the past decade. In contrast, the average annual change in the TIPS yield spread from July 1997 to July 2001 has been 0.66 percentage point. For example, the Livingston forecast edged down from 2.76 percent at the end of 1997 to 2.45 percent a year later and then crept back up to 2.53 percent by the end of 1999. Over the same period, the yield spread changed much more dramatically, from 2.46 percent in late 1997 to an astonishing low of 0.89 percent a year later, only to climb back to 2.00 percent at the end of 1999. Compared with changes in the survey forecast, the yield spread appears to be too volatile to be a reliable proxy of changes in expected inflation.

Another reason for doubting that changes in the yield spread are a good proxy for changes in expected inflation is that the fundamental factors affecting the long-term inflation outlook are unlikely to fluctuate back and forth to the same degree the yield spread has. Federal Reserve monetary policy determines the rate of inflation in the long run. Therefore, a perceived increase in the Federal Reserve's commitment to price stability would likely lead to a decline in long-term market inflation expectations. In contrast, a reduction in the Federal Reserve's inflation fighting credibility would likely be associated with an increase in long-term inflation expectations. It is difficult to argue, however, that there were fundamental changes from late 1997 to 1998 that vastly improved the credibility of the Federal Reserve. It is even more difficult to argue that other fundamental changes led to a comparable deterioration in the Federal Reserve's credibility in the following year.

To summarize, it appears that the level of the yield spread does not approximate expected inflation, nor do changes in the yield spread approximate changes in expected inflation. The level of the yield spread has been lower than both the historical average of inflation and survey forecasts of future inflation, suggesting that the liquidity premium on TIPS is larger than the inflation risk premium on conventional Treasuries. Further, changes in the yield spread appear too big to be due solely to changes in expected inflation, suggesting that either the liquidity premium or the inflation risk premium varies considerably over time.

III. CAN THE LIQUIDITY PREMIUM EXPLAIN THE POOR PERFORMANCE OF YIELD SPREADS AS A MEASURE OF EXPECTED INFLATION?

This section examines liquidity in more detail. First, it focuses on the liquidity difference between conventional Treasuries and TIPS. Then it examines the yield difference between the most liquid and some less liquid conventional Treasuries. The liquidity premium on TIPS is likely both sizable and highly volatile, suggesting that it is largely responsible for the poor performance of the yield spread in approximating either the level of expected inflation or the change in expected inflation.

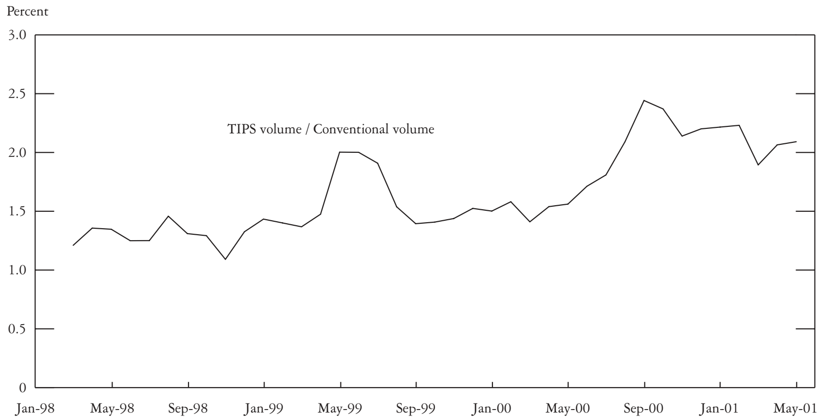
What do differences in trading volumes between conventional Treasuries and TIPS reveal?

Trading volume is much lower for TIPS than conventional Treasuries, suggesting that the TIPS market is considerably less liquid. The secondary market for conventional U.S. Treasuries is one of the most active financial markets in the world. Billions of dollars of conventional Treasuries are traded every day.[21] In contrast, the trading volume for TIPS is small due to their limited availability and their unfamiliarity to investors, who have been able to purchase and trade them only since 1997. As shown in Chart 4, in 1998 the monthly trading volume of TIPS was usually only about 1.3 percent of the trading volume of conventional Treasuries.[22] The ratio has since increased but is still very small, at around 2 percent.

The big difference in trading volumes between conventional and indexed Treasuries may be a good indicator of their relative market liquidity for two reasons. First, it is generally easier for investors to adjust their individual positions in a security with higher trading volume, because their trading actions are less likely to have an adverse impact on the price of the security. Second, high trading volume may itself be a result of higher liquidity in the underlying market. This is due to the fact

Chart 4

RATIO OF TRADING VOLUMES OF INDEXED AND CONVENTIONAL TREASURIES



Notes: Data are ratios of 3-month centered moving average volumes. Conventional volumes are for Treasuries with 5-year or more coupon maturity, and TIPS volumes are for all TIPS.

Sources: Board of Governors and authors' calculations

that, everything else equal, investors are more likely to trade in an asset that they perceive to have a more liquid market in order to save on liquidity costs. Thus, the enormous disparity in trading volumes between conventional Treasuries and TIPS suggests that investors perceive TIPS to be considerably less liquid than conventional Treasuries, and may thus require a sizable compensating liquidity premium to hold TIPS.

The disparity in trading volume between TIPS and conventional Treasuries also varies considerably over time, suggesting that the liquidity premium on TIPS may also be highly variable. As shown in Chart 4, the ratio of trading volumes can fluctuate by as much as 25 percent within a few months. For example, during the height of the financial market crisis in the fall of 1998, the ratio of trading volume plummeted from around 1.3 percent to about 1 percent, due to both increased trading in conventional Treasuries and reduced trading in TIPS. This drop suggests that investors' appreciation of liquidity risk may have changed significantly during the crisis. Indeed, the yield spread between conventional and indexed Treasuries reached its lowest point in the fall of 1998, which was consistent with a sharp increase in the liquidity premium on TIPS.

What does the liquidity premium on less liquid conventional Treasuries reveal?

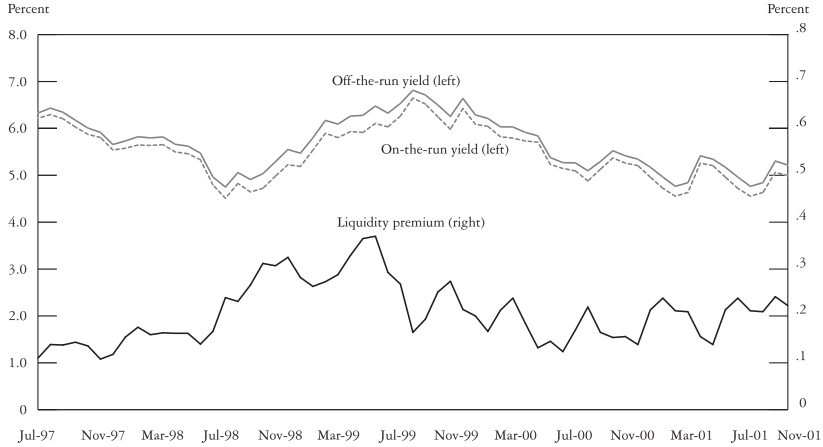
It is difficult to directly quantify the liquidity premium in the yield spread between conventional Treasuries and TIPS because the spread also depends on market expected inflation and inflation risk. A lower bound for the liquidity premium on TIPS can be determined by examining the liquidity premium on less liquid *conventional* Treasury securities. As it turns out, sizable differences in yields exist among conventional Treasury securities with a similar time to maturity and newly issued securities that are highly liquid bearing lower yields than less liquid, "aged" securities.

In the previous discussion, yield spreads were calculated using the yields of "benchmark" conventional and indexed 10-year Treasuries. A benchmark 10-year Treasury is the most recently auctioned 10-year Treasury, which is also called an "on-the-run" issue. A previously auctioned Treasury is called an "off-the-run" Treasury. Considerable differences exist between the market liquidity of on-the-run and off-the-run Treasuries. Typically, on-the-run Treasuries are traded the most and enjoy the most liquid market. An off-the-run Treasury, even though it may be identical in terms of maturity and cash flow to an on-the-run Treasury, is traded less frequently and therefore has lower market liquidity. For example, an off-the-run 30-year Treasury auctioned 20 years ago will be less liquid than a recently issued on-the-run 10-year Treasury.

Because on-the-run and off-the-run conventional Treasuries with similar time to maturity are almost identical except for their liquidity, the yield difference between the two types of Treasuries provides a clean measure of the liquidity premium built into off-the-run conventional Treasuries. The top of Chart 5 shows the average yields of 10-year off-the-run Treasuries and of 10-year on-the-run Treasuries. The bottom of the chart shows the yield difference, which is basically the liquidity premium on off-the-run Treasuries.[23]

Chart 5

YIELDS OF ON-THE-RUN VS. OFF-THE-RUN CONVENTIONAL TREASURIES



Source: Board of Governors

The liquidity premium on off-the-run conventional Treasuries has ranged between 0.1 and 0.4 percentage point since mid-1997. Before 1998, the liquidity premium was a little above 0.10 percentage point. During the height of the financial crisis in the fall of 1998, the liquidity premium increased to twice its pre-crisis average.[24] The premium remained large over the next year, but fell somewhat in 2000.[25] The average liquidity premium before the fall of 1998 was 0.14 percentage point, while the average since then has been about 0.23 percentage point, more than 50 percent higher. Many analysts believe that market participants have a new appreciation of liquidity risk after observing the events in the fall of 1998, and that consequently the liquidity premium on many financial assets has increased. The evidence in Chart 5 is consistent with this view.

The liquidity premium for off-the-run conventional Treasuries provides a lower bound for the liquidity premium in TIPS, since TIPS are even less liquid than off-the-run conventional Treasuries. Specifically, Chart 5 suggests that the average liquidity premium on TIPS has been at least 0.23 percentage point since the fall of 1998. Unfortunately, accurate data are unavailable on the relative trading volumes of TIPS and off-the-run Treasuries. However, there are good reasons for believing that TIPS are considerably less liquid than off-the-run Treasuries, so that the liquidity premium on TIPS exceeds the lower bound of 0.23 percentage point by a substantial margin. First, TIPS are relatively new, which means they are less familiar to investors than off-the-run Treasuries and less likely to be traded frequently. Second, TIPS are the only security free from inflation risk, which means no other security is directly comparable to them. This uniqueness makes TIPS more difficult to use in hedge transactions than off-the-run Treasuries, reducing their trading volume still further.[26]

The fact that the liquidity premium on off-the-run Treasuries varies considerably over time suggests that the liquidity premium on TIPS is also highly variable. Liquidity conditions in individual asset markets tend to evolve independently in the long run. In the short run, however, a common factor can cause large, simultaneous changes in liquidity in many separate asset markets. To the extent such broad disturbances account for the high volatility in the off-the-run liquidity premium, the TIPS liquidity premium should be highly volatile as well. Additional support for this view comes from the fact that monthly changes in the yield spread between conventional Treasuries and TIPS have been highly correlated with monthly changes in the off-the-run liquidity premium. Over the period shown in Chart 5, for example, the correlation coefficient between the two variables was slightly more than 0.5, which is a relatively high number.

Changes in the liquidity premium on off-the-run Treasuries can also provide valuable insight into specific changes in the TIPS yield spreads. As noted earlier, the spread between conventional Treasuries and TIPS plunged during the financial market crisis in the fall of 1998. As shown in Chart 5, the liquidity premium on off-the-run Treasuries more than trebled at the same time, as investors flew to safety and market liquidity deteriorated for almost all assets except on-the-run Treasuries. The fact that the yield spread decreased and the off-the-run liquidity premium increased at the same time reinforces the evidence from trading volumes that the drop in the yield spread during this episode was mainly due to an increase in the TIPS liquidity premium.[27]

To summarize, the evidence on relative trading volumes and the evidence on the yield difference between on-the-run and off-the-run conventional Treasuries both suggest there is a large and volatile liquidity premium on TIPS. It seems likely that this liquidity premium has been largely responsible for the yield spread being a poor measure of market expected inflation.

IV. CAN YIELD SPREADS STILL BE USEFUL FOR ASSESSING INFLATION EXPECTATIONS?

The large and variable liquidity premium in indexed Treasury securities appears to have diminished the reliability of the yield spread as an indicator of market inflation expectations. This does not mean, however, that the yield spread will never provide useful information about inflation expectations. Even now, the yield spread may still provide insight into market inflation expectations when complemented by other independent information. Further, as time goes on, the liquidity difference between conventional and indexed Treasuries is likely to become smaller, reducing the liquidity premium on TIPS and improving the accuracy of the yield spread as a measure of expected inflation.

As suggested in the previous section, one important case in which independent information can be used to improve inferences from the yield spreads about expected inflation is when liquidity premia are observed to increase on a broad range of assets. In the fall of 1998, for example, the liquidity premia on financial assets other than on-the-run Treasuries were increasing. In such circumstances, it would have clearly been unwise to interpret the decline in the yield spread between the conventional and indexed Treasuries as evidence that expected inflation had fallen. In other times, however, we may observe declines in the yield spread without any noticeable changes in the liquidity premia on other assets. In these instances, the decline in the yield spread is likely to be an indication that expected inflation has decreased.

In the future, the continuing reduction in liquidity differences between conventional and indexed Treasuries should also improve the usefulness of the yield spreads. The ratio of trading volumes of TIPS to conventional Treasuries has been trending upward (Chart 4). Several factors have contributed to this trend and should continue to reduce the liquidity differences between the two types of Treasuries over time. First, as investors become more familiar with inflation indexed Treasuries, their confidence and understanding will grow, leading to greater demand for and trading in TIPS. Second, because only conventional Treasuries are presently maturing, the total volume of outstanding TIPS relative to the total volume of outstanding conventional Treasuries continues to increase.[28] Such an increase in outstanding volume leads to a deeper and more liquid market, reducing the liquidity disparity between the two kinds of Treasuries. Finally, the simple mechanics of indexing causes the principal of TIPS to grow at the rate of inflation while the principal of conventional Treasuries remains fixed. This causes the total dollar volume of TIPS outstanding to grow relative to the total dollar volume of conventional Treasuries, which again deepens the TIPS market and reduces the liquidity premium on TIPS.

The experience of the UK (see appendix for more details) supports the view that the gradual increase in the liquidity of indexed bonds will reduce the liquidity premium in the yield spread between conventional and indexed securities. The indexed government debt market in the UK is still somewhat less liquid than the conventional government debt market. However, the trading volume for indexed government debt is usually more than one-tenth the trading volume for conventional government debt, suggesting that the liquidity difference there is much smaller than in the U.S. Furthermore, the yield spread is typically higher than survey forecasts of inflation, implying that in contrast to the U.S., the liquidity premium on indexed debt is smaller than the inflation risk premium on conventional debt. Such evidence offers hope that the liquidity of TIPS will improve and that the liquidity premium may eventually become small enough for the yield spread to provide valuable information about inflation expectations.

V. CONCLUSION

The yield spread between conventional and inflation indexed Treasuries contains useful information about market expectations of future inflation. The task of disentangling this information has been complicated, however, by other components in the yield spreads—in particular, the inflation risk premium on conventional Treasuries and the liquidity premium on indexed Treasuries. The liquidity premium has been especially important, causing the yield spread to understate market inflation expectations. The liquidity premium has also been highly volatile, causing the yield spread to vary too widely to reflect only changes in inflation expectations. Nevertheless, if current trends continue, indexed Treasuries should become more liquid and the liquidity premium should gradually decline, allowing the yield spread to more closely approximate market inflation expectations. Even if this happens, though, the yield spread may never be a perfect measure of expected inflation because both the inflation risk premium and the liquidity premium may still vary over time. As a result, it will always be advisable to combine yield spreads with other information to best estimate market expectations of future inflation.

APPENDIX

What Can We Learn from the UK Experience?

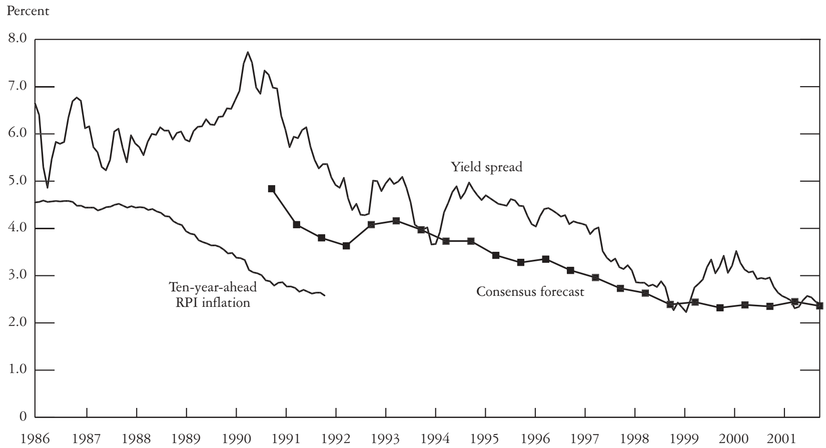
In 1981 the Bank of England began issuing government debt instruments that protect investors from the adverse effects of inflation by indexing both the principal and coupon payments to inflation. Called index-linked Gilts, these bonds pay a prespecified real coupon rate and adjust the cash flow for changes in the General Index of Retail Prices (RPI). By comparing the RPI at the time of the payment with the RPI when the bond was issued, the return to investors is adjusted for changes in the general price level.[29]

Because index-linked Gilts have been in existence far longer than TIPS, they provide a useful reference against which to compare the performance of the TIPS spread as a measure of expected inflation. Until 1991, for example, it was possible to directly compare the 10-year Gilt yield spread to realized average inflation for the following ten years. In contrast, the short history of TIPS makes it impossible to compare the TIPS spread with realized ten-year inflation.

The appendix chart shows the Gilt yield spread, realized ten-year average inflation, and the survey-based forecast of inflation compiled by Consensus Economics Inc. In sharp contrast with the U.S. experience, the UK yield spread has been consistently higher than either the actual realization of inflation or the forecast of inflation based on survey data. This suggests that in the UK, the inflation risk premium on conventional bonds dominates the liquidity premium on indexed bonds, and that the liquidity difference between conventional and indexed government bonds is much smaller there.

Data on trading volumes provide additional evidence that the liquidity difference between indexed and conventional bonds is smaller in the UK than the United States. In recent years, the ratio of the trading volume of indexed Gilts to that of conventional Gilts has usually been more than 10 percent. In contrast, the ratio of trading volumes for indexed and conventional U.S. Treasuries has ranged from 1 to 2½ percent. One reason there is less disparity in trading volumes in the UK is that the UK began issuing indexed debt earlier. As a result of this ear-

Appendix Chart
THE UK EXPERIENCE WITH INDEX LINKED GILTS



Sources: Bank of England, Consensus Economics Inc., and National Statistics

lier start, indexed debt constitutes a much larger portion of government debt in the UK—around 30 percent compared with less than 5 percent for the United States.

The fact that the yield spread in the UK appears to generally *exceed* expected inflation due to the inflation risk premium might seem to reduce the usefulness of the yield spread as indicator of market inflation expectations. For monetary policymakers, however, the distinction between an increase in market inflation expectations and an increase in the inflation risk premium may not be that important, as they both point to weakened public confidence in the central bank's ability to control inflation.[30] Therefore, for central banks, the variability of the inflation risk premium is less problematic than the variability of the liquidity premium because the knowledge of the change of the sum of inflation expectation and the inflation risk premium is as useful as the knowledge of the change in inflation expectation alone.

To summarize, the experience of the UK suggests that if the U.S. Treasury keeps issuing inflation indexed Treasuries and their liquidity continues to improve, the liquidity premium will decline over time.

That should allow the yield spread to better approximate market expected inflation, at least in noncrisis times.

ENDNOTES

[1] TIPS are officially called Treasury Inflation Indexed Securities (TIIS).

[2] For example, the first 10-year TIPS was issued in January 1997, with a total issuance of $7 billion. The issuance was "reopened" in April of the same year, at which time an additional $8 billion was auctioned off. Shen (1995), and Dupont and Sack provide detailed explanations of TIPS. Additional details can be found on the Treasury Department website, http://www.treasurydirect.gov/bpd/bpdhome.htm.

[3] On October 31, 2001, the Treasury suspended future auctions of both conventional and indexed 30-year Treasury securities.

[4] The numbers are based on the monthly statement of public debt at the end of September 2001, which can be found at http://www.treasurydirect.gov/opd/opdhisms.htm. Excluding debt instruments with maturities of less than one year (Treasury bills), the share represented by TIPS rises to 7 percent. Note that the ratio of the outstanding value of TIPS to the outstanding value of conventional Treasuries is higher than the ratio of *par* values because the principal of TIPS grows with inflation.

[5] In most of the article, we focus on the yield to maturity. If a debt instrument is sold before its maturity, its return may differ from the yield to maturity.

[6] The effects of inflation are especially serious when the security has a long maturity. For example, many investors bought 40-year Treasury bonds issued in 1955, which had a fixed nominal coupon rate of 3 percent. Because inflation averaged 4.4 percent for the next 40 years, investors who bought this bond at full price and held it to maturity *lost*, in terms of purchasing power, more than 43 percent in real terms. In other words, for every dollar investors lent to the government in 1955, all the interest payments and principal redemption in the following 40 years amounted to a total of less than 57 cents in terms of 1955 purchasing power.

[7] Strictly speaking, it is the average inflation from November 2000 to October 2010 that should be used in the calculation as the Treasury uses the CPI with a three-month lag when making the inflation adjustment.

[8] The discussion in the text ignores the effect of income tax. As income tax is levied on nominal investment incomes, all non tax-exempt investors are exposed to some inflation risk, including investors in TIPS. Nevertheless, the inflation risk is still smaller to TIPS investors than to investors in conventional Treasuries. For a detailed discussion of the tax effect, see Shen (1995).

[9] Nominal (real) yield is calculated by using the nominal (real) coupon rate of the Treasury and the market price for the par principal, assuming it is held to maturity.

[10] Another group of measures of market expected inflation use statistical models and observations on the term structure of interest rates. These measures, however, often provide a wide range of estimates and rely heavily on many explicit and implicit assumptions, making the results difficult to interpret.

[11] For example, the fee for selling both conventional and indexed Treasuries held in Treasury Direct accounts through the Federal Reserve Bank of Chicago is $34.

[12] Yet another risk associated with selling a debt instrument before its maturity is price risk. Theoretically, the price risk of an indexed Treasury can either be higher or lower than that of a conventional Treasury. For an indexed Treasury, the main price risk is due to changes in the market prevailing real interest rate. For a conventional Treasury, price risk can be caused by either changes in the real inter-

est rate or changes in market expected inflation. On one hand, conventional Treasuries may have higher price risk as their values are exposed to more kinds of risk. On the other hand, a given change in the real interest rate tends to have a bigger impact on the price of an indexed Treasury, because the cash payments of an indexed Treasury are more back-loaded. The empirical evidence in the UK government debt market suggests that the first effect outweighs the second, causing the price risk of an inflation indexed security to be lower than that of a conventional one (Shen 1998).

[13] The third section shows that the liquidity risks of different conventional Treasuries differ enough so that it is sometimes useful to distinguish among them.

[14] An additional complication is that the market for conventional Treasuries and the market for TIPS may serve two very different investing clienteles, which means that the yield difference may reflect differences in the expectations of the two groups. This factor may have been particularly important when the TIPS market was small and relatively new. As time goes by, presumably the clientele effect should decline as more and more investors get familiar with the market.

[15] As the spread is based on securities with different vintages, there may be a slight maturity difference between the conventional and inflation-indexed Treasuries. For example, in December, the yield on the TIPS issued in January of the same year is the yield on a security with nine years and one month to maturity. In contrast, the yield on the conventional Treasury has been adjusted so that it has exactly ten years to maturity.

[16] Although TIPS were first introduced in January 1997, the first few months of data are likely of poor quality because TIPS were a new instrument to the market. During this time, the market may have needed to adjust to and learn about the new security. For example, TIPS yields were initially low because of both high demand due to their novelty and small supply.

[17] For reasons why the average of all forecasts may be better than most individual forecasts, see Granger and Newbold (pp. 266-67).

[18] Various measures of inflation are available. This article focuses on CPI inflation is because TIPS are indexed to the CPI.

[19] While it is still too early to compare the yield spread with realized inflation, we can compute how low future inflation will have to be for the earlier forecast to be accurate. For example, the average yield spread was 1.53 percent in 1998. Actual inflation from 1998 to 2001 has averaged about 2.6 percent. Therefore, inflation from 2002 to 2007 will have to average only 0.8 percent for the forecast of yield spreads to hold.

[20] An alternative way to evaluate the yield spread as a measure of expected inflation is to compare the yield spread to recent inflation. Statistically, this approach is equivalent to assuming that future average inflation will be the same as the average of recent realized inflation. This approach also suggests that the yield spread has been too low to be a reasonable forecast of inflation.

[21] There are, however, still important differences in liquidity among conventional Treasuries, in particular, between those that are newly issued and those that are "aged." Later in the section, these differences will be explored.

[22] The ratio in Chart 4 uses the volume of conventional Treasuries with coupons due in more than five years. This is the relevant measure because available TIPS volume data include all maturities, most of which are greater than five years.

[23] These yields were kindly provided by Brian Sack at the Federal Reserve Board of Governors, who used off-the-run notes and bonds to create an off-the-run yield.

[24] The crisis started when Russia defaulted on its sovereign debt in late August and was further intensified by the near default of a hedge fund, Long Term Capital Management, in late September. The deterioration of financial market functions continued until mid-October. Market conditions gradually improved in November and December and the crisis was largely over by the spring of 1999.

[25] The yield difference declined sharply in February 2000, when investors suddenly came to the realization that an ever expanding federal budget surplus would render all Treasury securities scarce, including both on-the-run and off-the-run. The announcement of a Treasury buy-back program may also have helped the liquidity of some off-the-run securities.

[26] See Sack for a useful discussion of liquidity conditions in Treasury markets.

[27] Another way to exploit information on the off-the-run liquidity premium is to compute the yield spread using the yield on off-the-run Treasuries rather than the yield on on-the-run Treasuries. This alternative approach was used by Sack, who also adjusted in his study for the small difference in duration between 10-year TIPS and conventional Treasuries. This article ignores the issue of duration because first, as Sack showed in his study, it made little difference. Second, the concept of duration is not particularly applicable to inflation indexed securities (Shen, 1995).

[28] The first TIPS to mature were issued in July 1997 as a 5-year security. The next TIPS to mature were issued in January 1997 as a 10-year security. In addition, the Treasury could conceivably make a concerted effort to reduce the TIPS liquidity premium still further by increasing the quantity and frequency of new TIPS issues. Currently, new issues are heavily skewed toward conventional Treasuries. A slight shift toward increased TIPS issuance would be relatively easy to implement and would help to reduce the liquidity disparity between the two.

[29] Actually, the RPI figures used are from the month eight months prior to the relevant date. This lag allows for the time lag in the release of the RPI data and ensures that the nominal value of the next coupon payment is known before the start of that period. This long lag weakens the inflation protection for Gilts that are approaching their maturity. In contrast, the U.S. TIPS are indexed to CPI lagged by only three months.

[30] The Bank of England has regularly used the yield spread as one of the indicators to its credibility of meeting the inflation target. Deacon and Derry provide useful background information and many technical details. Barr and Campbell provide empirical analysis of the yield spread.

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Statement on Monetary Policy

MAY 2016

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Statement on Monetary Policy Enquiries

Secretary's Department
Tel: +61 2 9551 9830
Fax: +61 2 9551 8033
Email: rbainfo@rba.gov.au

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Overview

Economic conditions in Australia's major trading partners generally appear to have eased a little of late. Growth in China moderated further in the March quarter. Subdued investment growth in the manufacturing sector was partly offset by rising public infrastructure investment and a return to growth in real estate investment. The latter was consistent with a strengthening in the property market in recent months in response to a range of earlier measures to stimulate demand. The moderation of Chinese growth has affected Asian economies and emerging economies in other regions that have strong trade links with China. Economic activity remained weak in Japan, while growth eased in the United States but continued at an above-trend rate in the euro area. Meanwhile, there have been further improvements in labour market conditions across all three economies. Despite that, inflation in the major advanced economies remains below central banks' targets and inflation expectations have declined. This has been an important concern for central banks and contributed to the European Central Bank's decision to ease monetary policy further in March. Monetary policy settings remain very accommodative in Japan and the United States (where markets expect no further increase in the policy rate before late 2016).

Changes in expectations about the course of the monetary policies of the major central banks have been reflected in exchange rates and financial market prices more generally. Sentiment in global financial markets has improved since late February. The outlook for growth in Australia's major trading partners in 2016 has been revised a little lower since the February *Statement on Monetary Policy* to incorporate generally weaker-than-expected growth in the March quarter and a reassessment of growth momentum, particularly in Asia. Despite the moderation in Chinese growth in the March quarter, the outlook there is much as it was earlier forecast, based on the expectation of further support being provided by more stimulatory policy settings. The Chinese authorities appear, at present, to be giving greater priority to short-term growth objectives than to the longer-term goals of deleveraging and achieving growth that is less reliant on investment and heavy industry. The outlook for the Chinese economy continues to be a key source of uncertainty for the forecasts. One risk is that the pursuit of the authorities' near-term growth targets is likely to increase already elevated levels of debt and could potentially delay addressing the problem of excess capacity in the manufacturing and resources sectors.

While commodity prices are significantly lower than the peaks of a few years ago, the expectation of more policy stimulus in China has been accompanied by a sizeable increase in commodity prices over recent months. Iron ore and coking coal prices are around 60 per cent and 30 per cent above their low points in late 2015, respectively. This amounts to a rise in Australia's terms of trade in the near term. However, it is assumed that the prices of bulk commodities are not sustained at current levels. Chinese steel demand is still expected to decline over the next couple of years and a substantial amount of new, low-cost iron ore supply is likely to enter the market over that period. Meanwhile, liquefied natural gas (LNG) prices are expected to be higher than previously forecast, which will tend to increase the terms of trade. The net result of these various movements is that the terms of trade are expected to be around recent levels by the end of the forecast period.

Growth in the Australian economy over 2015 was a bit stronger than earlier anticipated, and a little above estimates of potential growth. Growth was moderate in the December quarter, however, and appears to have continued at about this pace into 2016, much as was forecast at the time of the February *Statement*. Consistent with this, employment growth has slowed from the strong pace of last year and leading indicators of employment have been somewhat mixed of late. Nevertheless, labour market conditions remain much better than a year ago. The unemployment rate has been around 5¾ per cent in recent months, having been as high as 6¼ per cent last year.

There has been no material change to the forecast for GDP growth or the unemployment rate. GDP growth is expected to strengthen gradually to an above-trend rate, reflecting the effects of low interest rates and the depreciation of the exchange rate since early 2013. Both have been helping activity to rebalance towards the non-resource sectors of the economy. As before, the unemployment rate is forecast to remain around current levels for the next year or so and then gradually decline as growth in economic activity strengthens. The outlook for the unemployment rate is consistent with spare capacity remaining in the labour market throughout the forecast period.

Growth in household consumption picked up in the second half of last year and is expected to be sustained at around that rate in the period ahead. The pace of growth in retail sales volumes was maintained in early 2016. And while surveys suggest that households' perceptions of their own finances have eased, they were around long-run average levels in April. Growth in consumption is forecast to be maintained at a pace that is a bit above average, despite only modest growth in wages. This implies a further gradual decline in the household saving ratio over the forecast period.

The amount of residential construction work still in the pipeline is substantial and has continued to increase. This points to further strong growth in dwelling investment, albeit at a gradually declining rate consistent with the decline in building approvals since last year. In established housing markets, conditions have stabilised over the past six months or so. Housing prices have grown moderately over 2016 to date, following a small decline at the end of 2015. Housing credit growth has eased a little over recent months to be around 7 per cent in six-month-ended annualised terms in early 2016. This follows increases in mortgage rates and the strengthening of banks' non-price lending terms in response to supervisory actions.

Surveyed conditions in the business sector remain above average and business credit growth has picked up over the past year or so. Nevertheless, indicators of investment intentions suggest that non-mining business investment is likely to remain subdued for a time, although it is expected to gradually pick up later in the forecast period as overall demand strengthens. Mining investment is expected to continue to fall as projects are progressively completed, although the magnitude of the falls should diminish over the next couple of years, consistent with the forecasts presented in the February *Statement*. Project completions will support further growth in resource exports. Net service exports are expected to continue to make a noticeable contribution to growth.

Inflation was lower than expected in the March quarter. The various measures suggest that underlying inflation declined to a little less than ¼ per cent in the quarter (compared with about ½ per cent in the December quarter), to be about 1½ per cent over the year. Headline inflation was lower still, partly reflecting some temporary factors. Nonetheless, the CPI data indicate that there has been broad-based weakness in domestic cost pressures. This is evident in the further decline in non-tradables inflation in the March quarter. In part, this reflects lower-than-expected growth in labour costs, with unit labour costs being little changed for four or more years now. In addition, there has been heightened retail competition, a moderation in conditions in housing rental and construction markets, and declines in the cost of some business inputs, such as fuel and utilities. A number of these factors are also likely to have mitigated some of the upward pressure on the prices of tradable items arising from increasing import prices following the depreciation of the exchange rate since early 2013.

The forecast for underlying inflation has been revised lower, reflecting the lower-than-expected outcome for inflation in the March quarter and an expectation that domestic cost pressures, including labour costs, will pick up more gradually than anticipated at the time of the February *Statement*. The outlook for domestic cost pressures is a key source of uncertainty. Despite above-trend growth in economic activity and improvements in labour market conditions over the past year, it is possible that domestic cost pressures may weaken further, and so inflation may not pick up as expected. However, it may be that the strengthening in the labour market embodied in the forecasts is associated with growth of labour costs picking up sooner or by more than is currently forecast.

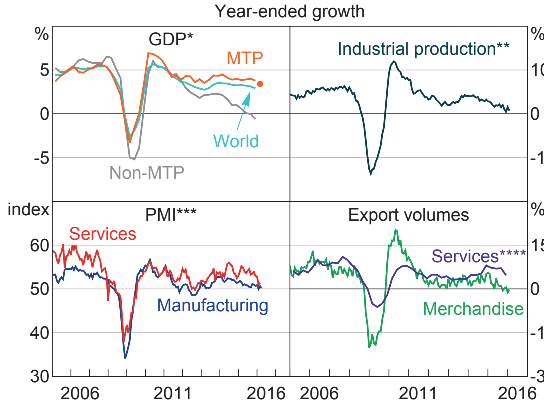
The substantial exchange rate depreciation over recent years is expected to continue to place some upward pressure on inflation for a time. While the exchange rate is assumed to remain around current levels over the forecast period, it may respond to a number of influences, including any unanticipated changes to the outlook for growth in China, commodity prices or the monetary policy decisions of the major central banks. It therefore represents a significant source of uncertainty for the forecasts of inflation, as well as for the outlook for growth in activity.

For some time, the Reserve Bank Board had noted that the inflation outlook provided scope for a further easing in monetary policy. After taking account of developments over recent months, the Board's assessment at its May meeting was that the outlook for economic activity and the unemployment rate was little changed, but that the inflation outlook was lower than earlier anticipated. At the same time, the Board took careful account of developments in the housing market, noting the effects of supervisory measures to strengthen lending standards, the recent easing in housing credit growth and the abatement of strong price pressures. Taking all of these considerations into account, the Board judged that the prospects for sustainable growth in the economy, with inflation returning to target over time, would be improved by further easing of monetary policy. Accordingly, the cash rate was reduced by 25 basis points. The Board will continue to assess the outlook and adjust policy as needed to foster sustainable growth in demand and inflation outcomes consistent with the inflation target over time.

1. International Economic Developments

Growth in Australia's major trading partners moderated around the turn of the year to be below its decade average in early 2016 (Graph 1.1). Over the past year or so, growth eased in the United States and stalled in Japan, but continued at an above-trend rate in the euro area. Growth in China has moderated, although the Chinese authorities remain committed to supporting growth, announcing a growth target for 2016 of 6.5–7 per cent. The slowing in growth in China has had significant flow-on effects on Asian economies and emerging economies in other regions that have strong trade links with China. Commodity prices have increased in recent months, but still remain low relative to recent years. The low level of oil prices should support growth in Australia's major trading partners, which are generally net oil importers. Expansionary monetary policy in most economies is also supporting growth.

Graph 1.1
Global Economic Activity
Year-ended growth



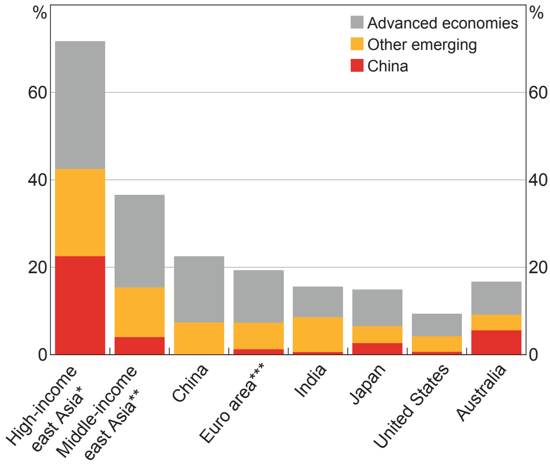
* Major trading partner (MTP) GDP weighted using Australia's export shares; dot indicates RBA estimate; other series are PPP-weighted
** Weighted by world industrial production shares at market exchange rates
*** Diffusion index
**** MTPs and Australia; excludes India, Malaysia and Singapore
Sources: ABS; Bloomberg; CEIC Data; CPB; IMF; Markit Economics; OECD; RBA; Thomson Reuters

Growth in Australia's major trading partners has been higher than growth in the world as a whole over recent years. Lower growth has been most pronounced in commodity-exporting emerging market economies, such as Brazil, with which Australia has little direct trade. The resilience of Australia's major trading partners' growth also reflects the increase in the share of Australia's exports going to China, where GDP growth remains relatively strong despite some moderation.

The growth of global industrial production and merchandise trade (which accounts for around 80 per cent of total trade) has declined over the past couple of years. Although services sector conditions had been more positive and growth in global service exports remains higher than it was a few years ago, surveys suggest that global services sector activity has weakened recently. The slowing growth in global trade has had a material impact on conditions in the high-income east Asian economies, which are significantly more trade exposed than the rest of Australia's major trading partners (Graph 1.2). In particular, a substantial share of these economies' exports goes to China and other emerging economies where growth has slowed noticeably. In contrast, the major advanced economies are less exposed to trade.

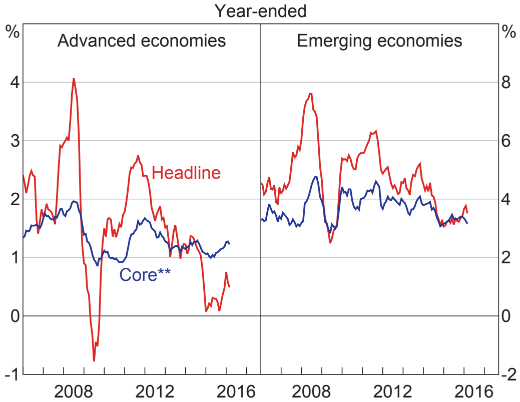
Globally, inflation remains low and is below central banks' targets in most advanced economies (Graph 1.3). Year-ended headline inflation has

Graph 1.2
Merchandise Export Values by Destination
Per cent of GDP, 2014



* Hong Kong, Singapore, South Korea and Taiwan
** Indonesia, Malaysia, Philippines and Thailand
*** Excludes intra-euro area trade
Sources: IMF; United Nations

Graph 1.3
Global Inflation*
Year-ended



* PPP-weighted; sum of emerging and advanced economies accounts for around 80 per cent of world GDP
** Excluding food and fuel
Sources: CEIC Data; IMF; RBA; Thomson Reuters

picked up a little in recent months, as the direct effect of some of the earlier oil price decline has moved out of the year-ended calculations. Core inflation has also increased in advanced economies over the past year, most notably in the United States, but it has been little changed over the past two years in emerging economies.

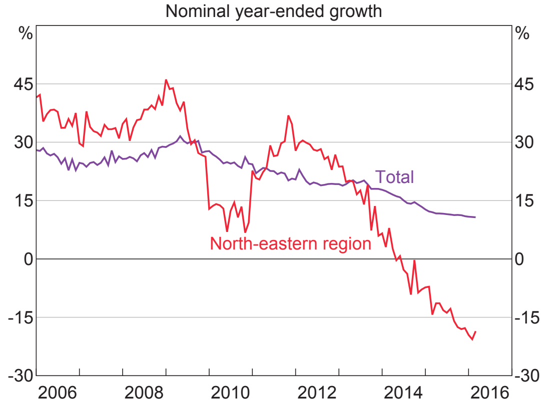
Asia-Pacific

In March, the Chinese Government announced a GDP growth target for 2016 of 6.5–7 per cent, down from 'around 7 per cent' in 2015. In related policy documents, the authorities acknowledged risks facing the domestic economy and financial system, including rising corporate debt, but placed considerable priority on meeting the new growth target. Consistent with this, the projected headline budget deficit for 2016 was increased to 3 per cent of GDP from 2.4 per cent and the authorities suggested that more fiscal and monetary support could be provided if required.

China's economic growth has moderated further in 2016, as excess capacity in the industrial sector has continued to weigh on growth in investment. Chinese GDP increased by 1.1 per cent in the March quarter, to be 6.7 per cent higher over the year. Longer-term structural factors, including an easing in growth in productivity and the urban workforce, may also be contributing to slower growth in China. Investment has fallen particularly sharply in the north-eastern region where there has been a substantial build-up of excess capacity in the mining and manufacturing industries (Graph 1.4).

The slowing in industrial activity during the past year has been accompanied by a decline in industrial profits, which has been most pronounced

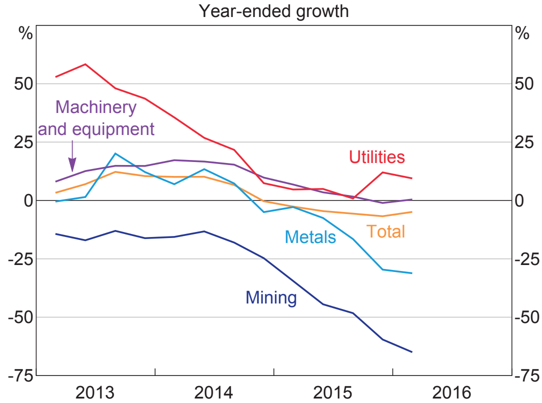
Graph 1.4
China – Fixed Asset Investment
Nominal year-ended growth



Sources: CEIC Data; RBA

for the mining and metals manufacturing industries (Graph 1.5). Mining profits have been declining for several years now, in line with the falls in commodity prices, and profits in the metals industry have been declining over the past year or more. The domestic production of crude steel and iron ore declined in the March quarter in seasonally adjusted terms (Graph 1.6). Iron ore imports remain around record highs and imports from Australia have maintained their market share. Chinese trade overall has continued to decline in 2016 in response to weaker domestic and external demand.

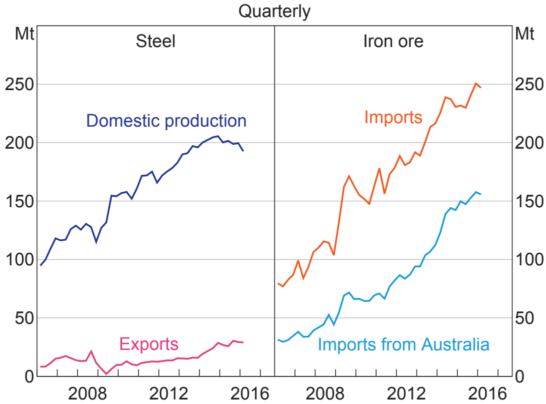
Graph 1.5
China – Industrial Profits*
Year-ended growth



* Four-quarter moving average

Sources: CEIC Data; RBA

Graph 1.6
China – Steel and Iron Ore*
Quarterly

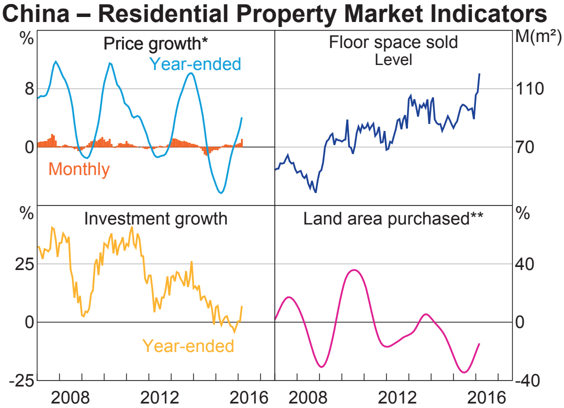


* Seasonally adjusted by RBA

Sources: CEIC Data; RBA

Conditions in the Chinese residential property market have improved noticeably in early 2016. The volume of floor space sold increased significantly in the first few months of the year, which has helped to reduce inventory-to-sales ratios. Real estate investment also picked up in the first quarter of 2016 (Graph 1.7). Property prices increased further in the larger cities and many smaller cities showed signs of price growth after a prolonged period of weakness. This follows a series of supportive measures introduced by the authorities over 2015 and early 2016, including lowering minimum mortgage down payments and benchmark lending rates. Stronger conditions in a few of the larger cities have prompted those local authorities to tighten borrowing requirements and restrictions on the number of properties people can purchase.

Graph 1.7
China – Residential Property Market Indicators



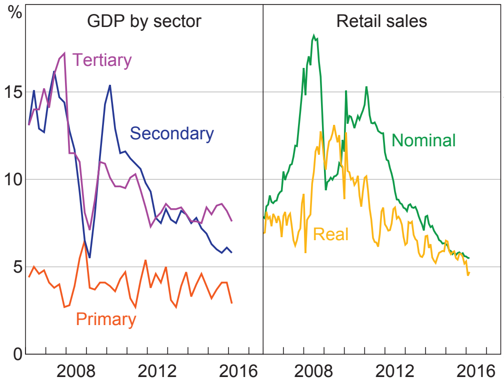
* Newly constructed property in 69 large and medium-sized cities

** Year-ended growth of trend series, includes non-residential land

Sources: CEIC Data; RBA; WIND Information

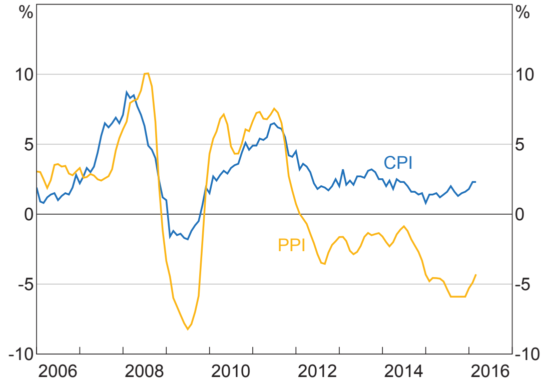
Growth in the services (tertiary) sector has been sustained at a relatively strong pace, which has helped to support overall growth in the face of lower growth in the industrial (secondary) sector (Graph 1.8). Financial services activity, which grew rapidly in the first half of 2015, has slowed in recent quarters, although a pick-up in real estate services activity in the March quarter has provided some offset to that. Growth in a number of indicators of household consumption has also eased, but remains relatively strong. Retail sales volumes

Graph 1.8
China – Activity Indicators
Year-ended growth



Sources: CEIC Data; RBA

Graph 1.9
China – Inflation
Year-ended



Sources: CEIC Data; RBA

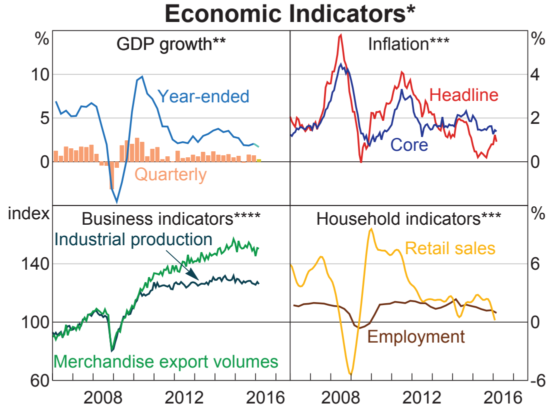
growth has moderated over the past year, while automobile sales declined in the March quarter after increasing strongly in late 2015, partly in response to earlier tax cuts.

Financial conditions remain very accommodative in China. Growth in total social financing (TSF) has increased strongly in 2016 to date, particularly when adjusted for the impact of the local government debt restructuring program. At the National People's Congress in March, a target for TSF growth in 2016 of 13 per cent was introduced. Although no specific quota of debt issuance was announced as part of the local government debt restructuring program, it is likely that local government bond issuance will make a sizeable contribution to growth of economy-wide financing in 2016. More generally, bank credit growth and corporate bond issuance have remained strong, offsetting weakness in a range of off-bank balance sheet components.

Inflationary pressures are subdued in China, consistent with excess capacity in a number of industries, although downward pressure on prices has moderated somewhat. CPI inflation has increased a little in recent months, driven by higher food prices (Graph 1.9). The rate of decline in the producer price index (PPI) has also eased, in part reflecting increases in commodity prices over recent months.

Economic growth in the high-income east Asian economies slowed in 2015 – driven by the softer demand from China and other emerging economies for the region's exports – and appears to have continued at a below-average rate in early 2016 (Graph 1.10). Merchandise export volumes have been little changed for around two years, despite substantial exchange rate depreciations in the region over the past year. Industrial production has not grown for two years. Investment was

Graph 1.10
High-income East Asia – Economic Indicators*



* Hong Kong, Singapore, South Korea and Taiwan

** March 2016 estimate based on advance releases from Singapore, South Korea and Taiwan

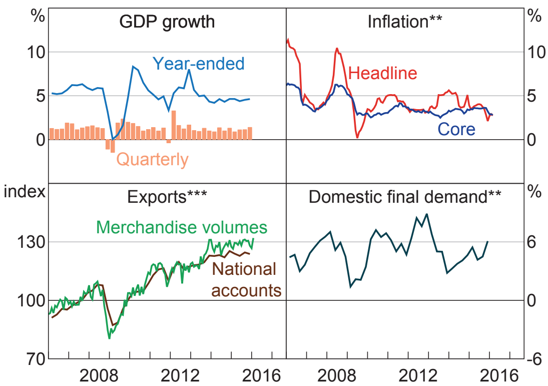
*** Year-ended growth; retail sales is a 13-term Henderson trend; employment is a quarter average.

**** 2007 average = 100

Sources: CEIC Data; RBA; Thomson Reuters; United Nations subdued over 2015 and recent indicators across the region suggest that this remained the case in early 2016. Consumption growth had been resilient over 2015, but in recent months consumer confidence has declined and retail sales growth has slowed. This may reflect the moderation in employment growth over the past six months. Core inflation has eased since late 2014, and headline inflation remains low. A number of central banks in the region have reduced policy rates since mid 2014 and several governments have increased spending and implemented temporary tax reductions during the past year.

In the middle-income east Asian economies, growth has been more resilient and remains at around its average rate over recent years (Graph 1.11). While these economies are also facing subdued external demand, they are less exposed to international trade than the high-income east Asian economies. Domestic final demand has continued to expand due to moderate consumption growth and a marked increase in investment growth over the second half of 2015. Both headline and core inflation remain relatively low across the region and have eased in recent months.

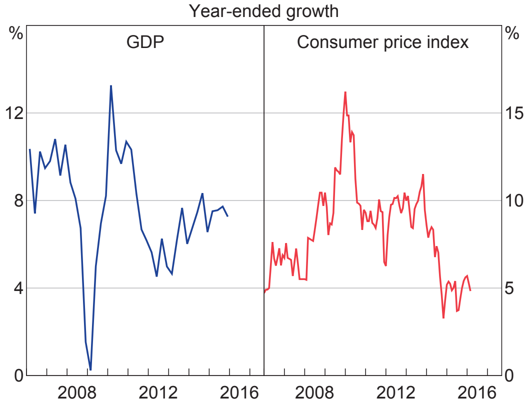
Graph 1.11
Middle-income East Asia – Economic Indicators*



* Indonesia, Malaysia, Philippines and Thailand
** Year-ended growth
*** 2007 average = 100
Sources: CEIC Data; RBA; Thomson Reuters; United Nations

In India, economic growth has picked up over recent years (Graph 1.12). Growth has been underpinned by household consumption and public sector investment, while private investment and external demand have been relatively weak. Subdued commodity prices have helped to contain inflation and support domestic demand. They have also assisted the process of fiscal consolidation by reducing government expenditure on energy subsidies. CPI inflation slowed to around 5 per cent in March 2016, driven by declining food price inflation. The Reserve Bank of India (RBI) eased the policy rate further in April, bringing the reduction over the past year to 100 basis points. The RBI cited weaker-than-expected inflationary pressures and downward pressure on growth stemming from the government's fiscal consolidation and muted global demand. The RBI is seeking to achieve CPI inflation of 5 per cent by March 2017.

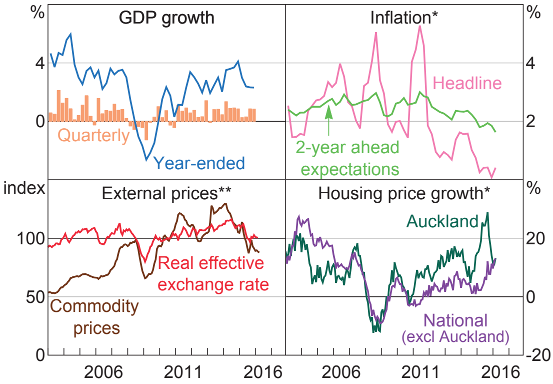
Graph 1.12
India – GDP Growth and Inflation
Year-ended growth



Source: CEIC Data

Growth in the New Zealand economy picked up in the second half of 2015, supported by accommodative monetary policy and the earlier exchange rate depreciation (Graph 1.13). Record high net immigration has boosted growth of the labour force, buoyed private consumption and added pressure to housing price growth. Tax and regulatory changes aimed at curtailing investor activity in the housing market have seen housing

Graph 1.13
New Zealand – Economic Indicators



* Year-ended

** 2010 average = 100

Sources: ANZ; BIS; RBA; RBNZ; REINZ; Thomson Reuters

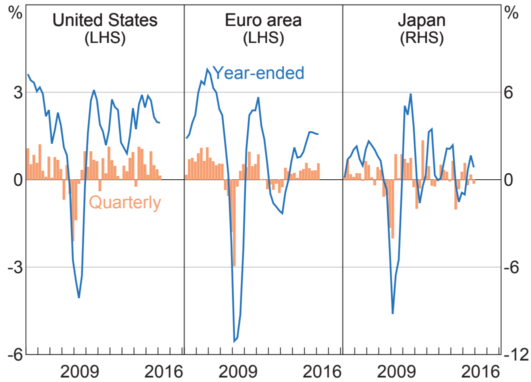
price growth moderate in Auckland since October last year, although it picked up in March. More generally, housing price growth remains relatively high across New Zealand and has picked up in recent months. Falling food and energy prices continue to exert downward pressure on inflation; headline inflation is around its lowest rate since 1999. Underlying inflationary pressures are also subdued. In early 2016, prices for New Zealand commodity exports declined, while the exchange rate was little changed. This, along with declining inflation expectations and low wage growth, led the Reserve Bank of New Zealand to reduce its policy rate by 25 basis points in March, following a cumulative 100 basis point reduction over 2015.

Major Advanced Economies

Growth in the major advanced economies over the past year has led to continued improvements in their labour markets. However, growth slowed over recent quarters in the United States and stalled part-way through 2015 in Japan (Graph 1.14). The euro area economy has continued to expand at above its trend growth rate.

Over the past two years private consumption growth has been a key driver of growth in the United States and the euro area (Graph 1.15). In contrast, consumption in Japan has remained subdued since the consumption tax increase

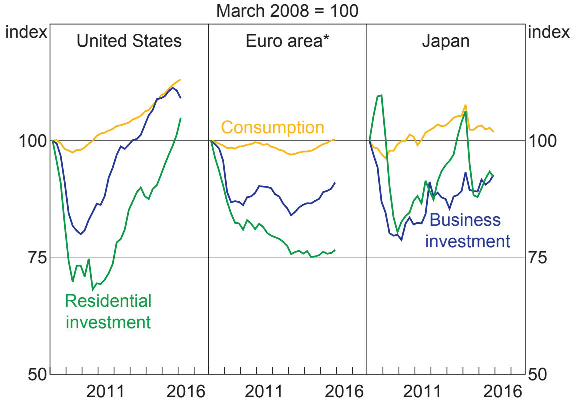
Graph 1.14
Major Advanced Economies – GDP Growth



Source: Thomson Reuters

Graph 1.15
Major Advanced Economies – Economic Indicators

March 2008 = 100



* Business investment in the euro area includes both public and private investment

Source: Thomson Reuters

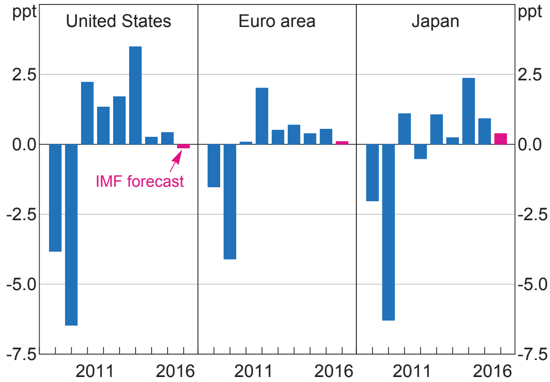
in early 2014, after growing over much of the preceding few years. Conditions in the major advanced economies generally remain supportive of consumption: employment growth has been strong; accommodative monetary policies are keeping borrowing rates low; household net wealth has been recovering, with housing prices approaching, or even exceeding, pre-crisis levels; and low fuel prices have been boosting real incomes. At the same time, however, nominal wage growth remains low and consumer confidence has declined recently, although it remains at or above long-run average levels.

A recovery in business investment has made an important contribution to growth in the major advanced economies over recent years. More recently, the strength in business investment waned in the United States, where declining investment in the oil & gas and manufacturing sectors, due to declining oil prices, weak external demand and the appreciation of the US dollar, subtracted from growth in recent quarters. In contrast, residential investment continued to grow strongly, supported by improvements in housing market conditions and low borrowing rates. In the euro area and Japan, investment has continued to grow, but remains well below its pre-crisis levels. Euro area investment growth, particularly in machinery and equipment, picked up in 2015 supported by above-average business confidence, and timely indicators suggest that this momentum has continued into early 2016. Similarly, timely indicators suggest that business investment has continued to grow in Japan, supported by strong corporate profit growth following the significant depreciation of the yen between 2012 and 2014. However, the recent appreciation of the yen and a decline in surveyed business conditions are less positive for the investment outlook.

After earlier fiscal tightenings, fiscal policy in the United States and Japan became less of a drag on economic activity recently and this is projected to continue this year (Graph 1.16). In the euro area, fiscal policy is also expected to be less contractionary in 2016.

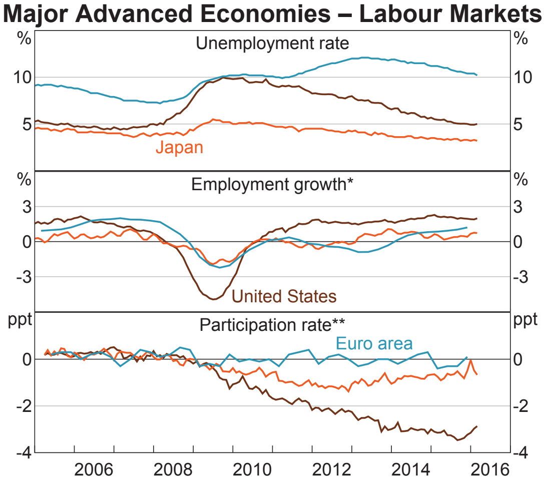
Labour markets have improved considerably in recent years across the major advanced economies (Graph 1.17). Employment growth has been robust in all three economies, resulting in declining unemployment rates. Unemployment rates in the United States and Japan are now at or below their long-run averages, indicating increasingly limited spare capacity. In contrast, the euro area unemployment rate remains well above its long-run average level. The strength in labour market conditions seems to have encouraged an increase

Graph 1.16
Major Advanced Economies – Change in Fiscal Balances
Per cent of GDP, annual



Sources: IMF; RBA

Graph 1.17
Major Advanced Economies – Labour Markets



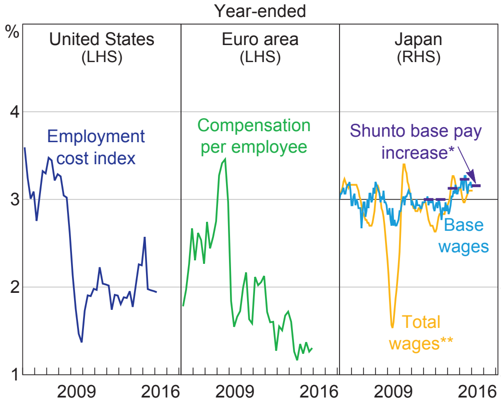
* Year-ended; three-month moving average growth rate for Japan
** Cumulative change since March 2005
Sources: Eurostat; RBA; Thomson Reuters

in workforce participation in Japan, and more recently in the United States, after earlier declines. Nonetheless, participation rates remain at or below their levels of a decade earlier, partly because of population ageing.

Nominal wage growth in the major advanced economies remains low despite the improvements in labour markets (Graph 1.18). In the United States, low productivity growth may be restraining wage growth in the face of the tightening labour market; unit labour costs have been growing at an above-average pace. Wage growth in Japan has been positive since 2014, consistent with the strengthening in the labour market. However, recent negotiations between labour unions and large employers (the so-called 'Shunto') point to some moderation in base-wage growth in the coming year. Growth in euro area compensation per employee remained close to its historic low during 2015, consistent with the relatively high level of unemployment.

Graph 1.18
Major Advanced Economies – Wage Growth

Year-ended



* Reported agreed base-wage increases in the annual Shunto negotiations between labour unions and large employers; 2016 estimate is based on a sample of negotiated wage agreements reported to date

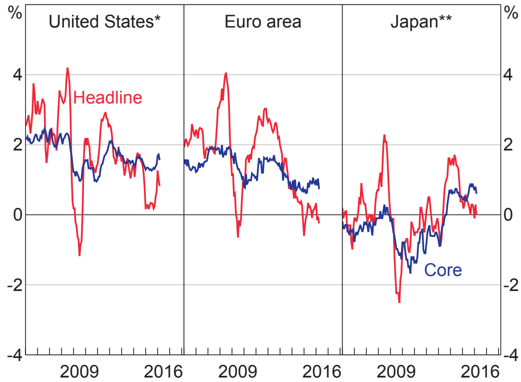
** 13-term Henderson trend

Sources: CEIC Data; Eurostat; Nomura; RBA; Thomson Reuters

Inflation in the major advanced economies remains below central banks' targets (Graph 1.19). Low nominal wage growth and the earlier decline in oil prices have contributed to the restrained price pressures. Even though core inflation has increased from its recent lows, most measures of inflation expectations in the major advanced economies have declined in recent years, and in the United States and euro area they are at around their lowest levels since the global financial crisis (Graph 1.20). To a large extent, the decline in inflation expectations has coincided with the decline in headline inflation. While long-term market-based measures of inflation expectations

Graph 1.19
Major Advanced Economies – Inflation

Year-ended

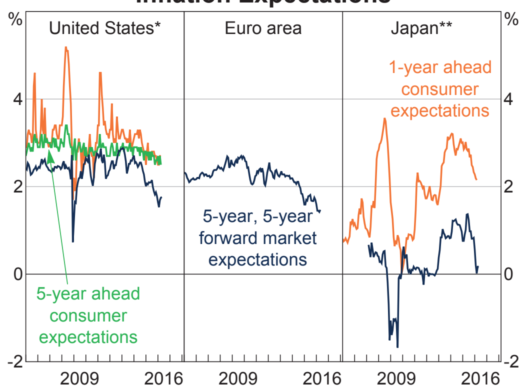


* Personal consumption expenditures (PCE) inflation

** Excluding the effects of the consumption tax increase in April 2014

Sources: RBA; Thomson Reuters

Graph 1.20
Major Advanced Economies – Inflation Expectations



* US expectations are for CPI inflation

** Calculated as a weighted average of responses to a monthly consumer survey; the survey asks respondents to indicate their price expectations over the next year within a given range

Sources: Bloomberg; RBA; Thomson Reuters

declined sharply in early 2016, especially in Japan, some caution should be applied in interpreting these measures because they can be affected by other developments in financial markets. Nevertheless, the European Central Bank (ECB) has noted its concern about the further decline in inflation expectations over recent months. In Japan, the anticipated effect of the scheduled increase in the consumption tax in April 2017 may be boosting consumers' short-term inflation expectations.

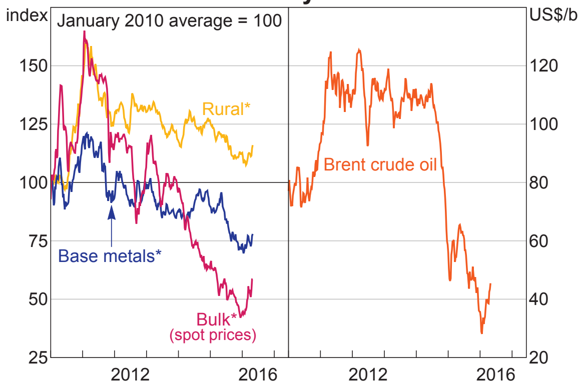
The persistence of low inflation (and the decline in oil prices up to early 2016) had prompted central banks in the major advanced economies to revise down their forecasts of inflation. The ECB undertook further monetary policy steps in March aimed at inflation reaching its target over an acceptable timeframe (see 'International and Foreign Exchange Markets' chapter).

Commodity Prices

The RBA Index of Commodity Prices (ICP) has increased in recent months, led by a large increase in the price of iron ore (Table 1.1; Graph 1.21). Nonetheless, commodity prices are around 50 per cent below their 2011 peak, reflecting both substantial increases in global supply as new resource projects have started production and weakness in global demand, especially from Asia. Lower bulk commodity prices contributed to a decline in Australia's terms of trade of 3 per cent in the December quarter and of 12 per cent over 2015.

The spot price of iron ore has increased significantly over recent months to be around 60 per cent above the low reached in December 2015, although it remains 70 per cent below its 2011 peak (Graph 1.22). The prices of iron ore and steel rose sharply after the Chinese Government announced

Graph 1.21
Commodity Prices



* RBA Index of Commodity Prices sub-indices, SDR
Sources: Bloomberg; RBA

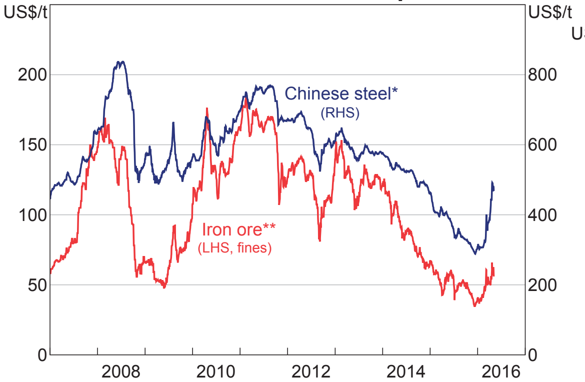
its growth targets for 2016 in early March, which led to improvements in the near-term outlook for steel demand. Re-stocking of iron ore inventories and some production cuts from high-cost global iron ore producers, including in China, are also likely to have supported prices. Speculative activity in futures markets may also have played a role. At the same time, however, the expected increase in the global supply of iron ore, as capacity expansions come on line in Australia and Brazil, may exert downward pressure on prices, and Chinese steel production is expected to moderate over the year ahead.

Table 1.1: Commodity Price Growth(a)
SDR, three-month-average prices, per cent

	Since previous *Statement*	Over the past year
Bulk commodities	18	–9
– Iron ore	31	–1
– Coking coal	9	–19
– Thermal coal	–1	–17
Rural	0	–7
Base metals	4	–17
Gold	13	3
Brent oil(b)	5	–33
RBA ICP	5	–15
– using spot prices for bulk commodities	9	–12

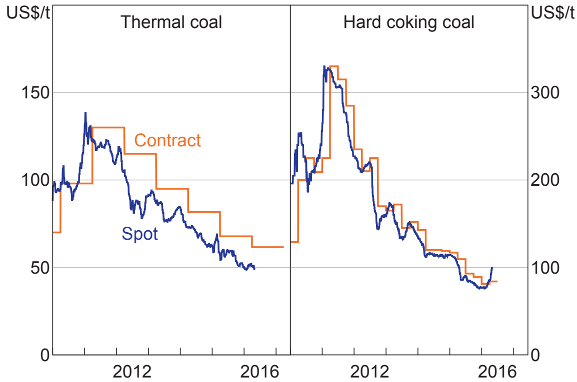
(a) Prices from the RBA ICP; bulk commodities prices are spot prices
(b) In US dollars
Sources: Bloomberg; IHS; RBA

Graph 1.22
Chinese Steel and Iron Ore Spot Prices



* Average of hot rolled steel sheet and steel rebar prices
** Free on board basis
Sources: Bloomberg; RBA

Graph 1.23
Coal Prices
Free on board basis



Sources: Department of Industry, Innovation and Science; IHS; RBA

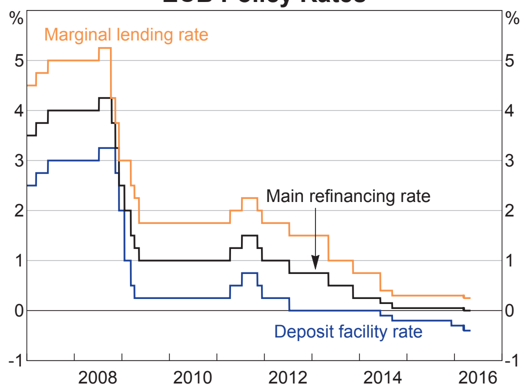
After declining for much of the past five years, coking coal prices have been supported by improved sentiment surrounding Chinese steel demand of late (Graph 1.23). Thermal coal prices remain under pressure from weaker global demand, particularly from the Asian region. At current prices, a substantial share of global coal production, including in Australia, remains unprofitable. Concerns about global demand, particularly subdued growth of global industrial production, have also led to declines in the prices of base metals over the past year, although these are also a little above their lows around the turn of the year. Declines in the production of some of these commodities may have provided some support to prices of late.

The Brent crude oil price has risen noticeably over recent months, after falling to its lowest level in over a decade around the turn of the year (Graph 1.21). The recent increase has been supported by speculation about potential production freezes by some of the major producers, although global supply remains little changed at relatively high levels. Changes in oil prices tend to be reflected in regional liquefied natural gas (LNG) prices with a lag of a few quarters. Looking further ahead, increased supply from Australian LNG exporters is likely to place downward pressure on regional LNG spot prices over the next couple of years. ✠

2. International and Foreign Exchange Markets

Sentiment in global financial markets has improved over the past few months as concerns about the outlook for the Chinese economy have eased and commodity prices have increased from their recent troughs. Current and expected policies of the major central banks continue to be an important driver of developments in global financial markets, with the European Central Bank (ECB) easing policy further and expectations for further policy tightening by the Federal Reserve being scaled back, which contributed to a depreciation of the US dollar and a decline in major market sovereign bond yields. The Japanese yen has appreciated sharply over recent months following the Bank of Japan's (BoJ) announcement of a negative policy rate.

Graph 2.1
ECB Policy Rates



Sources: Bloomberg; Thomson Reuters

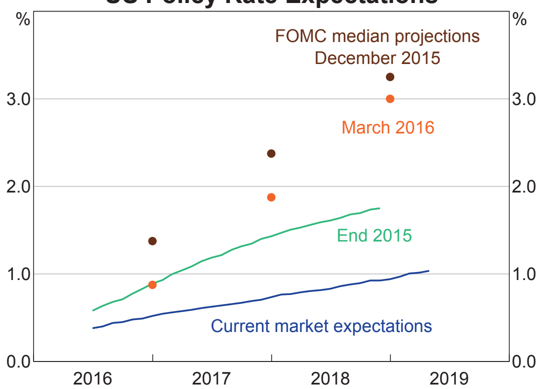
Central Bank Policy

The ECB eased policy further at its March meeting to address concerns about low inflation. The package of policy measures included a reduction in interest rates, an expansion of asset purchases and an enhanced term funding facility for banks. The ECB lowered the interest rate on its deposit facility by a further 10 basis points to –0.40 per cent and the interest rates for its main refinancing operations and marginal lending facility by 5 basis points to 0 per cent and 0.25 per cent, respectively (Graph 2.1).

The ECB also increased its monthly asset purchases by €20 billion to €80 billion and widened the scope of eligible assets to include bonds of investment-grade corporates (excluding banks). The reduction in policy rates and changes to the asset purchase program were supplemented by a new round of four targeted long-term refinancing operations (TLTRO II) starting in June 2016, which will provide four-year term funding (with optional repayment after two years) to euro area banks. The maximum amount that can be borrowed through TLTRO II is 30 per cent of a bank's eligible stock of business and personal loans (this compares to a maximum of 7 per cent under TLTRO I, which have been disbursed quarterly to banks since September 2014), implying total TLTRO II borrowing could be as much as €1.7 trillion. The interest rate at the time the loan is extended will be the main refinancing rate (currently 0 per cent), but can be as low as the deposit rate (currently –0.40 per cent) if the bank meets certain benchmarks for lending to the private sector.

The US Federal Open Market Committee (FOMC) left the target range for the federal funds rate at 0.25–0.50 per cent at both its March and April meetings. The March decision reflected the assessment of the majority of members that heightened global risks warranted caution in adjusting monetary policy. The FOMC toned down references to these risks in April, but cautioned about slightly weaker developments in the domestic economy. Consistent with these concerns, the FOMC reduced the median projections for the path of its policy rate for 2016 and 2017 by 50 basis points at the March meeting (Graph 2.2). Nonetheless, the pace of adjustment projected by the median FOMC member remains faster than the pace implied by market pricing: the most recent FOMC projections suggest two policy rate increases this year, while markets have priced at most one increase.

Graph 2.2
US Policy Rate Expectations



Sources: Bloomberg; Board of Governors of the Federal Reserve System

The BoJ has left its policy stance unchanged since the introduction of a negative interest rate on certain deposits in late January, though at its April meeting it pushed back the date by when it expects to achieve its 2 per cent inflation target to early 2018. The BoJ has been adjusting its tiered interest rate system to ensure only a small share of central bank deposits (currently around 10 per cent) attracts negative interest rates. At its March meeting, the BoJ exempted deposits of money reserve funds at trust banks from negative interest rates and allowed a greater proportion of deposits of banks participating in the BoJ's funding-for-lending programs to incur zero interest rather than a negative rate.

A number of other central banks have also eased policy in recent months (Table 2.1). The Swedish Riksbank reduced its policy rate by 15 basis points to –0.5 per cent and the Reserve Bank of New Zealand lowered its policy rate by 25 basis points to 2.25 per cent, amid concerns that persistently low inflation could make it harder to achieve inflation targets in both countries. The Riksbank also announced that it will extend its government bond purchase program over the second half of 2016. Norway's central bank also reduced its policy rate by 25 basis points in March, noting that growth prospects for the Norwegian economy had softened.

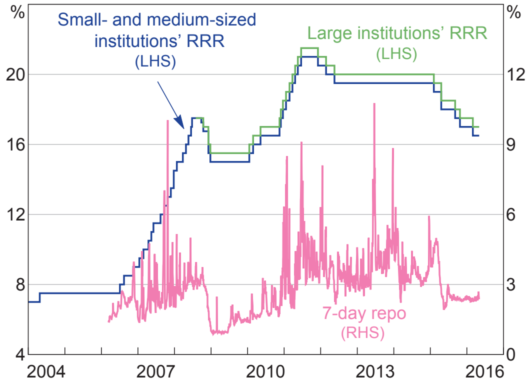
The People's Bank of China (PBC) lowered system-wide reserve requirement ratios (RRRs) by 50 basis points in late February, to be 300 basis points below their end-2014 levels (Graph 2.3). The reduction in

Table 2.1: Monetary Policy

	Policy rate Per cent		Most recent change
Euro area[a]	–0.40	↓	Mar 16
Japan[a]	–0.10	↓	Jan 16
United States[b]	0.375	↑	Dec 15
Australia	1.75	↓	May 16
Brazil	14.25	↑	Jul 15
Canada	0.50	↓	Jul 15
Chile	3.50	↑	Dec 15
India	6.50	↓	Apr 16
Indonesia	6.75	↓	Mar 16
Israel	0.10	↓	Feb 15
Malaysia	3.25	↑	Jul 14
Mexico	3.75	↑	Feb 16
New Zealand	2.25	↓	Mar 16
Norway	0.50	↓	Mar 16
Russia	11.00	↓	Jul 15
South Africa	7.00	↑	Mar 16
South Korea	1.50	↓	Jun 15
Sweden	–0.50	↓	Feb 16
Switzerland[b]	–0.75	↓	Jan 15
Thailand	1.50	↓	Apr 15
Turkey	7.50	↓	Feb 15
United Kingdom	0.50	↓	Mar 09

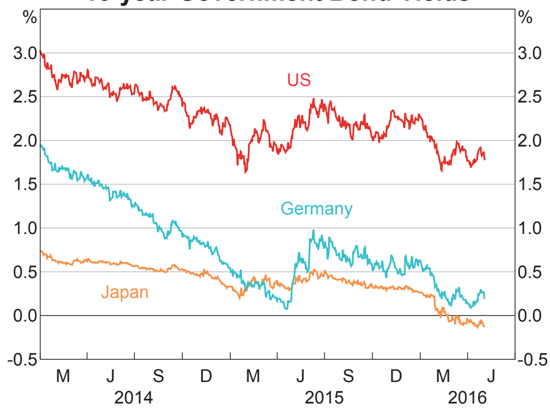
(a) Marginal rate paid on deposits at the central bank
(b) Midpoint of target range
Sources: Central banks; RBA; Thomson Reuters

Graph 2.3
Chinese Interest Rates



Source: CEIC Data

Graph 2.4
10-year Government Bond Yields



Source: Bloomberg

RRRs appears to have been a response to domestic liquidity needs arising from capital outflows and Chinese New Year rather than a signal of substantial policy easing, as evidenced by interbank interest rates having remained at low and stable levels.

Among other emerging market central banks, both the Reserve Bank of India and Bank Indonesia have eased their policy rates recently to boost economic activity, amid expectations of a further decline in inflation. Bank Indonesia has reduced its policy rate by a total of 75 basis points this year to 6.75 per cent. In contrast, the central banks of Mexico and South Africa raised their policy rates by 50 and 25 basis points, respectively, to stem inflationary pressure mainly arising from further exchange rate depreciation.

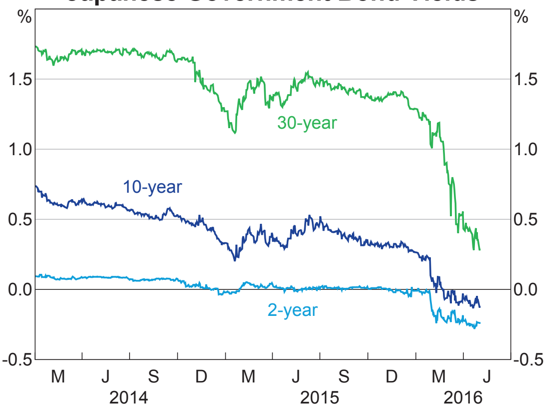
Sovereign Debt Markets

Ten-year sovereign bond yields in major developed markets have fallen since the beginning of the year, reflecting additional easing measures announced by the ECB and the BoJ, as well as a scaling back of expectations of further increases in the US policy rate target (Graph 2.4). Yields on 10-year US Treasuries have declined by around 50 basis points, with commentary from Federal Reserve officials over recent months about the need for caution in tightening monetary policy contributing to the fall. Yields on 10-year German Bunds have declined to around their historic low following the ECB's announcement of additional policy measures. Yields on German short-term sovereign securities have also declined materially since the beginning of 2016. Around 30 per cent of euro area government debt securities are currently trading at yields below zero.

The yield on 10-year Japanese government bonds (JGBs) fell below zero for the first time in February, following the BoJ's announcement of a negative deposit rate, and has been little changed since then at around –0.10 per cent (Graph 2.5). Yields on very long-term JGBs have also declined sharply and around two-thirds of JGBs are currently trading at yields below zero. In addition to ongoing purchases by the BoJ, foreign residents have continued to be net purchasers of JGBs so far this year, particularly of long-term bonds.

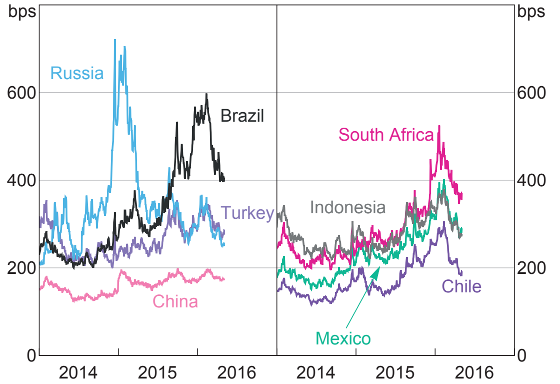
Spreads on bonds issued by governments in the European periphery over German Bund yields of equivalent maturity have narrowed since mid February as market sentiment has improved, although spreads on Greek and Portuguese bonds remain well above the levels recorded in late 2015. In particular, concerns remain about the Greek Government's ability to negotiate an acceptable package with creditors and legislate the required reforms in time to receive further bailout funds, which will allow it to meet upcoming large debt

Graph 2.5
Japanese Government Bond Yields



Source: Bloomberg

Graph 2.6
Emerging Market Government Bond Spreads*
US dollar-denominated



* To US Treasury bonds; duration matched

Sources: JP Morgan; Thomson Reuters

repayments (including €750 million due to the International Monetary Fund (IMF) and €2.3 billion due to the ECB in June and July 2016).

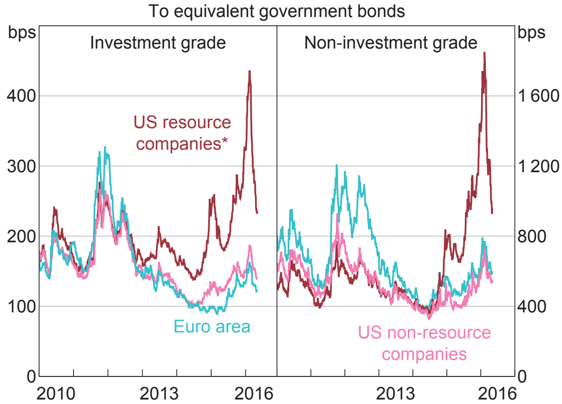
Yields on emerging market local currency-denominated sovereign bonds have generally declined since the start of the year, albeit to varying degrees across countries, consistent with the falls in US Treasury yields. Yields on Brazilian government bonds fell with rising anticipation of a change in the country's government as a consequence of the ongoing presidential impeachment process. Spreads to US Treasuries on emerging market US dollar-denominated sovereign bonds have narrowed considerably since the start of the year, with higher commodity prices supporting bonds of commodity-exporting countries (Graph 2.6). Argentina issued US$16.5 billion in government bonds to international investors in a heavily oversubscribed offering, the first such debt offering since the country defaulted in 2001. Part of the proceeds has been used to pay holdout investors, who have agreed to a settlement after previously blocking the Argentine Government from making payments on the restructured debt from the 2001 default.

Credit Markets

Conditions in both developed and most emerging corporate bond markets have eased since mid February, consistent with the improvement in financial market sentiment and higher commodity prices. Borrowing costs have fallen, largely driven by a narrowing in credit spreads (Graph 2.7). In contrast, conditions in Chinese corporate bond markets have tightened.

Alongside the increase in commodity prices, spreads on resource-related corporate bonds in the United States have fallen sharply since their peak

Graph 2.7
Corporate Bond Spreads
To equivalent government bonds



* Energy, metals, mining and steel sectors

Sources: Bank of America Merrill Lynch; RBA; Thomson Reuters in mid February, reversing much of their increase since mid 2015. Nevertheless, spreads on these bonds remain elevated, consistent with the low level of commodity prices. Reflecting the elevated spreads, borrowing costs for non-investment grade resource companies are above historical averages. The default rate on US non-investment grade bonds has increased steadily from 2 per cent in mid 2015 to around 4 per cent, driven largely by resource company defaults.

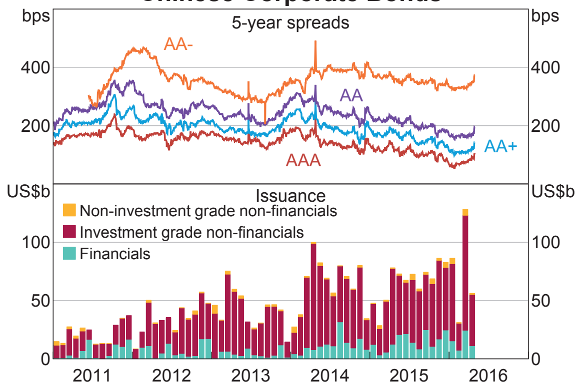
Spreads on bonds of US non-resource companies have also fallen as sentiment has improved. In particular, spreads on financial corporations' bonds have now reversed most of their increase since the start of 2016.

In the euro area, the improvement in conditions has been supported by the ECB's announcement that its asset purchase program would be extended to include bonds issued by non-bank investment-grade corporates. Spreads on these bonds have fallen by around 35 basis points since the announcement, while spreads on investment-grade bank bonds have fallen by less.

Issuance of both US and euro area corporate bonds has recovered after slowing in early February, in part due to corporations having postponed issuance while market conditions were volatile. Most notably, Apple and Exxon Mobil each raised US$12 billion in the second half of February, while brewer AB InBev followed its large bond issue in January by raising a further €13 billion in March.

Chinese corporate bond issuance was strong in the March quarter, with record high gross issuance in the month of March (Graph 2.8). Issuance by companies in the real estate and construction sectors grew quickly over the year to March, with growth concentrated in the onshore local currency-denominated market. However, issuance was lower in April and the number of planned corporate bond issues that have been cancelled has increased, reportedly due to concerns in the market over recent missed bond payments by some corporates,

Graph 2.8
Chinese Corporate Bonds



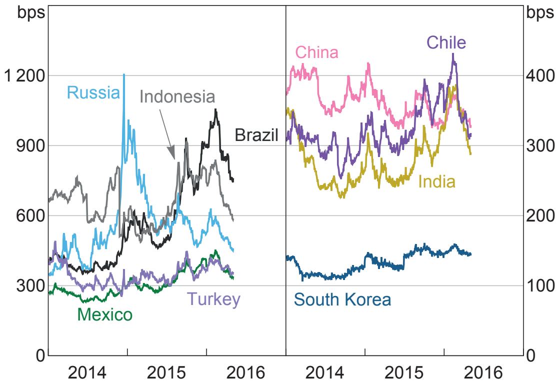
Sources: Bloomberg; CEIC Data; Dealogic; RBA

including some state-owned enterprises. Local currency-denominated corporate bond spreads have widened considerably over April, alongside heightened concerns about deteriorating corporate conditions and missed bond payments, to be back around their levels of mid 2015. Local government bond issuance remained strong in the March quarter, consistent with the continuation of the local government debt swap program.

Chinese authorities have stated they are considering a debt-for-equity swap program to reduce the debt burden of large companies in 'overcapacity' industries. Additionally, Chinese authorities have reportedly granted quotas to six large banks allowing them to issue asset-backed securities with non-performing loans as underlying assets.

Spreads to US Treasuries of US dollar-denominated bonds issued by emerging market corporations outside of China fell alongside higher commodity prices and the improvement in market sentiment (Graph 2.9). The narrowing in spreads was particularly pronounced for Indonesian and Brazilian corporations, consistent with the falls in sovereign spreads for those countries. New issuance remains relatively subdued, with cumulative gross issuance by emerging market corporations in the year-to-date at its slowest pace since 2009.

Graph 2.9
Emerging Market Corporate Bond Spreads
US dollar-denominated bonds

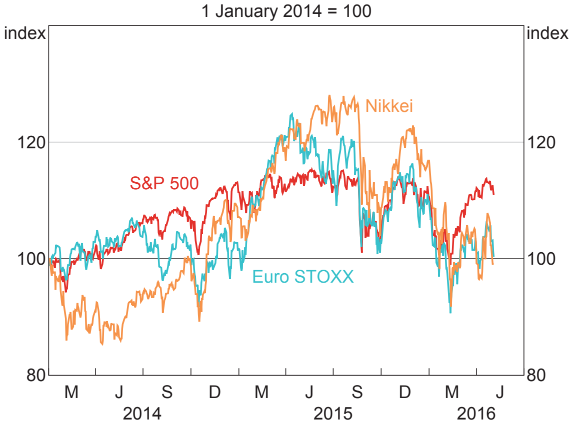


Source: JP Morgan

Equities

After sharp price declines of about 10 per cent between early January and mid February, equity prices in many economies have risen considerably and recovered most of their losses (Graph 2.10; Table 2.2). Share prices in the energy and materials sectors have seen the strongest increase, underpinned by a rise in the price of oil and other commodity prices. Share prices in Japan are a notable exception, which have declined alongside the appreciation of the Japanese yen. Overall, volatility declined and was relatively low over March and April.

Graph 2.10
Major Share Price Indices
1 January 2014 = 100



Source: Bloomberg

Table 2.2: Changes in International Share Prices
Per cent

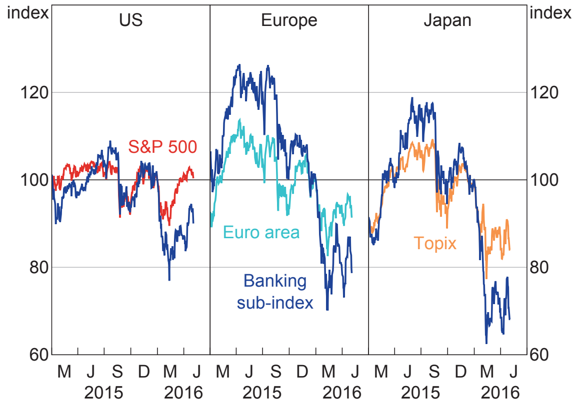
	Over 2015	2016 to date
United States – S&P 500	–1	0
Euro area – STOXX	8	–9
United Kingdom – FTSE	–5	–2
Japan – Nikkei	9	–15
Canada – TSE 300	–11	5
Australia – ASX 200	–2	0
China – MSCI All China	2	–13
MSCI indices		
– Emerging Asia	–8	–3
– Latin America	–11	13
– Emerging Europe	–4	6
– World	**–1**	**–3**

Source: Bloomberg

Bank share prices have risen since mid February, but are still well below their levels at the beginning of the year (Graph 2.11). The sell-off in bank shares – particularly in the euro area and Japan – reflected a broad range of concerns, including a weaker outlook for economic growth, persistently high levels of non-performing loans in some countries (in particular in Italy and Greece), the impact on bank profitability of a low interest rate environment and relatively flat yield curves (which reduce the profitability of banks' long-term lending) as well as a number of bank-specific concerns.

Major US banks reported that net income declined notably in the March quarter compared to the same quarter last year, generally driven by a sharp decline in institutional banking revenues (in particular, from fixed income trading), and a notable increase in provisions for credit losses in relation to exposures to the energy sector. These falls were partially offset by an increase in net interest income from the traditional banking business. The Federal Deposit Insurance Corporation and the Federal Reserve found shortcomings in the 'living wills' (recovery and resolution plans in the event of financial distress or failure) of five large US institutions: JP Morgan,

Graph 2.11
Major Market Bank Share Prices
1 January 2016 = 100



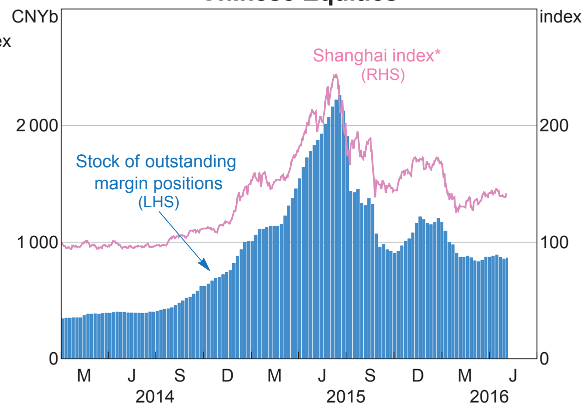
Source: Bloomberg

Bank of America, Wells Fargo, State Street and Bank of New York Mellon. The institutions have until October 2016 to address the identified deficiencies or face potential regulatory sanctions, which may include higher capital requirements. Most European banks also reported a decrease in earnings, largely driven by a decline in trading revenue.

Share prices in most emerging markets have outperformed those in advanced economies since mid February and over 2016 to date, reflecting higher commodity prices (most notably oil) and an increase in capital inflows. Of note, Brazilian equity prices have increased by about 20 per cent since the start of the year, more than offsetting the falls in 2015.

Chinese share prices have recovered some of their falls in early 2016 and have been less volatile recently (Graph 2.12). Overall, Chinese margin financing is only a little above its level in mid February, despite a resumption of short-term lending by China Securities Finance Corporation to brokerage firms for margin trading and an easing of capital requirements for brokerages by the China Securities Regulatory Commission.

Graph 2.12
Chinese Equities

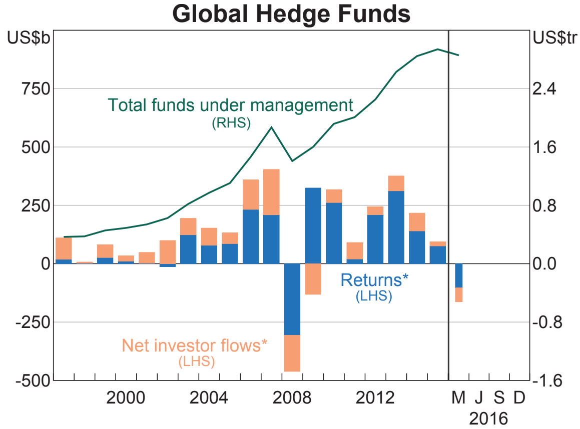


* 1 January 2014 = 100
Sources: Bloomberg; WIND Information

Hedge Funds

Global hedge funds recorded an asset-weighted return on investment of –2.2 per cent over the March quarter of 2016, underperforming a balanced portfolio of global bonds and equities (Graph 2.13). This follows a 0.5 per cent return on investment over the December quarter for the sector and a return close to zero over 2015. The global hedge fund losses in the March quarter primarily stem from equity hedge funds, in particular those with large exposures to the technology and healthcare sectors. Funds focused on emerging markets did a little

Graph 2.13
Global Hedge Funds



* Annualised for 2016 data
Sources: Hedge Fund Research, Inc.; RBA

better, led by the outperformance of funds targeting Latin American securities amid a rebound of Brazilian equity prices. Investors made net withdrawals from hedge funds for the second consecutive quarter, marking the largest quarterly outflows since 2009. Overall, assets under management declined by 1.4 per cent over the quarter to US$2.9 trillion.

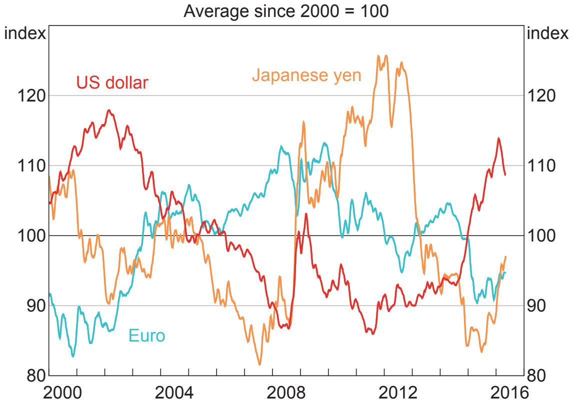
Foreign Exchange

In recent months, foreign exchange markets have primarily been influenced by the current and expected stance of monetary policy in the major advanced economies and an increase in commodity prices.

On a trade-weighted basis, the US dollar appreciated by around 25 per cent between mid 2014 and late January 2016, but has since depreciated by 5 per cent (Graph 2.14; Table 2.3). The depreciation has occurred alongside the FOMC lowering its median projection for the federal funds rate and market participants' expectations for the timing of the next rate increase also being pushed back. The depreciation has generally been more pronounced against the currencies of commodity exporters.

The Japanese yen has moved within a wide range over recent months alongside changes in expectations about further policy easing by the BoJ. Between late January and mid April the yen

Graph 2.14
Nominal Trade-weighted Indices*
Average since 2000 = 100



* 22-day rolling average

Sources: BIS; Bloomberg; Board of Governors of the Federal Reserve System

Table 2.3: Changes in the US Dollar against Selected Currencies
Per cent

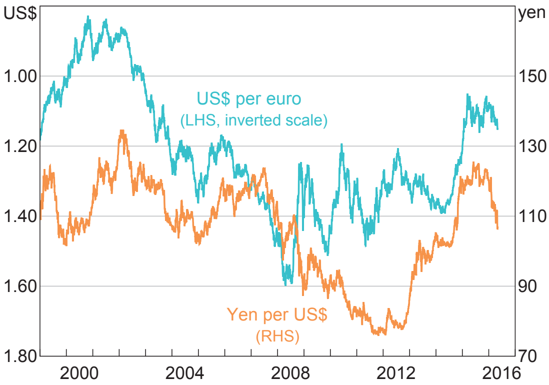
	Over 2015	2016 to date
Mexican peso	17	3
UK pound sterling	6	2
Philippine peso	5	1
Indian rupee	5	1
Chinese renminbi	5	0
New Zealand dollar	14	–1
New Taiwan dollar	4	–1
South Korean won	8	–2
Australian dollar	12	–2
Thai baht	10	–2
Indonesian rupiah	11	–4
Singapore dollar	7	–4
Swiss franc	1	–4
Swedish krona	8	–4
European euro	11	–5
Malaysian ringgit	22	–6
Canadian dollar	19	–7
Russian rouble	24	–7
Brazilian real	50	–10
Japanese yen	0	–11
TWI	**10**	**–3**

Sources: Bloomberg; Board of Governors of the Federal Reserve System

appreciated sharply, partly reflecting speculation by market participants that the BoJ may be approaching its limit to ease policy further. However, the yen then depreciated alongside increasing expectations of additional policy easing by the BoJ at its April meeting. Following the BoJ's decision to leave its policy stance unchanged, the yen appreciated sharply. Overall, the yen has appreciated by 7 per cent on a trade-weighted basis and by 11 per cent against the US dollar since late January (Graph 2.15).

The euro has appreciated by 6 per cent on a trade-weighted basis and by 9 per cent against the US dollar since its recent trough in late November. The appreciation has occurred despite the ECB's decision to ease policy at both its December and

Graph 2.15
US Dollar

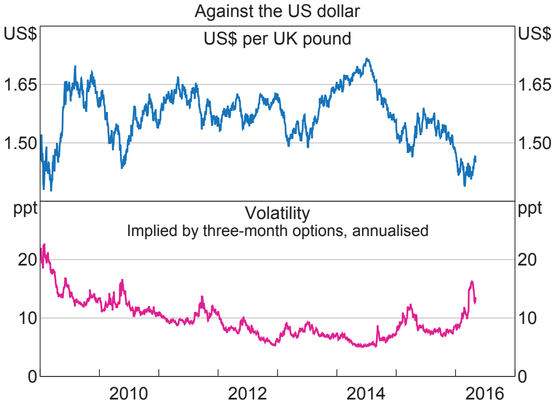


Source: Bloomberg

March meetings. Over recent months, the UK pound has been affected by uncertainty around the possibility of Britain exiting the European Union. Relatedly, the upcoming referendum on 23 June has resulted in a sharp increase in forward-looking measures of volatility in the GBP/USD currency pair; in mid April volatility reached its highest level since the UK general election in mid 2010 (Graph 2.16). While the UK pound has appreciated by around 5 per cent against the US dollar since its trough in late February, it remains around 15 per cent lower than its peak in mid 2014.

Graph 2.16
UK Pound

Against the US dollar

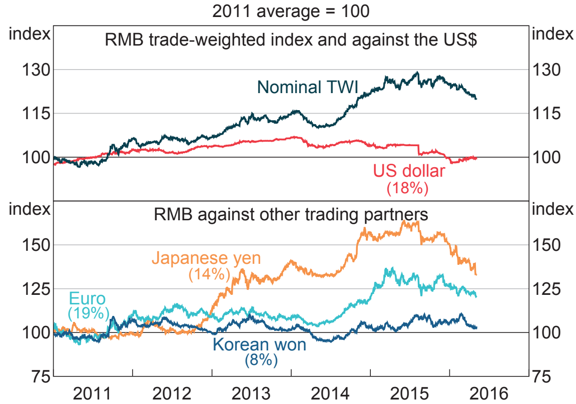


Source: Bloomberg

The Chinese renminbi (RMB) has appreciated by 1 per cent against the US dollar since its low in early January and has tended to move in a wider range in recent months, consistent with the PBC's policy aim to increase flexibility of the RMB (Graph 2.17). Except for the Chinese New Year period, the spread between RMB exchange rates in the onshore and offshore markets has been minimal. On a trade-weighted basis, the RMB has depreciated by 4 per cent since early January to be 7 per cent below its August 2015 peak. The value of the PBC's foreign currency reserves fell by US$118 billion over the March quarter 2016, largely as a result of a decline in January of around US$100 billion (Graph 2.18). The PBC's foreign

Graph 2.17
Chinese Renminbi*

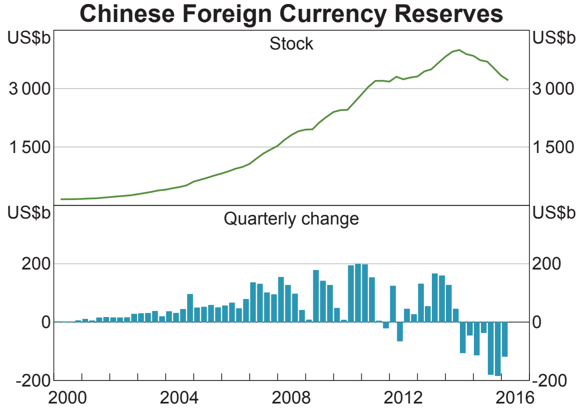
2011 average = 100



* Figures in parentheses represent currencies' weights in the trade-weighted index

Sources: BIS; Bloomberg; RBA

Graph 2.18
Chinese Foreign Currency Reserves



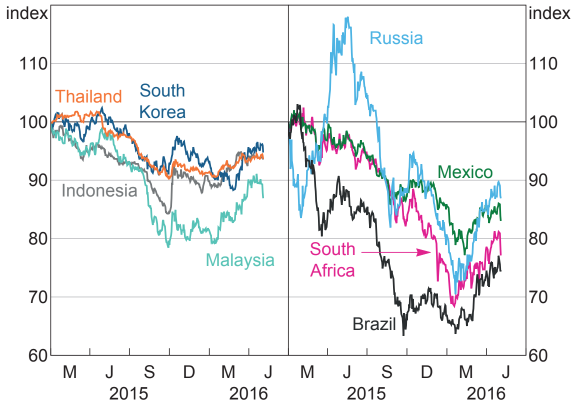
Source: CEIC Data

currency reserves have decreased by US$781 billion (or 20 per cent) since their peak in June 2014.

Most other Asian and emerging market currencies have appreciated against the US dollar since late January (Graph 2.19). The appreciations have typically been more pronounced for the currencies of commodity exporters. Most notably, the Russian rouble has appreciated by 22 per cent, and the Brazilian real, South African rand and Malaysian ringgit have appreciated by between 10–15 per cent alongside gains in oil and other commodity prices as well as a recovery in risk sentiment. In addition to the increase in commodity prices, the appreciation of the Brazilian real has reflected domestic political developments and has occurred despite recent action by Brazil's central bank to curb appreciation pressure on the currency. Volatility in most emerging market currencies remains above its average since 2010.

Graph 2.19
Asian and Emerging Market Currencies

Against the US dollar, 1 January 2015 = 100



Source: Bloomberg

The gross foreign currency reserves of most emerging market economies have been little changed or increased slightly since the end of December (Table 2.4). Saudi Arabian reserves have continued to decline but at a slower pace

Table 2.4: Gross Foreign Currency Reserves[(a)]

	Percentage change since:		Level
	End March 2015	End December 2015	US$ equivalent (billions)
China	–14	–4	3 213
Saudi Arabia	–16	–5	576
Taiwan[(b)]	4	1	432
South Korea	2	0	360
Brazil	–1	0	350
Hong Kong	9	0	348
India	6	3	338
Russia	6	3	316
Singapore	–1	–1	244
Mexico	–8	2	171
Thailand	12	12	166
Indonesia	–4	1	101
Turkey	–6	3	94
Malaysia	–7	3	89
Argentina	10	41	29

(a) Data to end March for China, Hong Kong, Indonesia, Mexico, Saudi Arabia, Singapore, South Korea, Taiwan and Thailand; to 15 April for Malaysia; to 22 April for India, Russia and Turkey; to end April for Argentina and Brazil.
(b) Foreign exchange reserves (includes foreign currency and other reserve assets).
Sources: Bloomberg; CEIC Data; central banks; IMF; RBA

than in late 2015 and early 2016, consistent with IMF projections for a smaller fiscal deficit in 2016. Argentina's gross foreign currency reserves increased by US$6.7 billion following the US$16.5 billion sovereign debt issuance. Since the start of 2016, gross foreign currency reserves have increased by around 40 per cent in Argentina; this also includes a loan to the central bank from a number of commercial banks in late January.

Australian Dollar

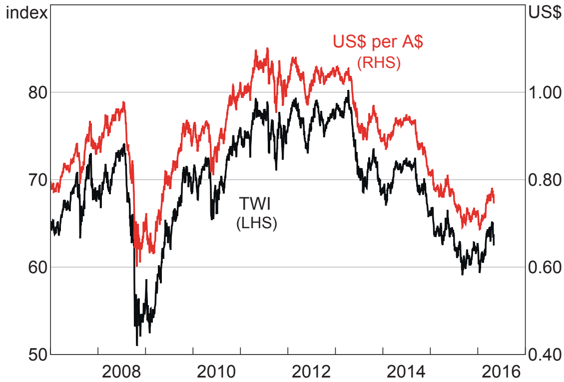
Overall, the Australian dollar is little changed on a trade-weighted (TWI) basis since the previous *Statement* (Table 2.5; Graph 2.20). Between early February and late April the Australian dollar appreciated by 6 per cent on a TWI basis and by 9 per cent against the US dollar, reflecting the markets' response to stronger-than-expected national accounts data, increases in commodity prices (including a 45 per cent increase in the iron ore price), and reduced expectations of the pace of policy tightening in the United States by both the FOMC and the market. However, the Australian dollar then depreciated sharply following lower-than-expected inflation data and the RBA's decision to ease monetary policy in early May.

Table 2.5: Changes in the Australian Dollar against Selected Currencies
Per cent

	Over 2015	2016 to date
UK pound sterling	–6	4
Indian rupee	–7	3
Chinese renminbi	–7	3
US dollar	–11	2
New Zealand dollar	2	2
South Korean won	–4	1
Thai baht	–2	0
South African rand	19	–1
Indonesian rupiah	–1	–2
Singapore dollar	–5	–2
Swiss franc	–10	–2
European euro	–1	–3
Malaysian ringgit	9	–4
Canadian dollar	6	–5
Japanese yen	–11	–9
TWI	**–6**	**0**

Sources: Bloomberg; RBA

Graph 2.20
Australian Dollar



Sources: Bloomberg; RBA

The Australian dollar is currently around 8 per cent higher against the US dollar and 6 per cent higher on a TWI basis than the low it reached in September 2015. In recent months, the average intraday trading range for the AUD/USD exchange rate was slightly above its post-2000 average.

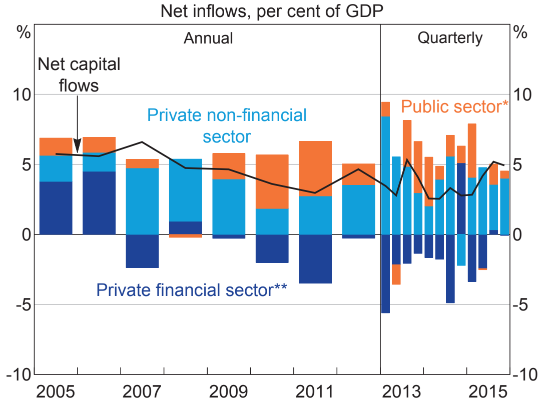
Capital Flows

Net capital inflows to the Australian economy were equivalent to 4.9 per cent of GDP in the December quarter, largely reflecting inflows to the private non-financial sector, in particular the mining sector (Graph 2.21). Within the financial sector, a net outflow from the banking sector in the quarter offset a net inflow to 'other financials' (which includes superannuation funds and other investment funds).

There was a modest net inflow to the public sector in the December quarter. This primarily reflected a net inflow to the general government sector, which was largely proportional to net issuance of Australian Government securities (AGS) in the quarter. As a result, the foreign ownership share of AGS remained unchanged at 63 per cent.

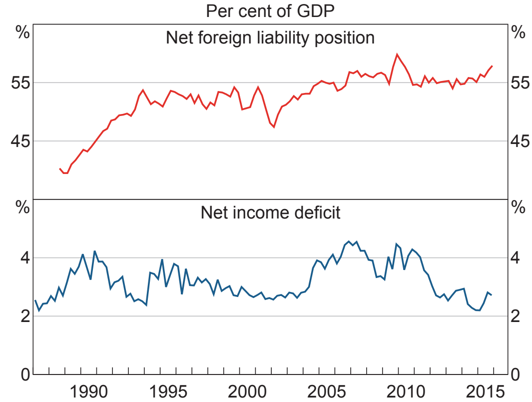
Consistent with net capital inflows in the December quarter, Australia's net foreign liability position increased to 58 per cent of GDP (Graph 2.22). The net income deficit, which largely comprises payments made on Australia's net foreign liabilities, narrowed to 2.7 per cent of GDP in the December quarter, primarily reflecting an increase in the estimated yield received on Australia's foreign debt and equity assets. ✠

Graph 2.21
Australian Capital Flows
Net inflows, per cent of GDP



* Excludes official reserves and other RBA flows
** Adjusted for US dollar swap facility in 2008 and 2009
Sources: ABS; RBA

Graph 2.22
Australia's External Position
Per cent of GDP

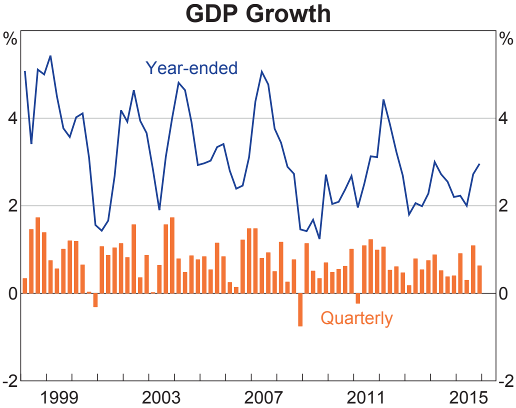


Sources: ABS; RBA

3. Domestic Economic Conditions

The Australian economy grew by 3 per cent over 2015, which is a little above central estimates of the economy's potential growth rate and was stronger than had been anticipated (Graph 3.1). In part, this reflected very strong growth in the September quarter following an upward revision to that estimate. GDP grew by 0.6 per cent in the December quarter and indications are that GDP has increased at a similar rate in early 2016.

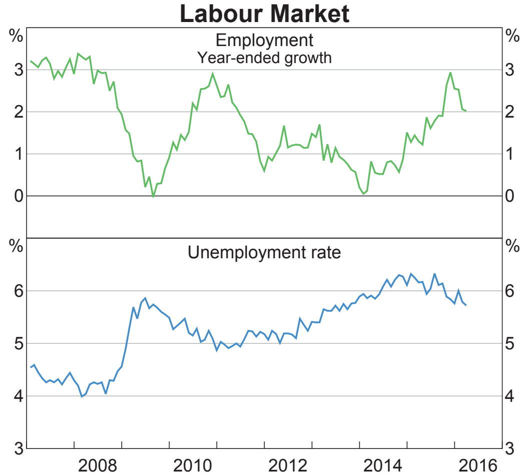
Graph 3.1
GDP Growth



Source: ABS

Stronger output growth over 2015 was accompanied by a large increase in employment and a decline in the unemployment rate (Graph 3.2). After particularly strong outcomes in late 2015, employment growth has moderated over the past few months, and forward-looking indicators provide mixed signals about the underlying pace of improvement in the labour market. The unemployment rate has continued to edge down, to be about ½ percentage point below its peak in 2015. Nevertheless, there is still evidence

Graph 3.2
Labour Market



Source: ABS

of spare capacity in the labour market, with wage growth remaining very low. While the protracted period of low wage growth has allowed for more employment than otherwise, it has also constrained growth in nominal household income in recent years. At the same time, gains in asset prices have supported increases in household wealth.

The rebalancing of economic activity away from the resources sector towards other sectors has continued. Activity in the non-resource sectors of the economy increased at an above-average rate over 2015, with output expanding fastest in industries that provide services to households and businesses. Growth in household consumption picked up in the second half of the year to be around average and dwelling investment continued to strengthen, supported by the very low level of interest rates (Table 3.1). Demand for

Table 3.1: Demand and Output Growth
Per cent

	December quarter 2015	September quarter 2015	Year to December quarter 2015
GDP	0.6	1.1	3.0
Consumption	0.8	0.9	2.9
Dwelling investment	2.2	1.9	9.8
Business investment	–2.7	–4.5	–12.0
Public demand	1.4	–0.8	3.5
Exports	0.6	5.4	5.7
Imports	0.6	–2.3	1.2
Nominal GDP	0.4	1.1	2.4
Real gross domestic income	0.0	0.5	0.3

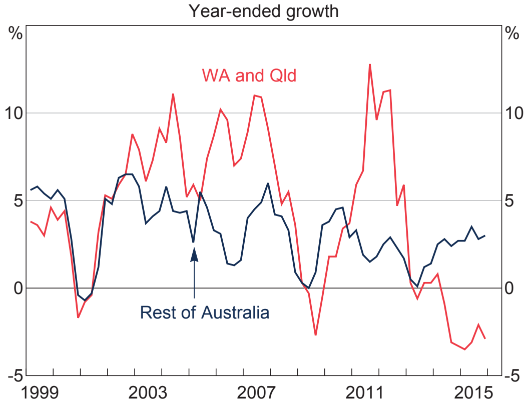
Sources: ABS; RBA

Australian production in trade-exposed industries continued to be boosted by the depreciation of the exchange rate since early 2013. Exports of services, in particular, increased noticeably over 2015 and imports of services have declined. Public demand contributed to growth over the year, while non-mining business investment remained subdued and has been little changed for several years.

In contrast, activity in the resources sector looks to have declined slightly over 2015. Mining investment continued to decline sharply, as more projects reach completion. This was partly offset by significant increases in the volume of resource exports. Mining activity is expected to pick up over the period ahead, reflecting further increases in resource exports – particularly liquefied natural gas (LNG) – and smaller declines in mining investment.

There continue to be significant differences in economic conditions across the country, consistent with the rebalancing of economic activity. Outside the resource-rich states of Queensland and Western Australia, growth has picked up over recent years (Graph 3.3). Unemployment rates have fallen noticeably in the eastern states, supported by an increase in demand, particularly for services. Overall, economic conditions in Queensland have improved a little of late, with weakness in the mining sector offset by improvements in construction and tourism

Graph 3.3
State Final Demand
Year-ended growth



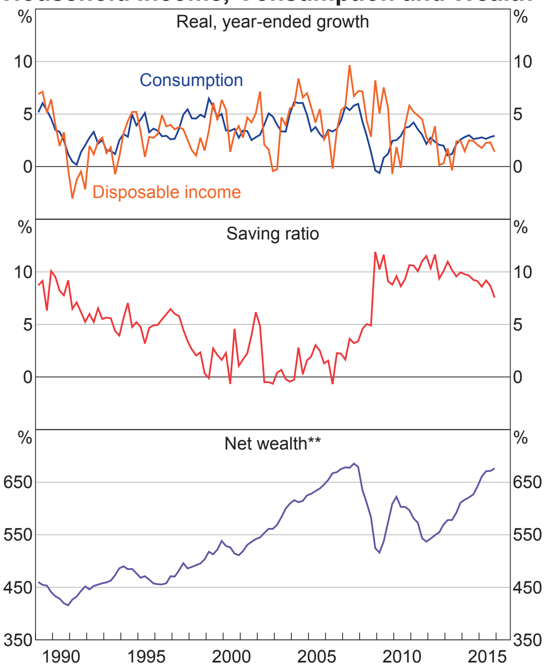
Sources: ABS; RBA

activity. In contrast, activity remains weak in Western Australia as investment and employment in the mining sector have fallen, and the unemployment rate has risen over the past few years.

Household Sector

Household consumption growth increased in the second half of 2015 to around its decade average in year-ended terms, driven by relatively strong growth in New South Wales and Victoria. Factors supporting the pick-up in consumption growth include solid employment growth and low interest rates, as well as the ongoing effects of lower petrol prices and a further increase in household wealth. With growth in household disposable income remaining below average, the saving ratio has continued to decline (Graph 3.4).

Graph 3.4
Household Income, Consumption and Wealth*



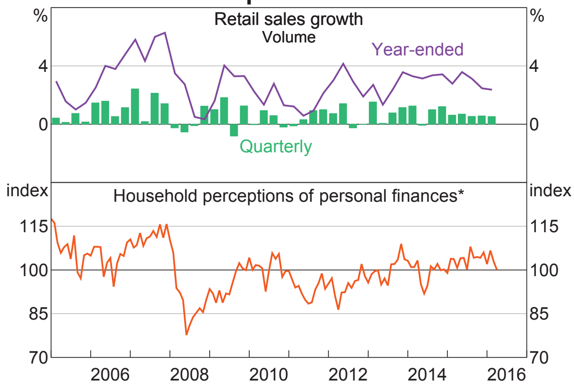
* Household sector includes unincorporated enterprises; disposable income is after tax and interest payments; income level smoothed with a two-quarter moving average between March quarter 2000 and March quarter 2002; saving ratio is net of depreciation

** Per cent of annual household disposable income, before the deduction of interest payments

Sources: ABS; RBA

Retail sales volumes grew at a similar pace in the March quarter as in late 2015, although other timely indicators of household consumption have eased of late (Graph 3.5). Motor vehicle sales to households have continued to decline in early 2016, though at a slower pace than in late 2015, and households' perceptions of their own finances have declined of late, although they remain around their long-run average. However, in the past these indicators have had only a modest correlation with quarterly aggregate consumption growth. Liaison suggests that trading conditions in the retail sector have softened in recent months, but remain generally positive.

Graph 3.5
Consumption Indicators



* Average of the ANZ-Roy Morgan and Westpac-Melbourne Institute consumer sentiment measures of respondents' perceptions of their personal finances relative to the previous year; average since 1980 = 100

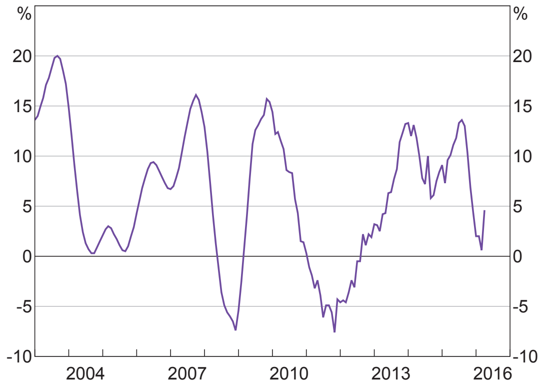
Sources: ABS; ANZ-Roy Morgan; RBA; Westpac and Melbourne Institute

Conditions in the established housing market have stabilised somewhat over the past two quarters or so. Housing prices increased in the early months of 2016, after easing slightly in the December quarter of 2015 (Graph 3.6). Auction clearance rates are above average in Sydney and Melbourne, although they remain lower than a year ago (Graph 3.7). The average number of days that a property is on the market is a little higher than the lows of last year, while the eventual discount on vendor asking prices is little changed. Housing turnover rates are below average.

Housing credit growth has eased a little in recent months, after stabilising in the second half of 2015. This follows an earlier period of rising credit growth, driven in large part by investor lending. This moderation has been consistent with the increases in mortgage interest rates implemented by most lenders towards the end of 2015 and the tightening of lending standards (see 'Domestic Financial Markets' chapter for further details on the developments in housing finance).

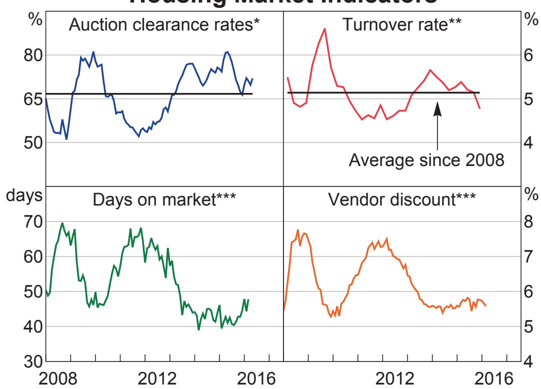
Conditions in the rental market have continued to soften. Growth in rents has declined and the aggregate rental vacancy rate has increased to around its average since 1990. While the recent increase in the national vacancy rate mainly reflects

Graph 3.6
Housing Price Growth
Six-month-ended annualised



Sources: CoreLogic RP Data; RBA

Graph 3.7
Housing Market Indicators



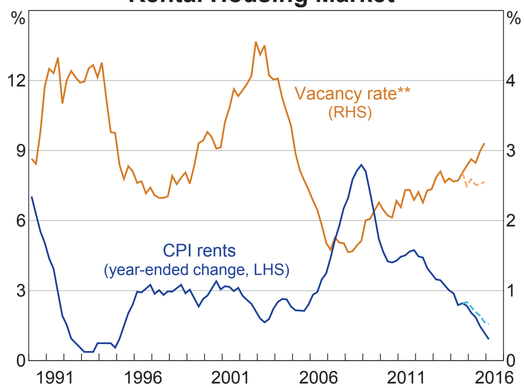
* Average of Melbourne and Sydney
** Share of dwelling stock, annualised
*** Capital city dwelling stock weighted median for private treaty sales only; vendor discounts reflect average difference between the original listing price and the final selling price

Sources: Australian Property Monitors; CoreLogic RP Data; RBA; Real Estate Institute of Victoria

developments in the Perth rental market, growth in rents has eased in most capital cities (Graph 3.8).

Dwelling investment has continued to grow strongly, supported by low interest rates and the significant increase in housing prices in recent years. Investment in higher-density housing grew at close to 30 per cent over 2015, accounting for most of dwelling investment growth over that period. More recently, the amount of residential construction work still in the pipeline has continued to rise and points to further strong growth in dwelling investment. The pace of growth is likely to moderate, however, consistent with the decline in building approvals since last year (Graph 3.9).

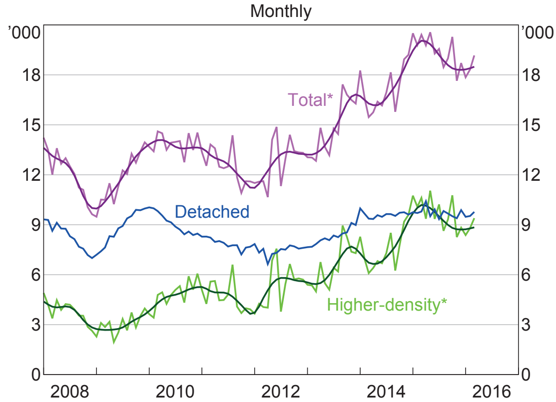
Graph 3.8
Rental Housing Market*



* Dotted lines exclude Perth
** Excludes Adelaide from March quarter 2015

Sources: ABS; RBA; Real Estate Institute of Australia

Graph 3.9
Private Residential Building Approvals
Monthly



* Smoothed lines are ABS trends

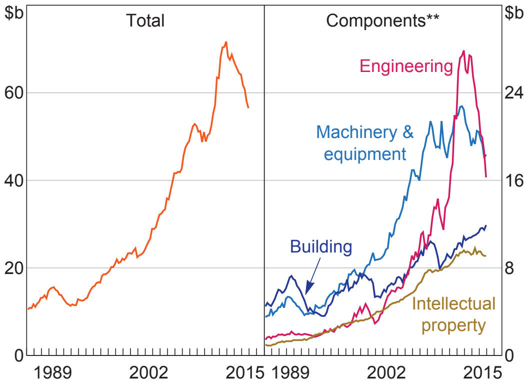
Source: ABS

Business Sector

Private business investment fell by 3 per cent in the December quarter and by 12 per cent over 2015 (Graph 3.10). The annual decline was led by a sharp fall in mining investment. Non-mining investment has been little changed for several years in real terms, notwithstanding a pick-up in profits in the non-mining sector in 2015 and above-average business conditions.

Graph 3.10
Private Business Investment

Chain volume*



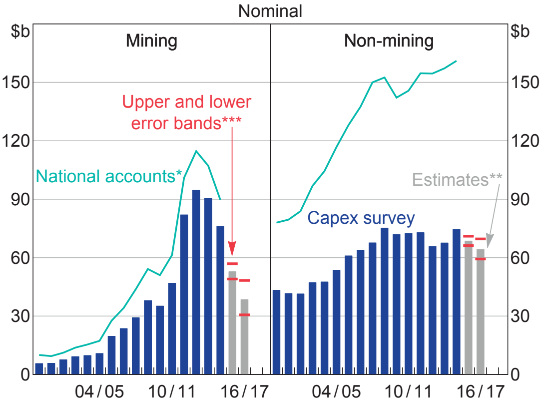
* Adjusted for second-hand asset transfers between the private and other sectors; reference year is 2013/14

** Excluding cultivated biological resources

Sources: ABS; RBA

Graph 3.11
Measures of Private Business Investment

Nominal



* Adjusted for second-hand asset transfers between the private and other sectors; excluding cultivated biological resources

** Estimates are firms' expected capital expenditure, adjusted for the past average difference between expected and realised spending

*** Error bands are based on the root mean square error of each adjusted estimate compared with the final outcome for investment in each year

Sources: ABS; RBA

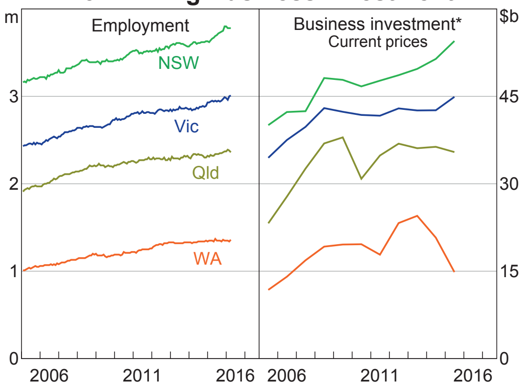
The decline in mining investment is expected to continue over coming years. Few new projects are expected to commence as the global supply of commodities has increased markedly, resulting in a significant fall in bulk commodity prices over recent years and a decline in mining sector profits. The recent rise in commodity prices, even if sustained, is unlikely to lead to additional mining investment over the next two years or so. The ABS capital expenditure (Capex) survey, along with Bank liaison, suggests that the decline in mining investment is likely to continue, although the largest subtraction from GDP growth is expected to be in the current financial year (Graph 3.11). It is likely that, by the end of 2016, the bulk of the decline in mining investment will have occurred; mining investment is currently 4 per cent of nominal GDP, down from its peak of 8 per cent in 2012.

Indicators of investment intentions suggest that non-mining investment will remain subdued for at least the next few quarters. The latest Capex survey continues to imply that a recovery in non-mining investment will not occur in either 2015/16 or 2016/17. Consistent with this, non-residential building approvals remain at relatively low levels, in part reflecting weak underlying conditions in the commercial property market. The estimates from the Capex survey are, however, subject to considerable uncertainty. Moreover, the survey does not cover a large share of non-mining investment that is captured in the national accounts, such as investment in agriculture, education, healthcare or intangible items.

Patterns in non-mining investment spending across the states appear to have varied considerably (Graph 3.12).[1] The direct and indirect effects of conditions in the mining sector on activity in the non-mining sector appear to be quite significant for the resource-rich states of Western Australia and Queensland. The direct effect arises because many non-mining firms provide inputs and support to firms involved in mining investment or resource extraction. There is also an indirect effect, whereby conditions in the mining sector affect economic conditions more broadly, for example via spending of profits, wages and tax revenues

1 Measurement issues suggest that the state-level estimates should be regarded as indicative. For each state, private non-mining business investment is estimated as total private business investment (excluding second-hand asset transfers) less mining investment. Mining investment by state is estimated as the sum of mining capital expenditure on machinery & equipment and buildings & structures (sourced from the Capex survey) and mining exploration expenditure (sourced from the ABS Mineral and Petroleum Exploration survey).

Graph 3.12
Employment and Non-mining Business Investment



* Refer to footnote 1 in the text

Sources: ABS; RBA

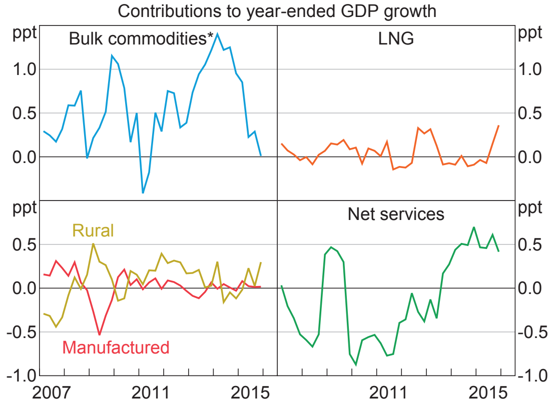
generated in mining and mining-related activities. Hence, declines in commodity prices and mining investment are likely to have had a larger 'knock-on' effect on employment and investment in Western Australia and Queensland. In contrast, in New South Wales and Victoria, which are less resource intensive, the recovery in non-mining business investment appears to have begun, supported by stronger demand growth due to very low interest rates and the depreciation of the Australian dollar over the past few years. Consistent with this, survey measures of business conditions in New South Wales and Victoria are clearly above average, while those in the resource-related states are more subdued.

External Sector

Export volumes rose by 6 per cent over 2015, with strength in resource, service and rural exports. Much of the strength in resource exports was driven by exports of LNG, which are expected to continue to increase substantially over the next couple of years as a number of LNG projects are completed and production capacity increases. Exports of iron ore grew at a more moderate pace over 2015 than they had previously. Iron ore exports are expected to continue to grow over the next couple of years, as production from the large, low-cost producers continues to expand. The recent weakness in coal exports is expected to continue, reflecting weak global demand and the relatively high cost of some Australian production.

Net service exports contributed more to GDP growth over 2015 than exports of bulk commodities, which is the first time this has happened since 2008 (Graph 3.13). This was assisted by the improved competitiveness associated with the depreciation of the Australian dollar. Tourism, education and business service exports have all expanded, while service imports have declined noticeably over the past couple of years, particularly for travel and business services (for more detail, see 'Box A: Australian Services Trade').

Graph 3.13
Exports

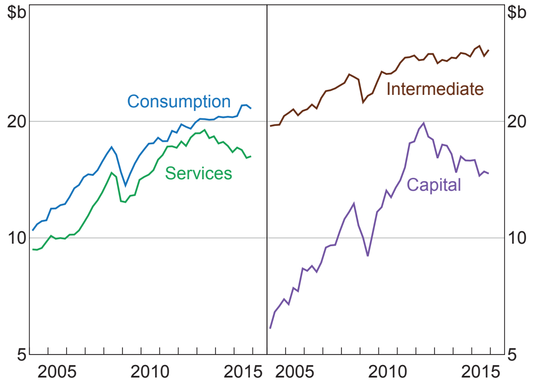


* Iron ore and coal

Sources: ABS; RBA

Overall import volumes increased modestly over 2015, reflecting growth in consumption and intermediate imports (Graph 3.14). The increase in intermediate imports was led by higher fuel import volumes, consistent with the substantial decline in oil prices over 2015. These increases were partly offset by a decline in service import volumes and the downward trend in capital goods imports associated with the decline in mining investment over recent years.

Graph 3.14
Import Volumes*
Log scale, quarterly

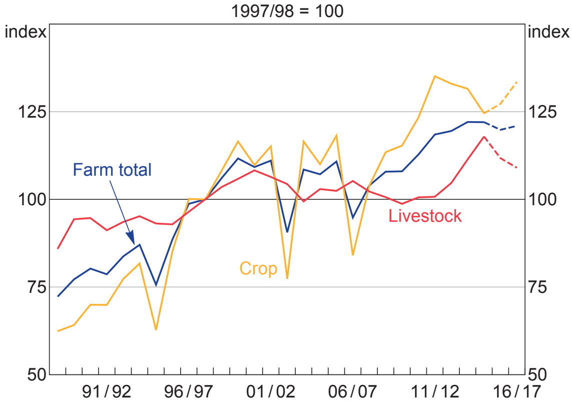


* Reference year is 2013/14
Source: ABS

Farm Sector

The Australian Bureau of Agricultural and Resource Economics and Sciences expects the volume of farm production to decline modestly in 2015/16 (Graph 3.15). Farm production has been supported in recent years by high levels of production from livestock, but these are expected to moderate in 2015/16 as herds are rebuilt; crop production is expected to grow modestly.

Graph 3.15
Farm Production Volumes*
1997/98 = 100

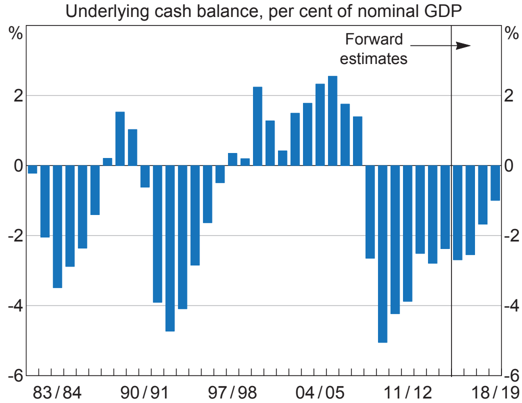


* Dotted lines represents 2015/16 and 2016/17 forecasts
Source: ABARES

Government Sector

Recent federal and state government budgets suggest there will be fiscal consolidation over coming years. Lower-than-expected growth of labour income has led to downward revisions to revenue growth in 2015/16, although this has been offset in part by higher-than-expected growth in stamp duty revenue in some states. The consolidated deficit is projected to be little changed from previous forecasts. In 2016/17, the consolidated deficit is expected to narrow to around 2½ per cent of GDP, and progressively lower deficits are expected in subsequent years (Graph 3.16).

Graph 3.16
Consolidated Budget Balance*
Underlying cash balance, per cent of nominal GDP

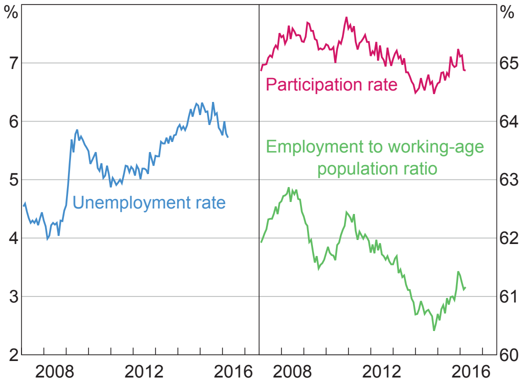


* Based on the 2016/17 Australian Government and Victorian budgets and 2015/16 mid-year updates for the other States and Territories; excludes the effect of the federal grant to the RBA in 2013/14
Sources: ABS; Australian Treasury; State and Territory Treasuries

Labour Market

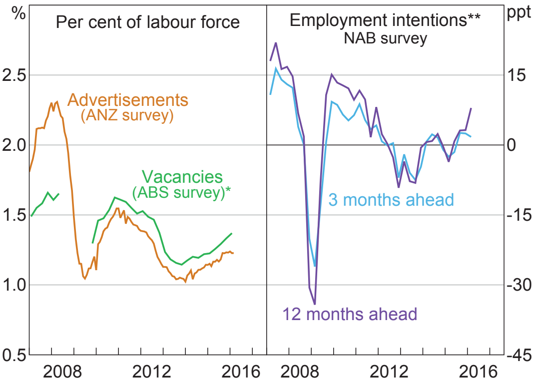
Labour market conditions are noticeably stronger than a year ago, although momentum has eased of late. Employment growth has been a little above its long-run average in year-ended terms, the unemployment rate has been on a downward trend since around mid 2015, and the employment-to-population ratio and participation rate have been on upward trends over the past year or so (Graph 3.17). This improvement has been broad based across part-time and full-time employment. Average hours

Graph 3.17
Labour Market



Source: ABS

Graph 3.18
Labour Market Indicators



* This survey was suspended between May 2008 and November 2009

** Net balance of employment intentions for the following period; deviation from average; 12-months-ahead measure seasonally adjusted by the RBA

Sources: ABS; ANZ; NAB; RBA

Graph 3.19
Employment Growth
Year to February 2016

* Includes personal services; religious, civic, professional and other interest group services; repair and maintenance activities; and private households employing staff

Source: ABS

worked have been little changed. As expected, there has been some moderation in employment growth in early 2016, following very strong employment growth in late 2015. The unemployment rate has remained around 5¾ per cent, about ½ percentage point below its peak in 2015.

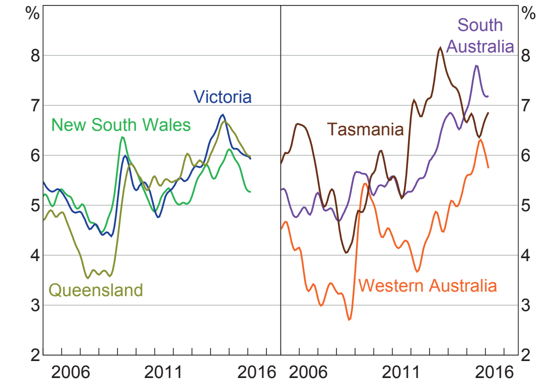
Other labour market indicators also suggest that conditions are better than a year ago, but provide mixed signals about how labour market conditions are likely to evolve in the near term. The NAB survey measures of businesses' hiring intentions remain above their long-run averages and job vacancies have continued to increase as a share of the labour force (Graph 3.18). However, the number of unemployment benefit recipients as a share of the labour force increased slightly in March, after having declined since mid 2015, and job advertisements have levelled out in recent months after a period of relatively consistent increases.

In recent years, the household and business services sectors have made the largest contributions to employment growth. This trend was somewhat reversed in the March quarter, although health & social assistance employment remains much higher than a year ago (Graph 3.19). Employment in a number of business services industries is also higher than a year ago, supported by a range of activities, including strong growth in residential building activity, public infrastructure spending in some states and the increase in service exports following the depreciation of the Australian dollar since 2013. Employment has risen in retail trade, transport, postal & warehousing and construction in recent quarters, consistent with the increased pace of consumption growth and continued dwelling investment.

The improvement in labour market conditions over the past year or so has been concentrated in the eastern states, consistent with other economic activity indicators. Unemployment rates have fallen in New South Wales, Victoria and Queensland (Graph 3.20). In contrast, the unemployment rate in Western Australia has risen over the past few years to be close to the national average in trend terms, after having been well below average during the mining investment boom. The strong growth in services employment over the past year or so has also been concentrated in the eastern states (Graph 3.21). Services employment has declined in Western Australia, reflecting the exposure of business services there to mining investment-related activity. Similarly, goods-related employment has increased a little in New South Wales and Victoria over the past year or so, while it has fallen in Western Australia and Queensland as a result of declining mining and mining-related employment.

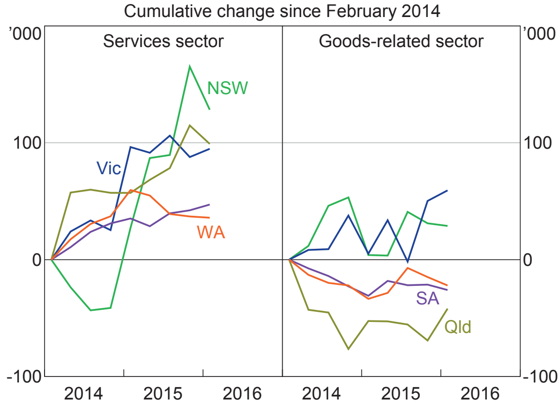
Notwithstanding the improvement in labour market conditions over the past year, there is still evidence of spare capacity. In all states, unemployment rates remain above the lows of recent years and wage growth is still very low (see 'Price and Wage Developments' chapter). ✠

Graph 3.20
Unemployment Rates by State
Trend



Source: ABS

Graph 3.21
Employment by State and Sector*
Cumulative change since February 2014



* Seasonally adjusted using ABS state seasonal factors; does not remove sectoral seasonal patterns

Sources: ABS; RBA

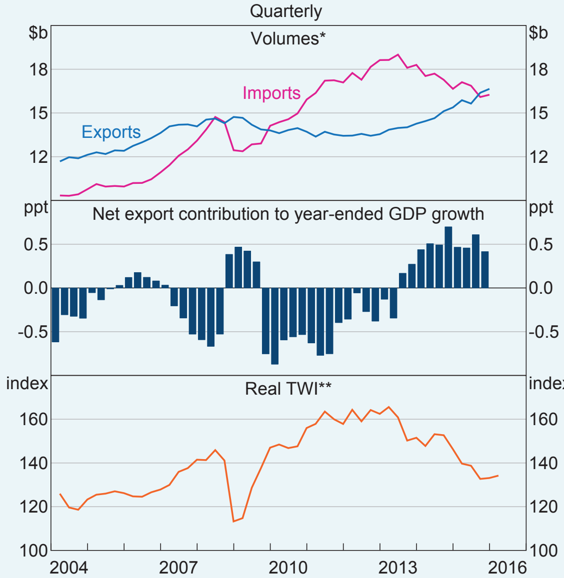
Box A

Australian Services Trade

Net service exports have contributed around ½ percentage point to annual GDP growth in Australia over the past couple of years, reflecting a pick-up in service export volumes and a decline in service imports (Graph A1). This follows a period of about four years during which net service exports subtracted from GDP growth, as service export growth was relatively subdued and service import volumes grew strongly. This Box discusses the key drivers of Australia's service exports and imports since the early 2000s and considers the prospects for net service exports over the coming years.

A range of factors affect Australia's services trade, including global demand for services in the case of exports and domestic demand for services in the case of imports. The exchange rate has also been a key driver. The resources boom in Australia was associated with a large appreciation of the Australian dollar.[1] Over the decade to 2013, this contributed to subdued growth in Australia's service exports, which became relatively more expensive in foreign currency terms. Slower growth in global demand since the financial crisis also played a role. Over the same period, the high level of the exchange rate supported strong growth in service imports to Australia, as they became relatively less expensive compared with domestically produced services.

Graph A1
Services Trade



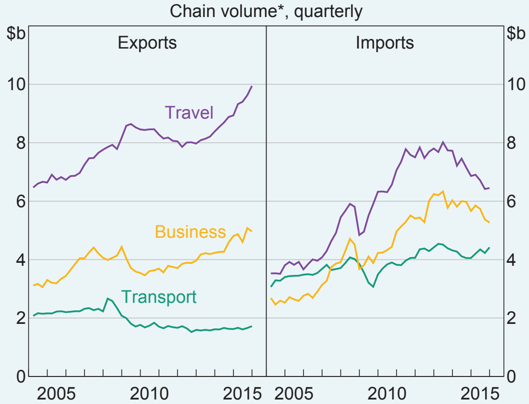
* Reference year is 2013/14
** March 1995 = 100
Sources: ABS; RBA

Since 2013, with the decline in commodity prices and mining investment, and the depreciation of the Australian dollar, these trends in services trade have reversed. Australia's exports of services, including education, tourism and business services, have increased over the past few years, while service imports to Australia have declined noticeably (Graph A2).

Trade in travel services, which includes tourism and education, has been particularly responsive to movements in the exchange rate. Exports of travel services have increased significantly in recent years in line with the substantial increase in visitor

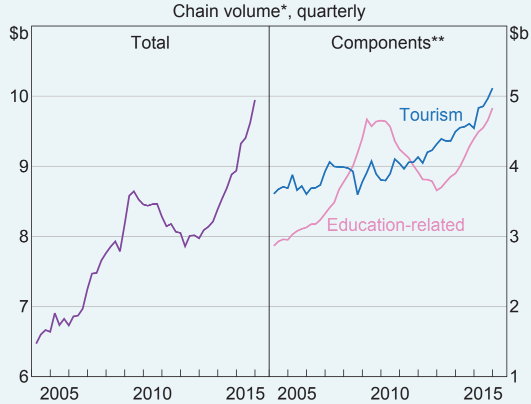
1 The resources boom has had a significant impact on production, demand and prices in Australia. Movements in the Australian dollar are heavily influenced by commodity prices (see Hambur J, L Cockerell, C Potter, P Smith and M Wright (2015), 'Modelling the Australian Dollar', RBA Research Discussion Paper No 2015-12). Large movements in the exchange rate have contributed to the relatively smooth adjustment of the macroeconomy to date. See, for example, Lowe P (2015), 'Managing Two Transitions', Speech at the Corporate Finance Forum, Sydney, 18 May.

Graph A2
Services Trade Components
Chain volume*, quarterly



* Reference year is 2013/14
Source: ABS

Graph A3
Travel Service Exports
Chain volume*, quarterly



* Reference year is 2013/14
** Tourism service exports are travel service exports less education-related exports; education-related exports are seasonally adjusted by RBA
Sources: ABS; RBA

arrivals, particularly from China and east Asia.[2] The spending of foreign visitors in Australia typically responds rapidly to the increase in the purchasing power of foreign currency in Australian dollar terms. The number of visitors appears to adjust more slowly, consistent with the substantial lead time in planning overseas travel. Education exports, which make up around half of travel service exports and capture the expenditure of overseas students studying in Australia, have been a major contributor to growth in travel service exports (Graph A3). While education exports are likely to respond to changes in the exchange rate, they also depend on other factors, such as the perceived quality of educational institutions and changes in migration policies, including requirements for student visas and the ability to use study in Australia as a pathway to permanent migration.[3]

While travel exports have risen substantially over recent years, travel imports have declined by almost as much, as Australians have shifted some of their spending away from international holidays – which have become relatively more expensive – to domestic trips. Growth in the number of Australians travelling internationally has slowed, especially to popular east Asian destinations such as Thailand.[4]

The second largest component of services trade is business services. The depreciation of the Australian dollar has also improved the international competitiveness of Australian business service firms. Consulting, financial and technical services provided by firms in Australia appear to be benefiting from the lower exchange rate, as business service exports have grown steadily in recent years and imports have declined. In the short to medium term, the depreciation is more likely to affect contract-based

2 Travel service exports provide an estimate of spending on goods and services by foreigners while they are in Australia, including tuition fees for international students. International transport fares, together with freight services, are included in transport service exports.

3 For further discussion of the factors affecting demand for education exports, see Productivity Commission (2015), 'Barriers to Growth in Service Exports', Research Report, Canberra. Available at <http://www.pc.gov.au/inquiries/completed/service-exports/report/service-exports.pdf>

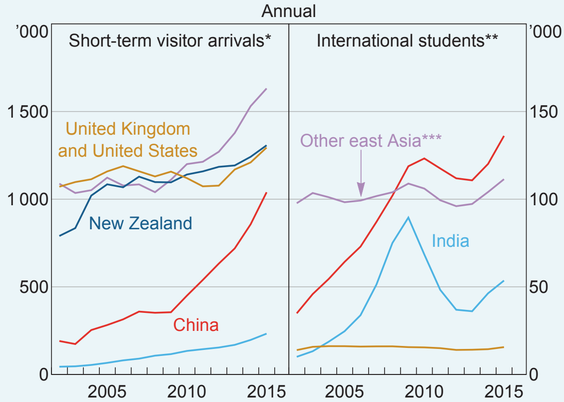
4 For discussion of developments in Australia's tourism industry, with perspectives from the Bank's business liaison program, see Dobson C and K Hooper (2015), 'Insights from the Australian Tourism Industry', RBA *Bulletin*, March, pp 21-31. See also, Tourism Research Australia (2016), 'Travel by Australians: December 2015 Quarterly Results of the National Visitor Survey', March. Available at <http://www.tra.gov.au/research/Travel-by-Australians-December-2015-quarterly-results-of-the-National-Visitor-Survey.html>.

work. However, if the exchange rate remains at lower levels for an extended period, some firms may choose to bring production of services back to Australia that had previously moved offshore to benefit from lower costs.

The east Asian region has been an important source of demand for Australia's service exports. Australia has benefited from its geographical proximity to the expanding middle class in China and the broader east Asian region. The strong growth in service exports to this region over recent years means that east Asia now accounts for about one quarter of Australia's business service exports and almost half of travel service exports. Around half of international students in Australia come from east Asia, and another 10 per cent or so come from India (Graph A4). The increase in travel service exports to the east Asian region has been most dramatic for China; Chinese visitors make up almost 15 per cent of total short-term arrivals, up from less than 5 per cent in the early 2000s.

There is considerable scope for Australian service exports to the Asian region to continue to increase over time. The prospects for further increases in per capita incomes in Asia imply that the demand for Australia's service exports is likely to continue to rise. As households' disposable incomes increase, they tend to consume more services such as education and travel, some of which they will pursue offshore. Similarly, as the region continues to grow, firms in east Asia are likely to demand more business services. Australia is well positioned to capitalise on this demand, although the future growth in Australia's services trade will also depend on the extent of competition, which is likely to be intense, and exchange rate movements, which will affect Australia's price competitiveness.

Graph A4
Visitors and International Students



* Visitors with length of stay less than 12 months; some students are also captured in the short-term arrivals data

** Students studying on an international student visa; New Zealand students do not require a student visa to study in Australia

*** Hong Kong, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan and Thailand

Sources: ABS; Department of Education and Training; RBA

4. Domestic Financial Markets

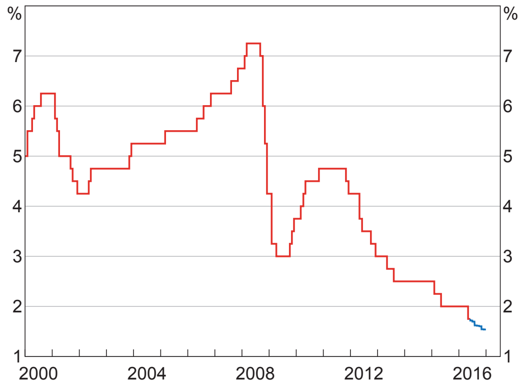
After a period of volatility at the start of the year, driven mainly by concerns about the outlook for the Chinese economy and declines in oil prices, conditions in domestic financial markets have been more stable. The cash rate was reduced at the May Board Meeting, and interest rates on the stock of housing and business loans have declined in response. Yields on paper issued by banks and non-financial corporations remain low. The increase in wholesale funding costs for banks earlier in the year has translated into only a modest pick-up in their average funding costs. Banks have been readily sourcing funding from wholesale markets, while deposit growth has slowed. Housing lending growth eased following the increases in lending rates in 2015 and the measures taken to strengthen lending standards. Business lending rates are at historic lows and business lending has continued to grow strongly. Australian equity prices have risen in recent months from their lows in February, particularly in the resource sector following increases in commodity prices.

Money Markets and Bond Yields

The Reserve Bank Board reduced the cash rate target to 1.75 per cent at its May meeting. Rates on overnight indexed swaps (OIS) suggest an expectation of a further reduction in the cash rate (Graph 4.1). Bank bill rates have also declined, with spreads between these rates and OIS remaining relatively stable.

Yields on long-term Australian Government securities (AGS) remain near historic lows.

Graph 4.1
Cash Rate*



* Data from June 2016 onwards are expectations derived from interbank cash rate futures

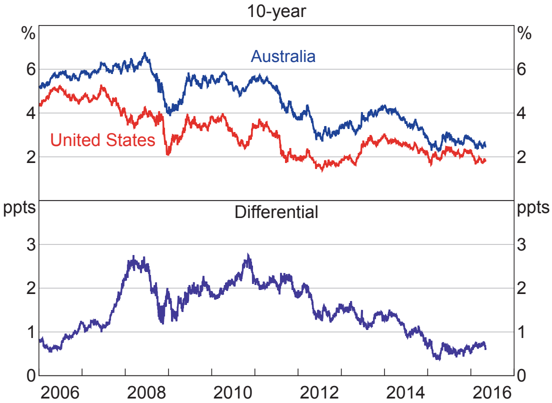
Sources: ASX; Bloomberg

Movements in AGS yields have continued to be largely influenced by movements in US Treasury yields, with the spread between the two remaining broadly steady over the past year or so (Graph 4.2).

The Australian Office of Financial Management has announced plans to issue around $70 billion of AGS in the 2016/17 financial year in net terms, which would see total AGS rise to around $500 billion (30 per cent of GDP) at the end of June 2017.

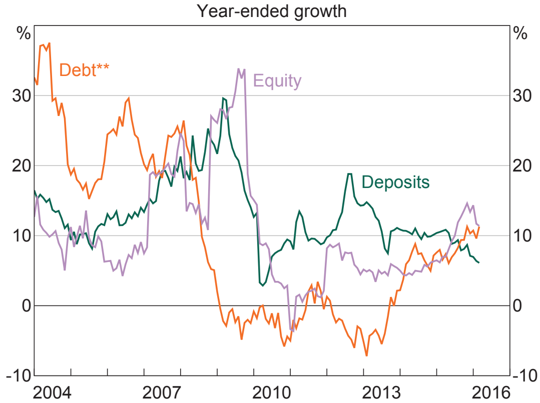
State and territory governments ('semis') have raised around $30 billion in bonds in the current financial year. After taking account of maturities, the total stock of bonds outstanding has declined to $239 billion. An increase in net borrowing by Western Australia was offset by reduced borrowing elsewhere. In early February, Moody's downgraded Western Australia's long-term credit rating by one notch to AA (Standard & Poor's equivalent) with a stable outlook.

Graph 4.2
Government Bond Yields
10-year



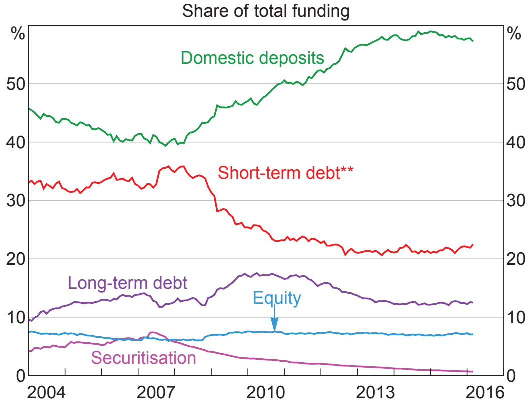
Sources: Bloomberg; RBA

Graph 4.3
Banks' Funding Liabilities*
Year-ended growth



* Adjusted for movements in foreign exchange rates
** Includes long-term debt, short-term debt and securitisation
Sources: APRA; RBA

Graph 4.4
Funding Composition of Banks in Australia*
Share of total funding



* Adjusted for movements in foreign exchange rates; tenor of debt is estimated on a residual maturity basis
** Includes deposits and intragroup funding from non-residents
Sources: APRA; RBA; Standard & Poor's

Bond issuance by non-residents into the domestic market ('Kangaroo' issuance) has totalled around $10 billion since the start of 2016. There has been a modest reduction in issuance over the past year, although a broad range of issuers remain active in the market. Secondary market spreads to AGS on Kangaroo bonds have widened over the past year, consistent with pricing trends in other markets.

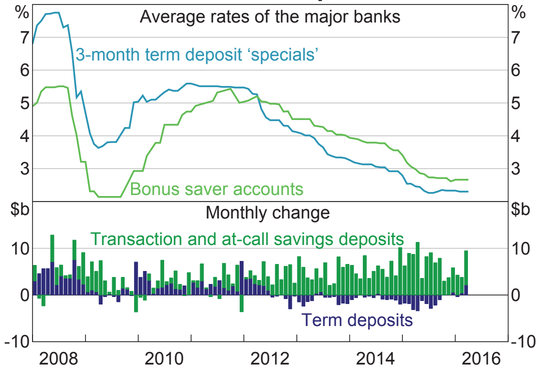
Financial Intermediaries

Banks' balance sheets have continued to grow at a moderate pace. Over the past year, growth in deposits has slowed, while growth in both wholesale and equity funding has picked up noticeably (Graph 4.3). Consistent with this, deposits as a share of total bank funding has declined a little, to around 57 per cent of total funding (Graph 4.4).

Prior to the May cash rate reduction, major banks' average debt funding costs were little changed since November 2015, notwithstanding increases in the cost of new wholesale debt. Funding costs on outstanding short-term wholesale debt are estimated to have risen by around 10 basis points over this period. The cost of new long-term issuance also rose, although it remains below the cost of outstanding issuance. Banks reported that higher wholesale funding costs had also begun to feed through to higher deposit rates, particularly wholesale term deposits. However, there was little pass-through of higher wholesale costs to overall deposit costs, which are estimated to have been little changed in recent months. Over this period, deposit growth slowed, and the business sector switched towards investing in banks' wholesale debt instruments. Household deposit growth remained strong, driven by growth in 'at-call' deposit products, such as offset accounts (Graph 4.5).

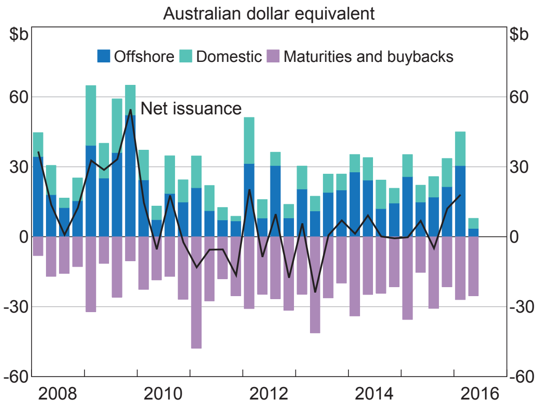
Australian bank bond issuance has been relatively high, with $53 billion in bonds issued since the start of the year (Graph 4.6). After accounting

Graph 4.5
Household Deposits



Sources: APRA; Canstar Cannex; RBA

Graph 4.6
Australian Banks' Bond Issuance*



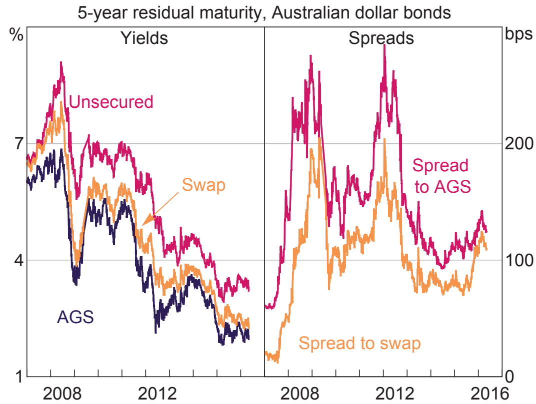
* Latest quarter issuance to date

Source: RBA

for maturities, net bond issuance was around $21 billion and the stock of bank bonds outstanding has increased to $514 billion. Secondary market yields on major banks' bonds have declined since the start of the year; spreads to benchmark rates increased in February amid concerns around banks globally, though the move has since moderated (Graph 4.7).

Australian banks have issued $2.6 billion in Basel III-compliant hybrid securities in 2016, the largest of which was Commonwealth Bank's $1.5 billion Additional Tier 1 hybrid note. The pace of issuance so far this year has been slower than in previous years. Hybrid issues in the secondary

Graph 4.7
Major Banks' Bond Pricing

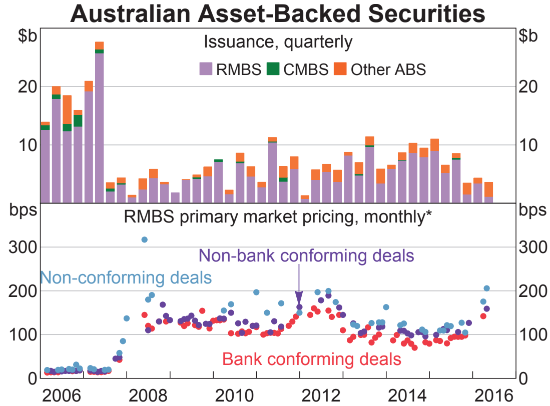


Sources: Bloomberg; UBS AG, Australia Branch

market are generally trading at a spread above the bank bill rate of around 475 basis points, an increase of around 100 basis points over the past year.

After a period of inactivity around the turn of the year, issuers of asset-backed securities have raised around $8 billion in recent months. Deals were backed by a broad range of collateral including conforming mortgages, non-conforming mortgages, automotive loans and equipment leases (Graph 4.8). Consistent with other wholesale funding markets, primary issuance spreads to the bank bill rate have widened compared to similar deals issued late last year.

Graph 4.8
Australian Asset-Backed Securities



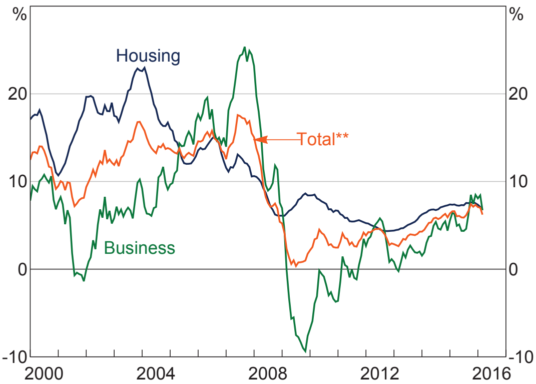
* Face-value weighted monthly average of the primary market spread to bank bill swap rate for AAA rated notes

Source: RBA

Financial Aggregates

Total credit growth has been steady in recent months at around 6 per cent in six-month annualised terms (Graph 4.9). Growth in housing credit has eased a little; business credit growth has continued to grow at a robust pace, notwithstanding some monthly volatility. Credit has been growing at around the same pace as broad money (Table 4.1).

Graph 4.9
Credit Growth by Sector*
Six-month-ended annualised

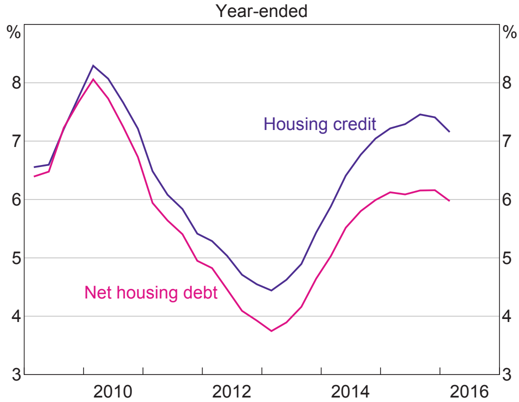


* Seasonally-adjusted and break-adjusted; including securitisation
** Includes housing, personal and business credit
Sources: ABS; APRA; RBA

Household Financing

The pace of housing credit growth has eased in recent months, to around 7 per cent. This follows increases in variable lending rates by most lenders in late 2015 and measures introduced by the Australian Prudential Regulation Authority (APRA) to strengthen lending standards. In particular, loan serviceability criteria have been tightened by lenders, which reduce the amount that some households can borrow. Consistent with these developments, there has been a decline in turnover in the housing market, along with slower growth in the average size of loans. Net housing debt has continued to grow around 1¼ percentage points slower than housing credit due to ongoing rapid growth in deposits in mortgage offset accounts (Graph 4.10). Recent housing loan approvals data suggest that housing credit will continue to grow at about its current pace.

Graph 4.10
Housing Credit Growth*
Year-ended



* Seasonally and break adjusted
Sources: ABS; APRA; RBA

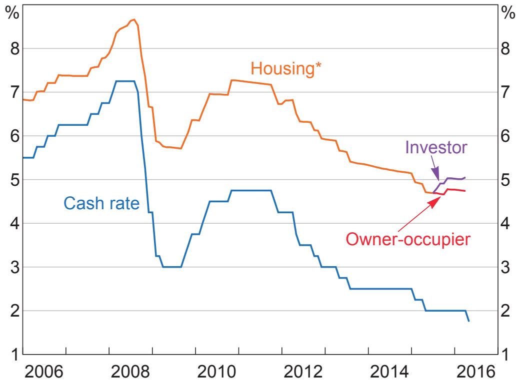
Table 4.1: Financial Aggregates
Percentage change(a)

	Three-month ended		Year-ended
	December 2015	March 2016	March 2016
Total credit	1.6	1.4	6.4
– Housing	1.8	1.5	7.2
– Owner-occupier	2.2	1.7	7.2
– Investor	1.1	1.3	7.0
– Personal	–0.4	–0.7	–1.0
– Business	1.6	1.7	6.5
Broad money	1.3	1.8	6.3

(a) Growth rates are break adjusted and seasonally adjusted
Sources: APRA; RBA

Prior to the May cash rate reduction, the estimated average outstanding housing interest rate had been little changed since lenders increased interest rates in the second half of 2015 (Graph 4.11). Following the May rate reduction, banks have lowered their standard variable rates by 19–25 basis points.

Graph 4.11
Interest Rates



* Estimated outstanding rate prior to the May cash rate reduction.
Sources: ABS; APRA; Perpetual; RBA

More broadly, there are signs that competition for both owner-occupier and investor loans is intensifying. New loans are typically benchmarked to standard variable rates, with lenders then offering discounts below these rates. Over recent months, interest rate discounts for new owner-occupier loans have increased and may be offsetting some of the increase in standard variable rates last year. Discounts for investors on variable-rate housing loans were reduced substantially last year but have increased in recent months. Fixed interest rates for housing loans continue to be priced competitively and, consistent with this, a higher share of mortgages has been taken out with fixed interest rates (Table 4.2).

Since the introduction of differential pricing for investor and owner-occupier lending by most major banks in the second half of 2015, growth in investor lending has slowed considerably, while growth in owner-occupier lending has accelerated. As noted previously, a large number of borrowers have contacted their existing lender to change the purpose of their loan, while there has also been a surge in owner-occupier refinancing and a drop in investor refinancing with different lenders.

Business Financing

Business credit has continued to grow strongly over recent months. This partly reflects a re-intermediation of business debt, with businesses engaging in less bond issuance. There has also been a slow-down in equity raisings.

The strength in business credit has been broad based across lending to both private non-financial corporations and unincorporated (typically smaller) businesses. The recent pace of business credit growth is consistent with business loan approvals which remain at a relatively high level. Foreign banks have increased their market share to around 15 per cent over the past year. The local operations of Japanese, Chinese and Singaporean institutions have driven the increase in business lending by foreign banks.

Prior to the May cash rate reduction, the estimated average outstanding cost of business borrowing had risen slightly in recent months, reflecting higher variable rates, alongside increases in rates for products linked to market interest rates (Graph 4.12). Lenders, including the major banks, raised average advertised variable rates on small business loans by around 15 basis points. Competition for large business lending has contributed to a narrowing of bank margins on these loans in recent years although this appears to have stabilised recently.

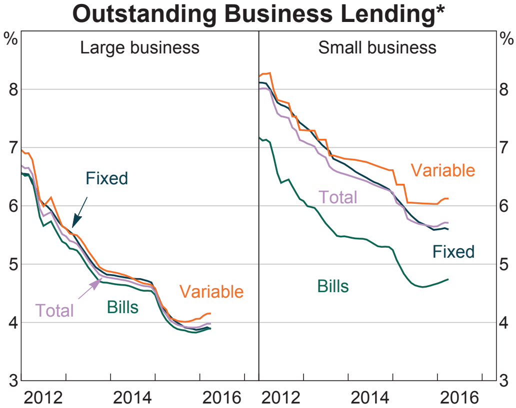
Australian corporate bond issuance for the year to date has totalled $5 billion, which is low compared to recent years. While secondary market corporate bond yields remain low for issuers outside the resource sector, spreads have risen over the past couple of years. For resource-related issuers, yields increased sharply in February, but have eased back as commodity prices have recovered (Graph 4.13).

Table 4.2: Intermediaries' Fixed and Variable Lending Rates
Prior to the May Cash Rate Reduction

	Interest rate Per cent	Change since January 2016 Basis points	Change since July 2015 Basis points
Housing loans			
– Standard variable rate[(a)(d)]			
– Owner-occupier	5.63	0	17
– Investor	5.87	–3	41
– Package variable rate[(b)(d)]			
– Owner-occupier	4.83	0	16
– Investor	5.07	–4	40
– Fixed rate[(c)(d)]			
– Owner-occupier	4.43	0	–23
– Investor	4.66	–4	–43
– Average outstanding rate[(d)]	4.85	–1	16
Personal loans			
– Variable rate[(e)]	11.40	9	19
Small business			
– Term loans variable rate[(f)]	6.75	15	15
– Overdraft variable rate[(f)]	7.63	15	15
– Fixed rate[(c)(f)]	5.42	–1	4
– Average outstanding rate[(d)]	5.71	6	–1
Large business			
Average outstanding rate[(d)]	3.98	5	2

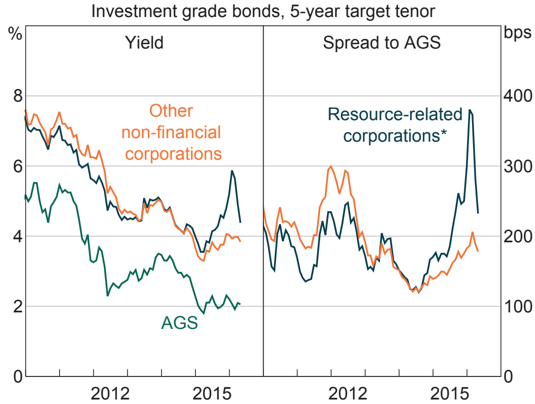
(a) Average of the major banks' standard variable rates
(b) Average of the major banks' discounted package rates on new, $250 000 full-doc loans
(c) Average of the major banks' 3-year fixed rates
(d) RBA estimates
(e) Weighted average of variable rate products
(f) Residentially secured, average of the major banks' advertised rates
Sources: ABS; APRA; Canstar Cannex; RBA

Graph 4.12
Average Interest Rates on Outstanding Business Lending*



* RBA estimates; prior to the May cash rate reduction
Sources: APRA; RBA

Graph 4.13
Australian Corporate Bond Pricing
Investment grade bonds, 5-year target tenor



* Includes Origin Energy
Sources: Bloomberg; RBA; S&P Capital IQ

The relatively weak conditions in the resource sector have led to ratings downgrades for several Australian firms. Since the start of the year, 19 resource-related firms, including BHP Billiton and Rio Tinto, have had their credit ratings downgraded or been placed on review for downgrade by the major ratings agencies.

Equity raisings by non-financial corporations (including real estate companies) have been relatively small so far this year. Raisings by corporations that are already listed have been low, though this follows a number of large equity raisings in the second half of last year. There have been only a limited number of initial public offerings.

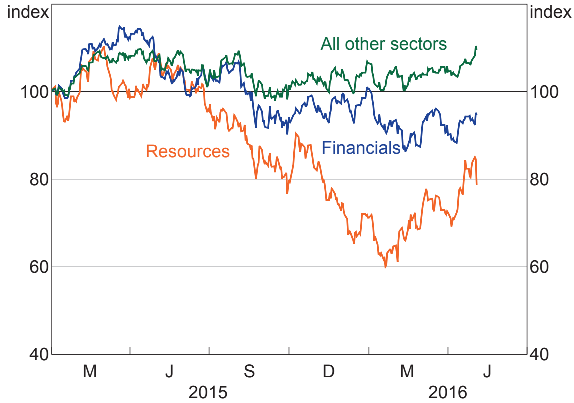
Mergers and acquisitions (M&A) activity in recent months has included the $9 billion takeover bid for Asciano by a consortium of investors including Qube Holdings and Brookfield, which was accepted in March. Excluding this deal, other M&A activity has totalled around $7 billion since the start of the year, which is below the average seen in recent years.

Equity Markets

The Australian equity market has risen from its lows in February, supported by large increases in resource sector share prices and a more recent recovery in financial sector share prices (Graph 4.14). Nevertheless, financials have underperformed the broader Australian market, which is slightly lower than at the start of the year.

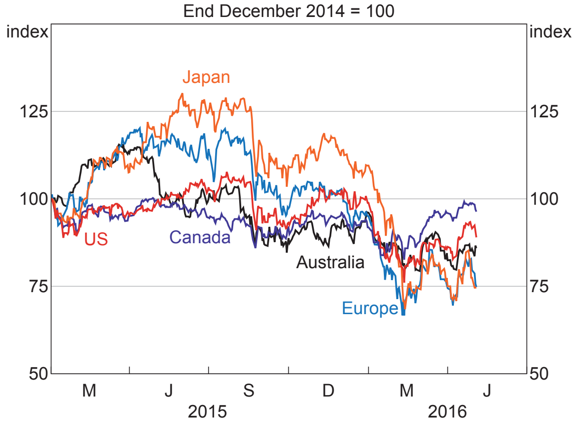
Financial sector share prices have traded in a wide range since the start of the year; bank share prices have fallen by 11 per cent over this period. Falls in global banking stocks amid increased concerns about bank profitability have been a factor, as has been the evidence of a levelling out in housing activity in Australia and signs of financial vulnerability in the resource sector (Graph 4.15). The latter has raised concern about the potential for a rise in bad debts. Against this backdrop, short selling of the major banks and their credit default swap (CDS) premia have increased.

Graph 4.14
Australian Share Price Indices
End December 2014 = 100



Source: Bloomberg

Graph 4.15
Banks' Share Prices
End December 2014 = 100



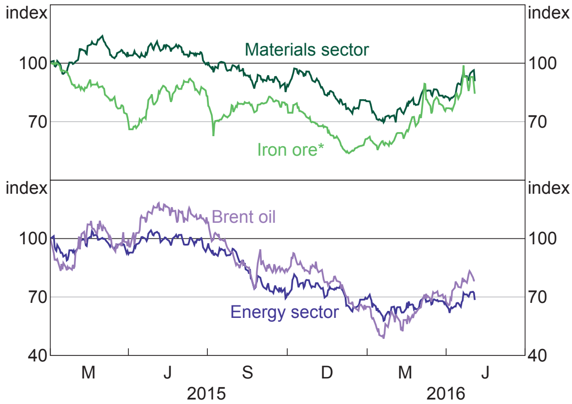
Sources: Bloomberg; RBA

Materials sector share prices have risen alongside a substantial increase in iron ore prices over recent months; energy sector share prices have also risen, albeit by less than oil prices (Graph 4.16). Equity prices for companies outside the financial and resource sectors have been mixed: share prices for consumer staples have fallen while industrials stocks have increased substantially.

Analyst earnings expectations for 2015/16 and 2016/17 have been revised lower since the start of the year, particularly for the resource sector. Analysts expect no earnings growth in the other sectors this financial year.

Graph 4.16
Resources Share Prices and Commodity Prices

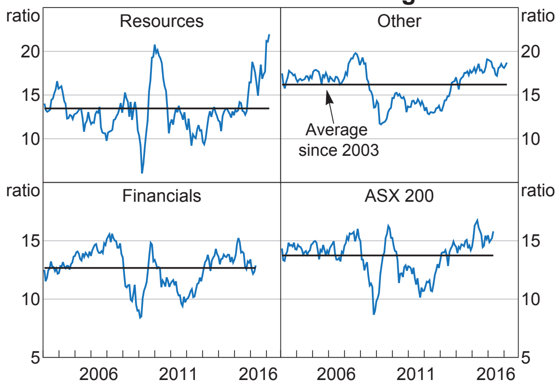
End December 2014 = 100



* Qingdao import iron ore spot price

Sources: Bloomberg; RBA

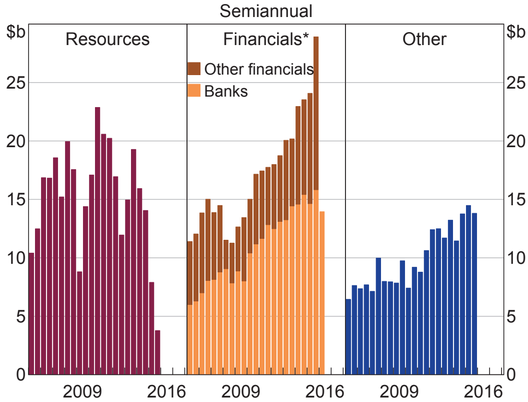
Graph 4.17
ASX 200 Forward Price-earnings Ratios



Source: Thomson Reuters

Graph 4.18
ASX 200 Underlying Profits

Semiannual



* The June 2016 half observation for banks is based on reported results during the half and consensus expectations for companies that have not yet reported

Sources: Bloomberg; Morningstar; RBA

Valuations of Australian equities, as measured by forward price-earnings ratios, remain around or above their long-term averages across all broad sectors (Graph 4.17). Financial sector valuations have declined amid lower bank share prices. The sharp rise in resource sector valuations reflects the combination of higher equity prices and lower earnings expectations; the range of analysts' earnings expectations for the resource sector has been unusually wide recently.

ASX 200 companies reported their December half 2015 results in February. Aggregate underlying profits declined by 8 per cent from the same period last year, reflecting a sharp fall in resource sector profits (Graph 4.18).

Resource sector profits were around 70 per cent lower than the same period last year, largely tracking lower commodity prices. The decline in profits was partly offset by extensive cost-cutting (including further capital expenditure reductions) and the depreciation of the Australian dollar, which lowered production costs for the major miners that report in US dollars. Many resource companies also recorded sizeable asset impairments as commodity price assumptions were revised downward.

Financial companies reported a large increase in underlying profits in the December half driven by real estate and diversified financial companies. Profits of real estate companies were supported by sizeable revaluation gains, as well as heightened activity in the residential property market.

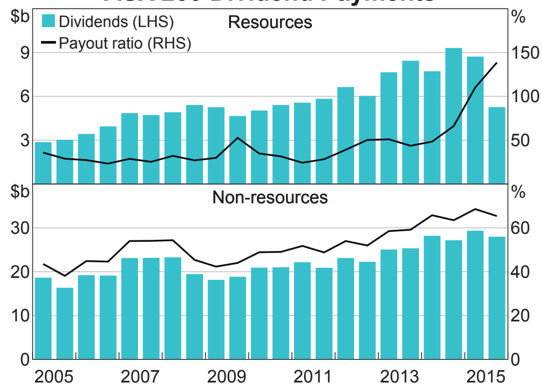
Banks reported lower underlying profit in the half year to March compared with the same period in the previous year. Net interest income was supported by growth in interest-earning assets. Net interest margins for the major banks were little changed, with higher interest rates on housing lending offset by competition in business lending markets. Bad and doubtful debt charges increased, primarily driven by a relatively small number of exposures including to businesses in the resources sector and in Asia.

Underlying profits for companies outside the resource and financial sectors were generally higher in the December half. Industrial sector profits increased substantially, supported by transportation companies which benefited from lower oil prices. In contrast, companies in the consumer staples and discretionary sectors reported lower profits in aggregate, weighed by mixed performance across the major supermarkets and lower earnings from consumer service companies.

Reflecting the decline in profits, aggregate shareholder distributions fell by almost 10 per cent in the December half 2015 from the same period last year, and the payout ratio – the ratio of dividends to earnings – remained unchanged. Much of the decline in dividends was attributable to resource companies, which substantially reduced their dividend payments in order to preserve cash and reduce leverage (Graph 4.19). In particular, the major diversified miners both shifted from progressive dividend policies to more flexible regimes. Nonetheless, the payout ratio for the resource sector increased to over 100 per cent reflecting the sharp fall in earnings.

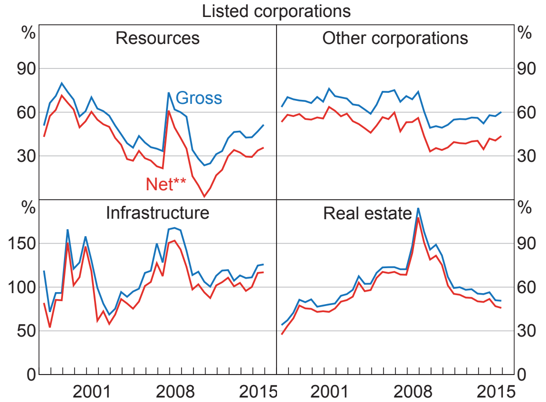
Listed corporations balance sheets expanded by 1 per cent over the December half 2015, largely driven by acquisitions outside the resource sector (Graph 4.20). The increase in assets was largely funded by debt, while aggregate equity declined slightly. As a result, the gross book value gearing ratio (the ratio of debt to equity) rose by 3 percentage points to 59 per cent. ✠

Graph 4.19
ASX 200 Dividend Payments



Sources: ASX; Morningstar; RBA

Graph 4.20
Gearing Ratios by Sector*
Listed corporations



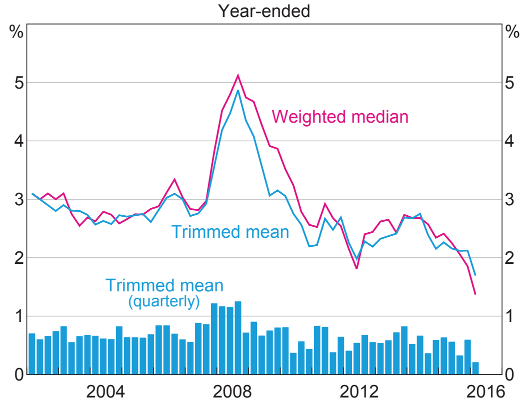
* Excludes foreign-domiciled companies listed on the ASX
** The net gearing ratio is total debt less cash divided by total equity
Sources: Bloomberg; Morningstar; RBA

5. Price and Wage Developments

Recent Developments in Inflation

Inflation was low in the March quarter. Measures of underlying inflation declined to a little less than ¼ per cent in the March quarter, to be around 1½ per cent over the year (Table 5.1 and Graph 5.1). The headline consumer price index (CPI) fell by 0.1 per cent (in seasonally adjusted terms) to be 1.3 per cent higher over the year, partly reflecting a decline in fuel prices (Graph 5.2). The March quarter inflation data were lower than the forecast in the February *Statement*. Although some temporary factors contributed to the low result, the data indicate that there has been broad-based weakness in domestic cost pressures, reflecting low wage

Graph 5.1
Measures of Underlying Inflation
Year-ended



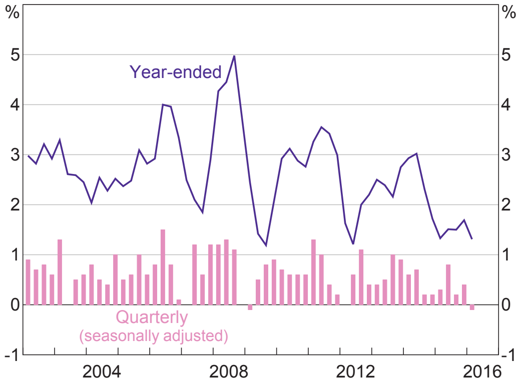
Source: ABS

Table 5.1: Measures of Consumer Price Inflation
Per cent

	Quarterly[a]		Year-ended[b]	
	March quarter 2016	December quarter 2015	March quarter 2016	December quarter 2015
Consumer Price Index	–0.2	0.4	1.3	1.7
Seasonally adjusted CPI	–0.1	0.4		
– Tradables	–0.7	0.3	0.6	0.8
– Tradables (excl. volatile items and tobacco)[c]	0.1	0.6	0.5	0.8
– Non-tradables	0.2	0.4	1.7	2.3
Selected underlying measures				
Trimmed mean	0.2	0.6	1.7	2.1
Weighted median	0.1	0.4	1.4	1.9
CPI excl. volatile items[c]	0.2	0.7	1.7	2.1

(a) Except for the headline CPI, quarterly changes are based on seasonally adjusted data; those not published by the Australian Bureau of Statistics (ABS) are calculated by the RBA using seasonal factors published by the ABS
(b) Year-ended changes are based on non-seasonally adjusted data, except for the trimmed mean and weighted median
(c) Volatile items are fruit, vegetables and automotive fuel
Sources: ABS; RBA

Graph 5.2
Consumer Price Inflation

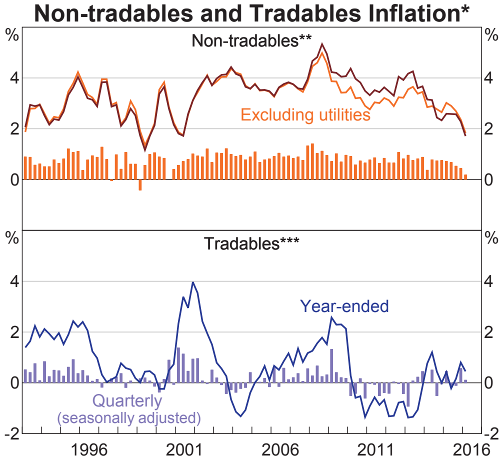


Source: ABS

growth, heightened retail competition, softer conditions in rental and housing construction markets and declines in the cost of business inputs such as fuel and utilities. This has been partly offset by some upward pressure on the prices of tradable items following the depreciation of the Australian dollar over the past few years.

Non-tradables inflation declined further in the March quarter and, in year-ended terms, was around its lowest level since the late 1990s (Graph 5.3). Most components of non-tradables

Graph 5.3
Non-tradables and Tradables Inflation*



* Adjusted for the tax changes of 1999–2000

** Excluding interest charges prior to the September quarter 1998 and deposit & loan facilities to June quarter 2011

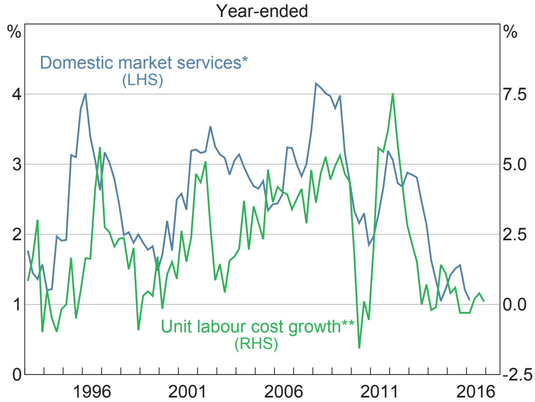
*** Excluding volatile items (fruit, vegetables and automotive fuel) and tobacco

Sources: ABS; RBA

inflation were well below their inflation-targeting averages. Market services inflation was particularly low, consistent with low growth in unit labour costs (Graph 5.4). Residential rent inflation was also very low across capital cities (Graph 5.5). Inflation in the cost of new dwellings has also declined over the past few quarters, following a period of higher inflation. Outcomes for housing inflation (including rents and the cost of new dwellings) have been particularly low in Perth, consistent with weaker demand for housing following the end of

Graph 5.4
Market Services Inflation

Year-ended

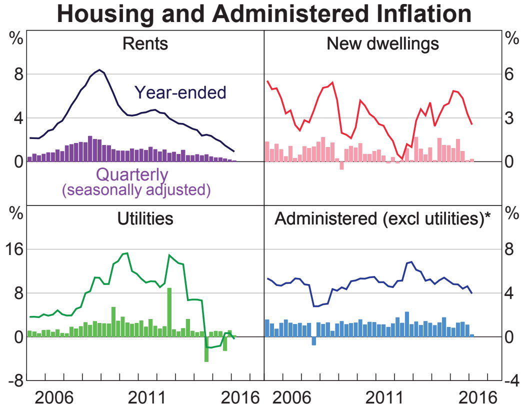


* Excludes deposit & loan facilities to June quarter 2011, housing services and domestic travel; adjusted for the tax changes of 1999–2000

** Non-farm, moved forward by four quarters

Sources: ABS; RBA

Graph 5.5
Housing and Administered Inflation



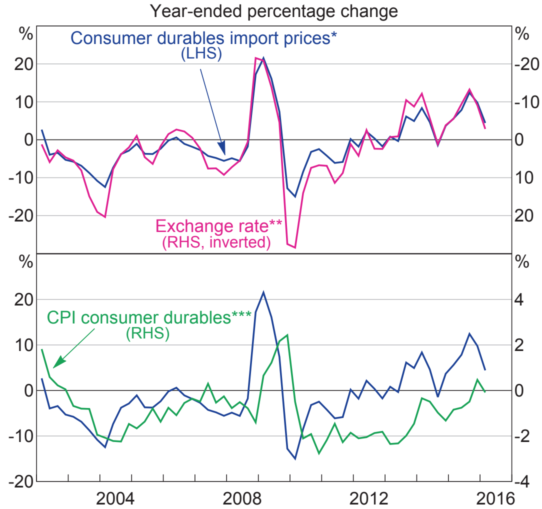
* Includes education, child care, health services, property rates, urban transport fares, postal services, some motor vehicle services and pharmaceutical products

Sources: ABS; RBA

the mining investment boom and the large fall in commodity prices over recent years. Inflation in items with administered prices was also low in the quarter; urban transport fares, education and pharmaceutical prices all declined (in seasonally adjusted terms), in part due to temporary factors.

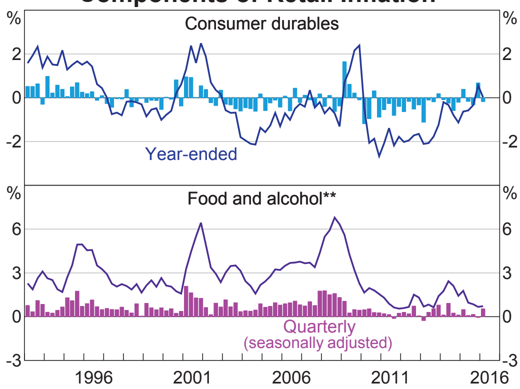
The prices of tradable items (excluding volatile items and tobacco) were little changed in the March quarter and were 0.5 per cent higher over the year. The final prices of tradable items are influenced by external factors as they are exposed to international trade via imports and exports. The substantial depreciation of the exchange rate over the past few years has increased import and export prices in Australian dollar terms, placing upward pressure on the final prices of tradable items (Graph 5.6). On the other hand, low wage growth and heightened retail competition have placed downward pressure on retail prices. The net effect has been subdued inflation in consumer durables, following price falls for several years, and continued subdued inflation in food and alcohol (Graph 5.7).

Graph 5.6
Consumer Prices and the Exchange Rate
Year-ended percentage change



* Consumption goods (excluding food and beverages), reweighted using CPI weights
** Import-weighted index, quarter average
*** Retail items (excluding food and alcohol)
Sources: ABS; RBA

Graph 5.7
Components of Retail Inflation*

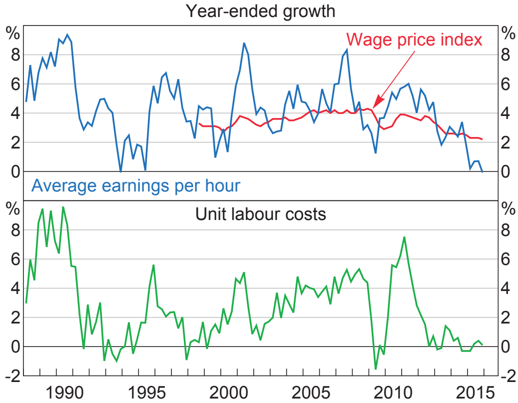


* Adjusted for the tax changes of 1999–2000
** Excluding fruit, vegetables, and meals out and take away foods
Sources: ABS; RBA

Labour Costs

Labour cost pressures remain weak. The wage price index (WPI) increased by 0.5 per cent in the December quarter, to be 2.2 per cent higher over the year (Graph 5.8). Average earnings per hour from the national accounts (AENA) – which captures a broader range of payments to labour as well as the effect of changes in the composition of employment – declined in the December quarter and was little changed over the year. This growth is comparable to the period of weakness in the early to mid 1990s at a time of considerably higher unemployment.

Graph 5.8
Labour Costs
Year-ended growth

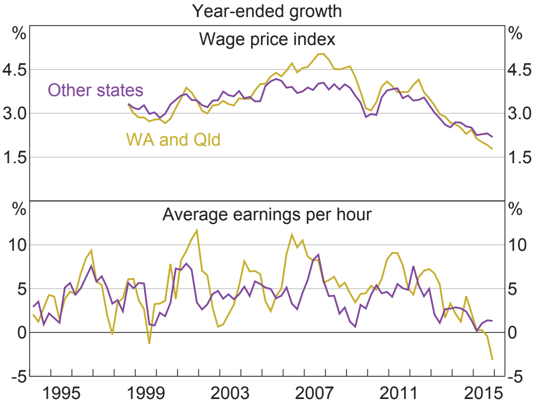


Sources: ABS; RBA

Growth in AENA has been much weaker than WPI growth over the past year, as was the case in previous episodes of declining wage growth. Most of the decline in earnings growth of late appears to have been driven by changes that are occurring within industries, rather than shifts in employment between industries. One factor contributing to this is the movement of some workers from high-paying jobs in mining-related activities to similar work in lower-paying positions in the non-mining economy. For example, liaison suggests that many workers employed in construction during the investment phase of the mining boom have returned to jobs in civil and residential construction at lower wage rates. In addition, liaison suggests that spare capacity in the labour market more generally is allowing firms to replace workers who leave their jobs with new employees on lower salaries, while promotion rates may also be below average. Low growth in AENA may also reflect changes in non-wage payments. For example, liaison suggests that firms have been able to reduce allowances for travel and accommodation.

Wage growth is low in all states and industries (see 'Box B: Wage Developments by Industry' for further detail). Nevertheless, the largest declines in wage growth over recent years have taken place in the mining states, where wage growth had previously been above the national average for some time (Graph 5.9). AENA has fallen more sharply relative to the WPI in the mining states, consistent with compositional change in employment and weakness in non-wage payments being most pronounced in those states.

Graph 5.9
Labour Costs
Year-ended growth



Sources: ABS; RBA

Low wage growth is consistent with a degree of spare capacity in the labour market. However, wage growth has been lower than implied by its historical relationship with the unemployment rate. Several factors may have contributed to this, including the decline in inflation expectations over recent years and the significant fall in the terms of trade, which implies a decline in national income.[1] Increased labour market flexibility over the past few decades may have also provided firms with greater scope to adjust wages in response to a given change in demand for their goods and services. Moreover, low wage growth has been evident in a range of advanced economies, even where unemployment rates have fallen significantly (see 'International Economic Developments' chapter).

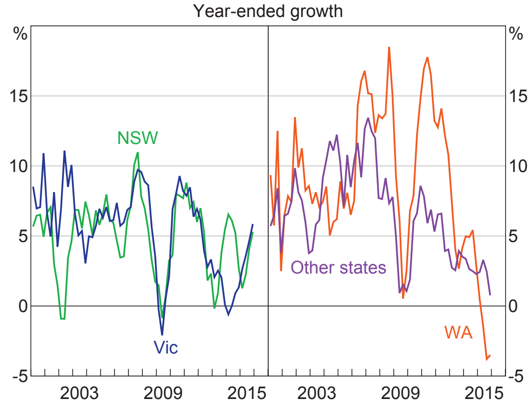
Firms' unit labour costs have been little changed for around four years, as any growth in average earnings per hour has been broadly matched by growth in labour productivity (output per hour worked). Together with the depreciation of the nominal exchange rate over recent years, low unit labour cost growth is helping to improve the international competitiveness of Australia's labour, following a period of relatively strong growth in unit labour costs.

1 For a more detailed discussion of these factors, see Jacobs D and A Rush (2015), 'Why is Wage Growth So Low?', RBA *Bulletin*, June Quarter, pp 9–18.

While low wage growth has directly contributed to low growth in household disposable income, lower growth in labour costs may have encouraged firms to employ more people than otherwise, thereby supporting growth in overall household spending. Growth in total compensation of employees – which reflects growth in both earnings and the number of employees – has picked up to around its long-run average in New South Wales and Victoria over the past year (Graph 5.10). In contrast, compensation of employees declined in Western Australia over 2015, after growing strongly during the mining investment boom, and growth has been low in the other states over recent years.

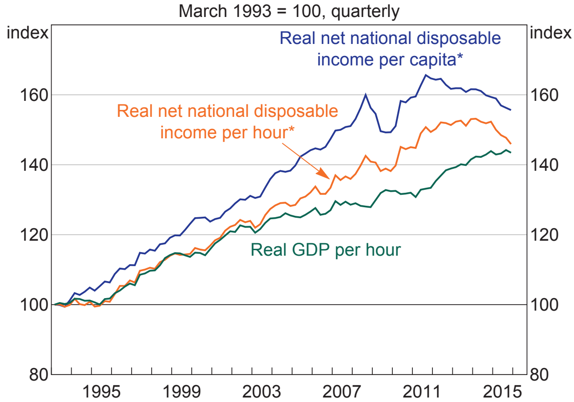
A broader indicator of living standards is net national disposable income (NNDI) per capita. This takes into account changes to national income due to movements in labour productivity, the terms of trade, depreciation of the capital stock and the share of the population in paid employment. NNDI per capita has declined over recent years, after growing relatively strongly during the terms of trade boom (Graph 5.11). The effect of the sharp fall in the terms of trade over 2015 was offset to some extent by an increase in hours worked as the employment-to-population ratio rose, while labour productivity was little changed.

Graph 5.10
Compensation of Employees
Year-ended growth



Source: ABS

Graph 5.11
Productivity and Income
March 1993 = 100, quarterly



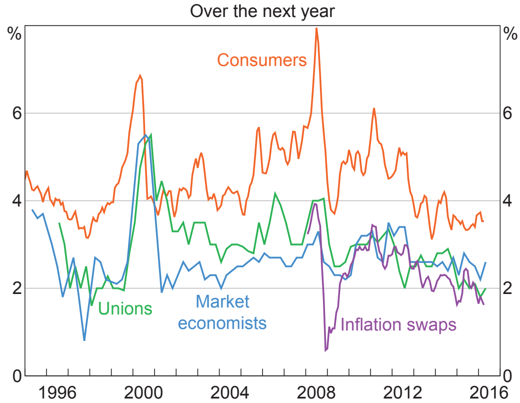
* Real GDP adjusted for the purchasing power effects of changes to the terms of trade, depreciation of the capital stock and net income transfers to the rest of the world

Sources: ABS; RBA

Inflation Expectations

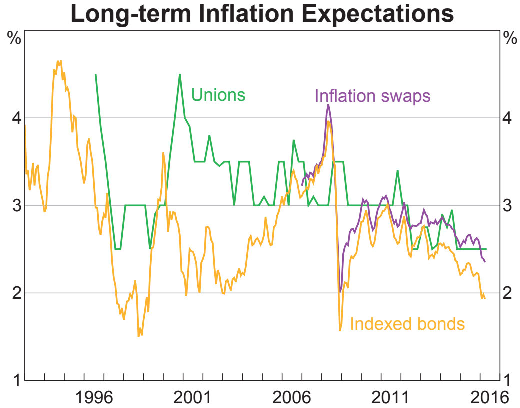
Measures of inflation expectations – from consumers, market economists, union officials and inflation swaps – remain below average (Graph 5.12 and Graph 5.13).[2] Long-term financial market measures of inflation expectations have declined noticeably over the past few months, although they may have been affected by other developments in financial markets. The expectations of consumers and market economists have been little changed over the past year or so. Unions' short-term inflation expectations have declined of late, but their longer-term expectations remain anchored at 2½ per cent. Inflation expectations in Australia have not fallen to the same extent as they have in a range of other advanced economies (see 'International Economic Developments' chapter). ✠

Graph 5.12
Short-term Inflation Expectations
Over the next year



Sources: Australian Council of Trade Unions; Bloomberg; Melbourne Institute of Applied Economic and Social Research; RBA; Workplace Research Centre

Graph 5.13
Long-term Inflation Expectations



Sources: Australian Council of Trade Unions; Bloomberg; RBA; Workplace Research Centre; Yieldbroker

2 Of the short-term measures: the series for consumer expectations is the three-month moving average of the trimmed mean of individuals' inflation expectations over the next year; union expectations are the median of union officials' expectations of inflation over the next year; market economist expectations are the median of market economists' expectations of inflation over the next year; inflation swap expectations are those implied by one-year zero-coupon inflation swaps. Of the long-term measures: union expectations are the median of union officials' expectations of inflation on average over the next five to 10 years; inflation swap expectations are those implied by 10-year zero-coupon inflation swaps; the series for indexed bonds is the break-even 10-year inflation rate on indexed bonds (where interpolation is used to match exact maturity).

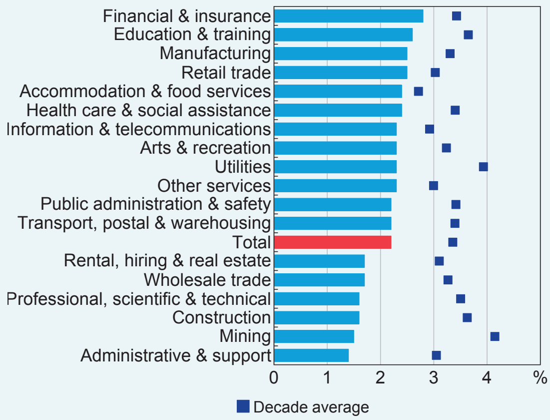
Box B

Wage Developments by Industry

As discussed in the 'Price and Wage Developments' chapter, wage growth in Australia has been very low, and lower than implied by its historical relationship with the unemployment rate. Wage growth is well below its decade average in all industries, and dispersion across industries is around its lowest level since the late 1990s when the wage price index (WPI) began (Graph B1 and Graph B2).

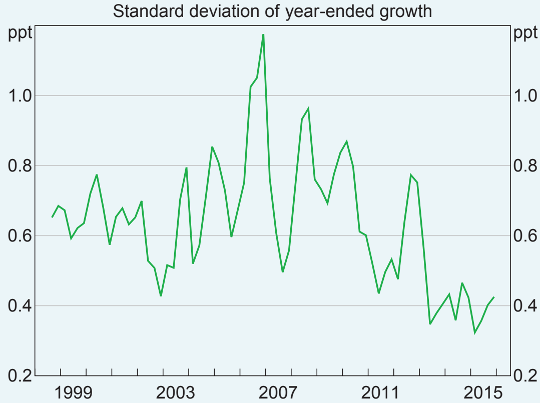
While wage growth is low in every industry, it is currently lowest in industries that are more exposed to the end of the mining investment boom, such as mining, construction and administrative & support services (which include labour hire companies that provide a range of workers – such as construction labourers, truck drivers and administrative assistants – to mining and mining-related firms). In addition, wage growth has been relatively weak in professional, scientific & technical services, and rental, hiring & real estate services, which also include firms that support the mining industry.

While these industries have experienced wage growth below the national average of late, this follows a period of above-average wage growth for many of them during the mining investment boom. The overall level of earnings in the mining, construction and professional, scientific & technical service industries (based on average weekly earnings data) appears to have risen somewhat relative to the national average since the mid 2000s (Graph B3).[1] In contrast, the level of earnings in the rental, hiring & real estate industry has fallen relative



* Wage price index; total uses seasonally adjusted data

Source: ABS

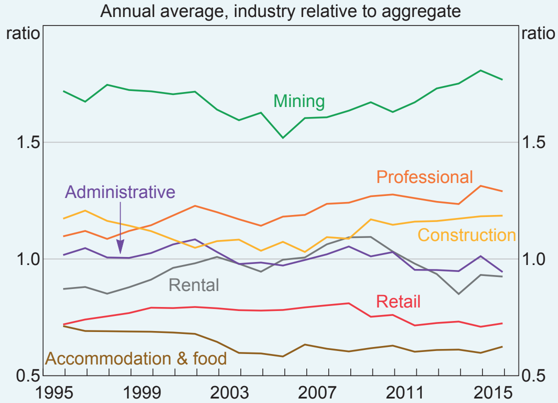


* Wage price index

Sources: ABS; RBA

1 The average weekly earnings series is designed to estimate the level of wages, rather than the change over time. It is affected by compositional change in employment unlike the WPI, which holds the quality and quantity of labour constant. See Australian Bureau of Statistics (2014), 'Feature Article: Average Weekly Earnings and Wage Price Index – What Do They Measure?', *Average Weekly Earnings*, May.

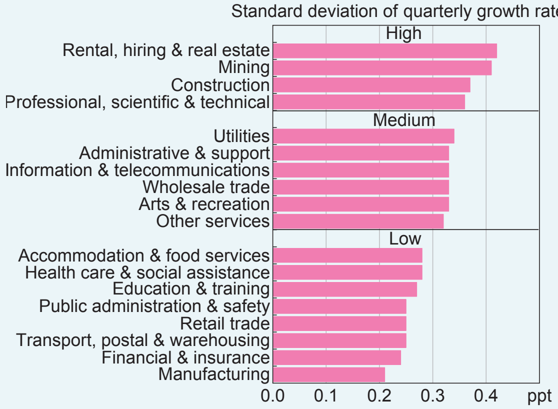
Graph B3
Average Hourly Earnings*
Annual average, industry relative to aggregate



* Average weekly earnings divided by average weekly hours worked

Source: ABS

Graph B4
Wage Growth Volatility
Standard deviation of quarterly growth rates*



* Wage price index; seasonally adjusted; since series began in 1997

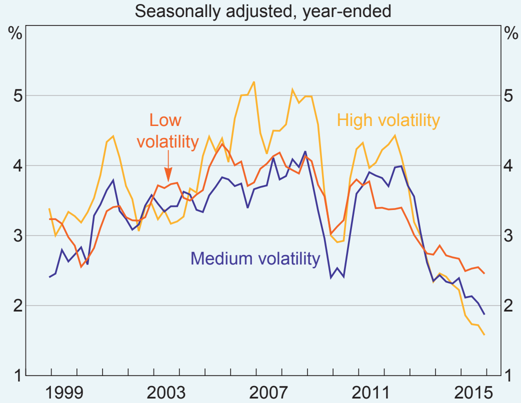
Sources: ABS; RBA

to the national average. Wage relativities have been more stable for most other industries.

Most of the industries that have experienced relatively low wage growth recently also experience more volatile wage growth (from quarter to quarter) than other industries over time (Graph B4 and Graph B5). It is unclear to what extent this volatility reflects: the nature of wage setting in these industries; the possibility that these industries are more cyclically sensitive than others; and/or the possibility that they have just been affected by the largest changes in labour demand and supply associated with the rise and fall of mining investment.

Wage growth has generally been higher in industries where employment growth has been stronger of late, with a few notable exceptions (Graph B6). For example, while wage growth has been weak in administration & support services, employment in the industry rose quite strongly in 2015. Liaison suggests that the wages in labour hire companies, which fall into this category, have declined as there has been a shift in demand for their workers from mining-related businesses that paid relatively high wages to other firms that pay

Graph B5
Wage Growth by Industry Group*
Seasonally adjusted, year-ended

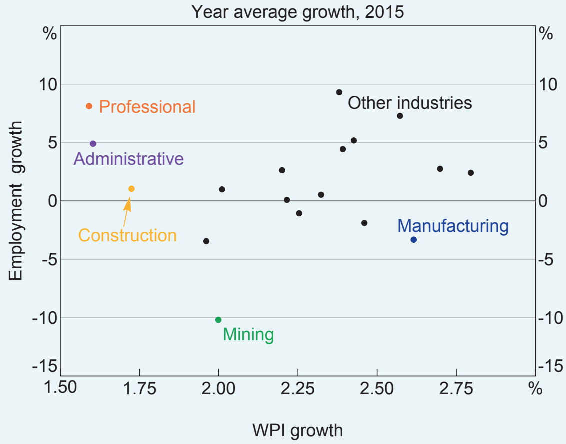


* Wage price index; industries grouped by standard deviation of seasonally adjusted quarterly growth

Sources: ABS; RBA

lower wages. In addition, labour hire firms may have also experienced an increase in the availability of labour, as similar workers have left mining and mining-related firms. Professional, scientific & technical services firms have also had weak wage growth and strong employment growth in the past year. This may also reflect a change in the composition of the clients they work for and an increase in labour availability as similar workers have left the mining industry. In contrast, manufacturing wage growth remains high relative to other

Graph B6
Employment and Wages



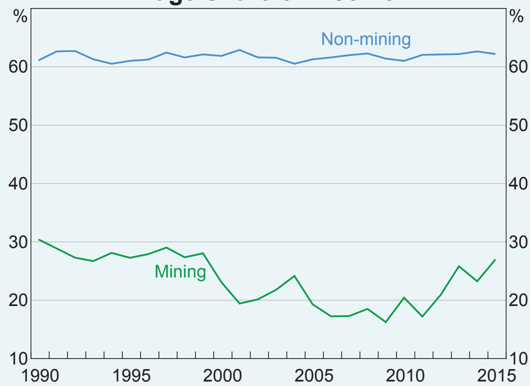
Sources: ABS; RBA

industries at the same time as employment in manufacturing has declined.

Growth in average earnings per hour from the national accounts, a broader measure of labour income, tends to be higher in industries that have stronger growth in labour productivity over the long run.[2] This would be expected if wages remain a constant share of an industry's total income. Indeed, the wage share of total factor income has been relatively stable in the non-mining sector, despite below-average wage growth (Graph B7). However, there has been an increase in the wage share of income in the mining industry because the decline in commodity prices over recent years has weighed more heavily on profits than wages, just as the earlier increase in commodity prices accrued more to profits than to wages.

2 Average earnings per hour from the national accounts is affected by compositional change and a broader range of labour income payments than the WPI, such as payments related to redundancies, allowances and fringe benefits. The relationship between earnings and productivity growth by industry is not always clear from one year to the next because productivity growth is volatile and productivity improvements are more difficult to measure for some industries than others. Productivity is more challenging to measure for services than for goods. It is also more difficult to measure productivity for services where public sector provision is a significant share of output than for services where prices are market determined.

Graph B7
Wage Share of Income*



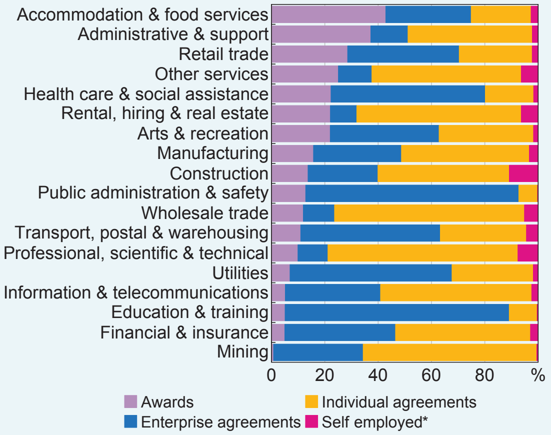
* Compensation of employees as a share of factor income

Sources: ABS; RBA

Wage-setting methods vary significantly across industries. Enterprise agreements between employers and groups of employees are used to set the pay and conditions for a little more than 40 per cent of employees. Individual agreements between employers and employees cover almost another 40 per cent of employees, while around 20 per cent of employees have their pay determined directly by awards. Most awards are determined by the Fair Work Commission and also indirectly affect a significant proportion of employees covered by enterprise agreements or individual contracts where they set minimum standards for an occupation or industry.

Industries that have the highest share of workers whose pay is directly determined by awards include accommodation & food services (43 per cent), administrative & support services (37 per cent) and retail trade (29 per cent) (Graph B8). Industries with a significant public sector presence, such as education & training, public administration & safety, and health care & social assistance, tend to have a large share of enterprise agreements. In most other industries, at least half of all employees have their pay and conditions determined by individual agreements.

Graph B8
Method of Setting Pay
Per cent of industry employees, 2014



* Owner-manager of incorporated enterprise

Source: ABS

The relationship between wage-setting methods and wage outcomes is unclear. Awards are more prevalent in industries with lower wages as they provide minimum standards. Changes in wage growth and labour market outcomes by industry may reflect differences in wage flexibility or bargaining power, but these are difficult to distinguish from a wide range of other determinants of wages, including variation in industry performance, the balance of demand and supply for different skills, and productivity.

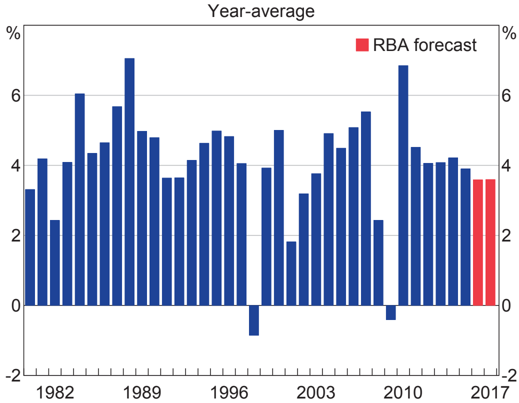
6. Economic Outlook

The International Economy

The outlook for GDP growth of Australia's major trading partners has been lowered a little since the February *Statement*, reflecting weaker-than-expected data for the March quarter across a number of major trading partners, and some reassessment of growth momentum, particularly in Asia. Despite that, the recent rise in commodity prices suggests that Australia's terms of trade are likely to be a bit higher in the near term than earlier forecast.

Over the next two years, growth of Australia's major trading partners is expected to be about ½ percentage point below its decade average (Graph 6.1). Growth will be supported by accommodative monetary policies, less restrictive fiscal policy in some advanced economies and some modest fiscal stimulus in the Asian region.

Graph 6.1
Australia's Trading Partner Growth*
Year-average



* Aggregated using total export shares

Sources: ABS; CEIC Data; RBA; Thomson Reuters

Notwithstanding the recent increase, oil prices remain relatively low, which should also support growth because most of Australia's major trading partners are net oil importers.

Growth in China is expected to moderate over the forecast period, largely as forecast previously. In the near term, weaker-than-expected growth of activity in the March quarter is expected to be offset by the effects of policy stimulus over the coming year as the authorities seek to achieve their economic growth target for 2016.

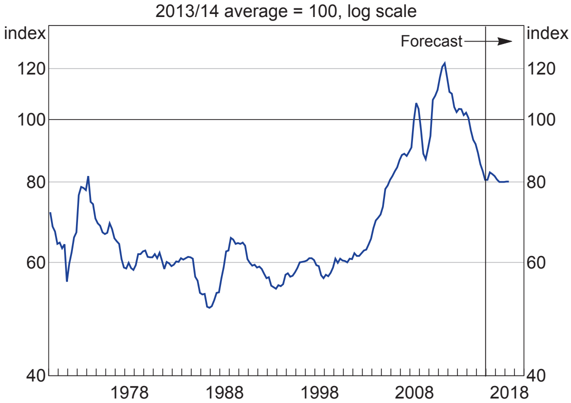
Over the next two years, Japanese GDP growth is expected to be below its trend rate, in part as a result of the scheduled increase in the consumption tax in early 2017. In other east Asian economies, the ongoing weakness in external demand conditions is likely to continue to dampen export demand and investment growth in the private sector; consumption is also likely to be more subdued than previously expected. Although growth in the region is expected to pick up gradually, it is likely to remain below its decade average over the next two years.

Despite some slowing in growth recently, the US economy is expected to grow at an above-trend rate over the next two years. Conditions in the US labour market remain strong and should support consumption growth. US monetary policy remains very accommodative and, after a few years of fiscal consolidation, government spending is likely to add to growth this year. In the euro area, growth is also expected to remain above trend, supported by accommodative monetary policy, fiscal policies that are becoming less contractionary and a gradually improving labour market.

Globally, core inflation has been low for some years, reflecting spare capacity in many labour, product and commodity markets. This suggests that headline inflation rates will remain below central bank targets for some time yet, particularly in advanced economies, although the recent rise in oil prices, if sustained, should place a little upward pressure on inflation.

The terms of trade have been revised a bit higher in the near term since the February *Statement*, following the increase in commodity prices over recent months (Graph 6.2). The rise in commodity prices partly reflects the effect of positive sentiment on commodity demand following the announcement of China's growth target for 2016. However, it is assumed that the prices of bulk commodities will not be sustained at current levels. Indeed, the forecasts for iron ore and coal prices after 2016 have not been revised higher. This reflects an expectation that Chinese steel demand will decline over the next few years, largely as previously forecast. Also, a substantial increase in global production of low-cost iron ore is expected over the next year or two. Furthermore, the forecasts assume that there will be only a limited reduction in the supply of iron ore from high-cost producers, particularly those in China, over the forecast period.

Graph 6.2
Terms of Trade
2013/14 average = 100, log scale



Sources: ABS; RBA

The increase in oil prices over recent months has also affected the terms of trade and its outlook. Currently, higher oil prices tend to reduce the terms of trade because Australia is a net oil importer. However, as exports of liquefied natural gas (LNG) ramp up, a rise in oil prices will, by itself, tend to increase Australia's terms of trade because the price of LNG is linked to the price of oil.

Domestic Activity

In preparing the domestic forecasts, a number of technical assumptions have been employed. The forecasts are conditioned on the assumption that the cash rate moves broadly in line with market pricing as at the time of writing. This assumption does not represent a commitment by the Reserve Bank Board to any particular path for policy. The exchange rate is assumed to remain at its current level over the forecast period (trade-weighted index (TWI) at 62.5 and A$ at US$0.75). The TWI is little changed from the assumption underlying the forecasts in the February *Statement*. The forecasts are based on the price of Brent crude oil being US$47 per barrel over the forecast period, which is around 30 per cent higher than the assumption used in February and in line with futures pricing for the near term. Similar to the previous *Statement*, the working-age population is assumed to grow by 1.5 per cent over 2016 and by 1.6 per cent over 2017, drawing on forecasts from the Department of Immigration and Border Protection.

The starting point for the forecasts is that the Australian economy grew at an above-trend pace over the year to the December quarter 2015. This was stronger than expected at the time of the February *Statement* and, in part, reflected upward revisions to growth, particularly in the September quarter, which is now recorded as having been very strong. Growth was also slightly stronger than expected in the December quarter, though still moderate. Recent indicators are consistent with that moderate pace being maintained in the early part of 2016.

Activity continued to shift from the mining to non-mining sectors of the economy over 2015, supported by low interest rates and the ongoing effects of the exchange rate depreciation since early 2013. Non-mining activity grew at an above-average pace and growth was strongest in industries that provide services to households and businesses. Net service exports increased noticeably over 2015. Growth in household consumption increased in the latter part of the year and dwelling investment continued to grow strongly. Public demand contributed to growth over the year, while non-mining business investment remained subdued. Further sharp declines in mining investment were offset in part by increases in the volume of resource exports.

Overall, the forecast for GDP growth is little changed from that presented in the February *Statement*, although the year-ended growth rate in the near term is a little higher given the recent national accounts data. Growth is forecast to be 2½–3½ per cent over the year to December 2016, and to increase to 3–4 per cent over the year to June 2018, which is above estimates of potential growth in the Australian economy (Table 6.1).

Low interest rates and gains to employment are expected to support continued strength in household demand, despite only modest growth in household income in the near term. Forecasts for growth in real household disposable income have been revised down as a result of a somewhat weaker outlook for nominal wage growth, which has been offset to some extent by downward revisions to the outlook for inflation. Nevertheless, consumption growth is projected to be a little above its longer-term average over the forecast period, consistent with the forecasts in the February *Statement*. Together, the forecasts for household consumption and income growth imply that the household saving ratio will continue the mild downward trend of the past few years.

The substantial amount of residential construction work in the pipeline is expected to translate into further strong growth in dwelling investment in the near term. However, the decline in higher-density dwelling approvals suggests that the pace of growth in dwelling investment will moderate over time.

The outlook for resource exports by the end of the forecast period is little changed. However, there have been some changes to the profile for iron ore and LNG exports, reflecting expected production delays for some of these projects. While exports of iron ore are expected to increase and production of LNG is set to ramp up substantially, the scope for additional growth in coal exports appears limited, given weak global demand for coal and the relatively high cost of some Australian production. The depreciation of the Australian dollar since

Table 6.1: Output Growth and Inflation Forecasts[(a)]
Per cent

	Year-ended					
	Dec 2015	Jun 2016	Dec 2016	Jun 2017	Dec 2017	Jun 2018
GDP growth	3	2½–3½	2½–3½	2½–3½	2½–3½	3–4
CPI inflation	1.7	1	1–2	1½-2½	1½-2½	1½-2½
Underlying inflation	2	1½	1–2	1½-2½	1½-2½	1½-2½
	Year-average					
	2015	2015/16	2016	2016/17	2017	2017/18
GDP growth	2½	2½	2½–3½	2½–3½	2½–3½	2½–3½

(a) Technical assumptions include A$ at US$0.75, TWI at 62.5 and Brent crude oil price at US$47 per barrel; shaded regions are historical data
Sources: ABS; RBA

early 2013 has been assisting domestic producers of tradable items. Net service exports, which are particularly sensitive to exchange rate movements, are forecast to continue growing.

Mining investment is expected to continue to fall over the forecast period, as large resource-related projects are completed and few new projects are expected to commence, although the extent of this contraction is expected to diminish over time. The recent increases in commodity prices are not expected to result in a significant increase in planned mining investment over the next few years, given the existing capacity and expectations that there will only be moderate growth in global demand for commodities.

Non-mining business investment is expected to remain subdued in the near term, consistent with the ABS capital expenditure survey of firms' investment intentions and the low level of non-residential building approvals. However, very low interest rates and the depreciation of the Australian dollar over the past few years have supported an improvement in business conditions (which is clearly evident in the various survey measures and consistent with the rise in employment) and there is evidence that investment has increased in areas of the economy that have been less affected by the decline in mining investment and commodity prices.

The labour market forecasts are little changed from the February *Statement*. The pace of employment growth has moderated in early 2016, much as expected, following particularly strong outcomes in late 2015. As GDP growth is expected to be a little lower over 2016 compared with 2015, employment growth is also likely to remain lower than last year. Leading indicators of labour demand, such as survey measures of hiring intentions, job advertisements and vacancies, have been mixed of late but, when taken together, they suggest that conditions in the labour market are continuing to improve, albeit at a slower pace than last year. Employment growth is expected to pick up to an above-average pace by the end of the forecast period, driven by a pick-up in GDP growth. Employment appears to have been supported by much lower wage growth than would have been implied by historical relationships with the unemployment rate. In this respect, the forecast for low wage growth can be viewed as providing some further assistance to employment growth. The participation rate is expected to increase as more people enter the labour force in response to the improvement in labour market conditions. In combination, this implies that the unemployment rate is expected to remain around its current rate until mid 2017, before declining gradually, and that there is likely to be a degree of spare capacity in the labour market for some time.

Inflation

The March quarter underlying inflation outcome was around ¼ percentage point lower than expected at the time of the February *Statement*. The broad-based nature of the weakness in non-tradables inflation and the fact that wage outcomes were lower than expected over 2015 has resulted in a reassessment of the extent of domestic inflationary pressures, leading to downward revisions to the forecasts for inflation and wage growth. Underlying inflation is now expected to remain around 1–2 per cent over 2016 and to pick up to 1½–2½ per cent at the end of the forecast period.

Wage growth has been low over recent years and has been much lower than suggested by its historical relationship with measures of spare capacity, such as the unemployment rate. This may reflect the effect of the decline in inflation expectations and/or the terms of trade, as well as a more flexible labour market than in earlier decades. It is notable also that the phenomenon of surprisingly low wage growth for given labour market conditions has been apparent across a number of advanced economies. Furthermore, the recent inflation data indicate that the weakness in domestic cost pressures is not only evident in low growth of nominal wages but is more broadly based. Indeed, unit labour costs, which incorporate a broader range of labour costs than the wage price index (WPI) and account for changes in the composition of the labour force, have been growing more slowly than the WPI. This reflects the usual cyclical effects of compositional change and weakness in non-wage payments such as allowances. It is also consistent with the movement of workers from highly paid mining-related jobs to other employment.

Given data observed over the past few months, the recovery in wage growth and labour costs underpinning the inflation forecasts has been revised lower. The expectation is that growth in the WPI will remain around current low levels for longer than previously forecast and pick up only very gradually over the forecast period. Unit labour cost growth, which is strongly correlated with non-tradables inflation, is expected to pick up a little faster than the WPI. This reflects an expectation that the dampening effects of compositional change will wane, including because the movement of labour from mining and mining-related firms is already well advanced. In addition, employers may increase bonuses and other labour income payments before increasing the pace of growth in wages. Based on historical experience, unit labour cost growth tends to pick up after the unemployment rate has started to decline. Even so, the increase in unit labour costs is expected to be slower than has occurred in previous comparable episodes, such as the mid 1990s or following the global financial crisis.

The prices of tradable items are expected to rise over the next few years, notwithstanding low global inflation, as the increases in import prices resulting from the exchange rate depreciation since early 2013 are gradually passed through to the prices paid by consumers. Based on historical relationships, the direct effects of the exchange rate depreciation since early 2013 are expected to add a bit less than ½ percentage point to underlying inflation over each year of the forecast period. However, assessments of the size and timing of exchange rate pass-through are inevitably imprecise and other influences are also at work. Heightened competitive pressures in the retail market are expected to continue to limit the extent to which higher import prices become evident in final retail prices for some time.

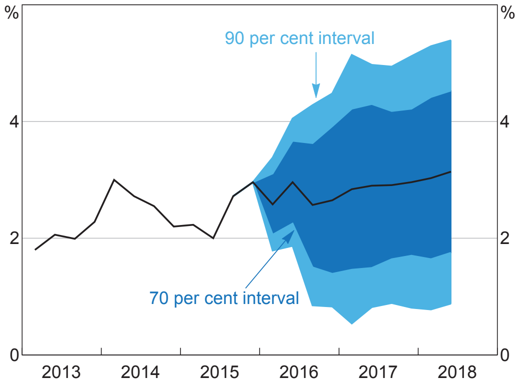
Headline inflation has been lower than underlying inflation over the past year or so, partly as a result of factors that are likely to have a temporary effect, such as lower fuel prices and changes to utility prices stemming from regulatory and policy decisions. As the direct effects of these factors pass, headline inflation is expected to converge towards underlying inflation over the forecast period. The declines in fuel and utility prices over the past year or so have reduced input costs for a range of businesses, and these lower costs are expected to be passed on gradually to the prices that these businesses charge for their goods and services. The magnitude and timing of these indirect effects on inflation are difficult to gauge. A further increase in the tobacco excise later in 2016 is expected to contribute around ¼ percentage point to year-ended headline inflation, but to have little effect on underlying inflation.

Uncertainties

The forecasts are based on a range of assumptions about the evolution of some variables, such as the exchange rate, and judgements about how developments in one part of the economy will affect others. One way of demonstrating the uncertainty surrounding the central forecasts is to present confidence intervals based on historical forecast errors (Graph 6.3, Graph 6.4 and Graph 6.5).

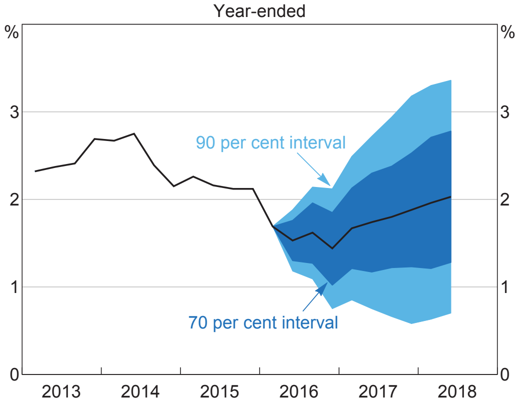
It is also worth considering the consequences that different assumptions and judgements might have on the forecasts and the possibility of events occurring that are not part of the central forecast. One of the key sources of uncertainty continues to be the outlook for growth in China and the implications of high levels of debt there. In turn,

Graph 6.3
GDP Growth Forecast*
Year-ended



* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

Graph 6.4
Trimmed Mean Inflation Forecast*
Year-ended

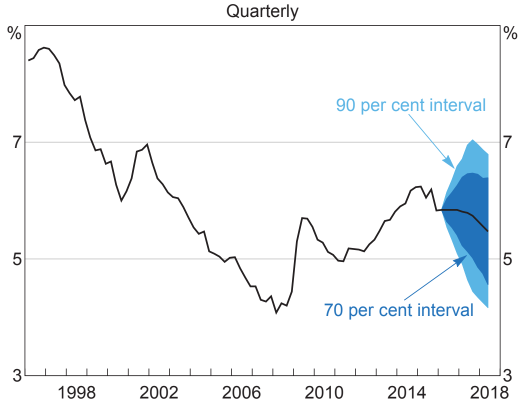


* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

that has implications for commodity demand and ultimately for the forecasts for the terms of trade. The outlook for commodities also depends on the responsiveness of supply to price movements seen to date. Another uncertainty arising from the international environment is the extent to which labour market tightness in a number of advanced economies will affect wage growth and, ultimately, inflation.

Developments in both commodity prices and the expected path of monetary policy in major advanced economies (based on changes in their

Graph 6.5
Unemployment Rate Forecast*
Quarterly



* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

outlook for inflation) will have potential implications for the Australian dollar. Based on a number of estimates produced by Reserve Bank staff and academic researchers, a useful rule of thumb is that, all else constant, an exchange rate appreciation of 10 per cent reduces the level of GDP by between ½ and 1½ per cent, generally within two years. However, an exchange rate appreciation caused by a sustained increase in commodity prices may even be associated with a modest increase in economic activity, particularly if higher prices allow some of the smaller Australian resource firms to remain in the market. Domestically, there is also considerable uncertainty about the extent to which wage growth and domestic inflationary pressures more broadly will pick up over the next few years. This raises uncertainty about the outlook for inflation and activity.

The Chinese economy

China's growth outlook continues to represent a considerable source of uncertainty for the Australian economy. The recent improvement in Chinese property market conditions appears to reflect policy efforts to support the sector over the past year. Stronger property prices and activity could assist the process of reducing China's large stock of unsold residential property and could, for a time, underpin more resilient demand in a range of upstream industries, including the steel industry. However, the sustainability of the present improvement in property markets is uncertain and it appears that substantial excess capacity persists in the manufacturing sector, including the steel industry. More generally, the outcomes of the March political meetings suggest that the Chinese Government is, for the time being, prioritising short-term growth over its longer-term objectives of achieving deleveraging and growth that is less reliant on investment and heavy industry. On the one hand, an increase in debt-funded growth, including a strong pick-up in public spending on infrastructure, may lead to stronger growth in overall activity than otherwise in 2016. On the other hand, this growth would be likely to be achieved by adding to the already substantial stock of debt, potentially delaying efforts to reduce excess capacity in the manufacturing and resources sectors. Declining industrial profits and deteriorating economic conditions in the north-east of the country have the potential to cause financial distress. This poses risks for financial institutions with sizeable on- and off-balance sheet exposures to affected industries and regions, and to China's growth trajectory more broadly.

Commodity prices and trade

The outlook for commodity prices is sensitive to demand, particularly from the Chinese industrial and construction sectors. The current forecasts assume that the level of Chinese steel demand continues to decline over the forecast period, albeit at a slower rate in the near term than assumed in the previous *Statement*. The medium-term trajectory is underpinned by lower steel demand from construction and manufacturing and, more generally, a gradual shift away from investment-led growth, which is relatively steel intensive, toward a more consumption-led growth path. However, recent signs of a pick-up in construction activity and increased policy support for growth may mitigate or even temporarily reverse the expected moderation in steel demand. This, in turn, would keep iron ore prices higher for longer than expected and so represents an upside risk to the forecasts for Australia's terms of trade.

Global inflation

Labour markets in a number of advanced economies have been improving over recent years. Unemployment rates have been declining, and are close to levels consistent with most estimates of full employment in the United States, the United Kingdom and Japan. Broader measures of labour underutilisation have also declined towards long-run average levels.

Despite this, nominal wage growth has remained subdued and this has contributed to low inflation outcomes. In the United States, low productivity growth has meant that growth in unit labour costs, which is what matters for inflationary pressures, has been above its long-run average. Nonetheless, there is uncertainty about the extent to which the increasing tightness of labour markets will feed through to growth in wages and unit labour costs, and subsequently to inflation. In some advanced economies, some measures of inflation expectations have declined further, and this has increased the uncertainty about the outlook for inflation.

Concerns about the prospects for a sustained pick-up in inflation have contributed to expectations of easier monetary policy in the major advanced economies. Should inflationary pressures build more rapidly in some advanced economies than currently expected, this could imply a significant change in the expected path of monetary policy, which would have implications for exchange rates. This could be expected to lead to a depreciation of the Australian dollar.

Domestic cost pressures

There is also considerable uncertainty about the extent to which wage growth, and domestic inflationary pressures more broadly, will pick up over the next few years in Australia. The forecasts for wage growth and inflation have been revised lower to take into account recent data, which suggest that domestic cost pressures have been lower than previously anticipated. However, despite above-trend growth in economic activity and improvements in labour market conditions over the past year or so, it is possible that domestic cost pressures will be weaker than reflected in the forecasts, and so inflation may not pick up as expected. It is possible, for example, that inflation expectations will be persistently lower for longer than currently anticipated, given the forecast of a period of low inflation, which could weigh on wage outcomes.

It is also possible, however, that wage growth will pick up more quickly than forecast. In particular, some of the explanations for why wage growth has been much lower than suggested by its historical relationship with the unemployment rate, such as increased flexibility in the labour market, would be consistent with wage growth picking up quite quickly as spare capacity in the labour market diminishes. For instance, employees may demand larger-than-forecast wage increases to compensate for the prolonged period of unusually low wage growth. Also, the compositional change associated with labour moving from mining and mining-related industries to the non-mining economy is likely to have lowered growth in average earnings per hour. As this process of structural change slows, it is possible that the downward pressure on earnings growth in the non-mining economy will diminish more quickly than expected. Moreover, the unemployment rate may decline more rapidly than anticipated, which would allow wage and earnings growth to pick up by more than currently forecast.

Consumption and income growth

The outlook for wage growth has implications for household consumption growth. The forecasts assume that households will respond to near-term weakness in income growth by reducing their rate of saving to sustain their consumption growth. This is likely to be a reasonable assumption if households expect the weakness in income growth to be temporary, especially given relatively high rates of saving and gains to household wealth over recent years. If, however, a longer period of low wage growth leads households to lower their expectations for income growth over the longer term, household consumption may not increase to the extent forecast. It is also worth considering alternative explanations for lower wage growth. For example, if wage growth is currently lower than expected because of a rise in the effective supply of labour, the effect on household income is likely to be mitigated by higher-than-expected employment growth.

Statement on Monetary Policy

AUGUST 2016

Contents

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Statement on Monetary Policy enquiries

Secretary's Department
Tel: +61 2 9551 9830
Fax: +61 2 9551 8033
Email: rbainfo@rba.gov.au

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Overview

Growth in economic activity in Australia's major trading partners has remained a little below average over the first half of 2016. Despite this, commodity prices overall have increased since the beginning of the year, partly because of reductions in supply by some high-cost producers of commodities, including iron ore and coal. The outlook for overall growth in Australia's major trading partners and the outlook for the terms of trade are little changed from three months ago. The terms of trade are forecast to remain close to current levels over the next couple of years. This is around 35 per cent lower than their peak in late 2011, but still well above levels that prevailed prior to the mining boom.

In China, subdued growth in private sector investment has been only partially offset by additional policy measures to support demand. Conditions in the Chinese residential property market have eased a little recently, while growth in the services sector has remained relatively strong. The effects of the gradual easing in economic growth in China have been evident in a number of east Asian economies and emerging economies in other regions that have strong trade links to China. The outlook for the Chinese economy remains an important source of uncertainty for global growth and demand for commodities. A substantial slowing in demand in the Chinese property market would pose risks for property developers and related industries, including the steel industry. There is also uncertainty related to how the Chinese authorities will respond to the difficult trade-off involved in supporting growth and avoiding financial disruption in the near term, while achieving more financial discipline and broader reforms over the longer term.

In the major advanced economies, growth in GDP has been sufficient to drive further improvements in labour market conditions over the past year. Indeed, a number of economies are close to full employment. Despite this, wage growth remains subdued in most advanced economies.

Inflation remains below most central banks' targets. Globally, monetary policy continues to be remarkably accommodative and, for most jurisdictions, market participants generally expect it to remain so for an extended period or to become even more stimulatory. In an environment of low inflation and low inflation expectations, the Bank of Japan announced some additional stimulus measures at its July meeting. Market participants anticipate further easing by the European Central Bank and while the Bank of England left its policy rate unchanged at its July meeting, it signalled that it expects to ease policy in August. Market expectations for the US federal funds rate have declined over the past few months such that the next rate rise in the United States is not priced in until late 2017, although members of the Federal Open Market Committee have signalled that there is a reasonable likelihood of an increase before the end of 2016.

Volatility in foreign exchange and other financial markets increased significantly around the time of the UK referendum. Despite that volatility, financial markets, including those in Australia, continued to function effectively. Volatility has since declined to more normal levels. Meanwhile, funding costs for high-quality borrowers remain low. The Australian dollar has appreciated a little since the previous *Statement on Monetary Policy*.

In Australia, low interest rates and the depreciation of the Australian dollar exchange rate since early 2013 are continuing to support the rebalancing of economic activity towards non-resource sectors. Growth in GDP was stronger than expected in the March quarter, in large part because of a substantial rise in resource exports, which were boosted by unusually favourable weather conditions. More recent data suggest that real GDP growth was more moderate in the June quarter, as expected.

The unemployment rate has remained at around 5¾ per cent over 2016, which is around ½ percentage point lower than a year or so ago. Following particularly strong growth late last year, employment growth has been slower this year. While this was largely expected, recent employment growth has been concentrated in part-time employment. Forward-looking indicators of the labour market have been mixed of late. Those indicators overall are consistent with a modest pace of employment growth in the near term and little change in the unemployment rate.

There has been very little change to the outlook for economic activity since the previous *Statement*. GDP growth is expected to be around 2½–3½ per cent over 2016, before increasing to around 3–4 per cent by 2018, which is above estimates of potential growth in the Australian economy.

Consistent with the profile for economic activity, employment growth is expected to increase gradually and the unemployment rate is expected to fall a little. This would imply spare capacity remaining in the labour market throughout the forecast period. However, there is considerable uncertainty about the outlook for the labour market. In part, this reflects the recent divergence between growth in employment and hours worked. In addition, past relationships between growth in GDP and employment may be less useful as a guide in the coming years given the strong prospective contribution to GDP growth from liquefied natural gas production, which is less labour intensive than most other industries.

Household consumption growth is expected to be close to its long-run average over the next couple of years. Surveys suggest that households' perceptions of their own finances have been above average in recent months – notwithstanding relatively weak income growth – and expectations of unemployment are lower than in recent years. Income growth is expected to pick up gradually, but it is likely to remain a bit lower than consumption growth for a time. This implies that the household saving ratio will decline gradually, extending the downward trend of the past few years.

Dwelling investment has continued to grow strongly. While building approvals have declined over the past year, they remain elevated and the pipeline of dwelling construction is at very high levels. This is expected to support dwelling investment for some time, but also raises the risk of oversupply in some markets.

Conditions in the established housing market appear to have eased since last year. While one source of data recorded strong growth in housing prices in April and May, that growth appears to have been overstated and other sources suggest that housing price growth was modest over those and more recent months. Moreover, a range of other indicators are consistent with an easing in conditions. In particular, housing credit growth remains lower than a year ago, consistent with the tightening in lending standards towards the end of 2015 and the decline in turnover in the housing market to low levels this year. Also, the rental vacancy rate has drifted higher, to be close to its long-run average, and inflation in rents has eased to multi-decade lows.

Trade data indicate that net exports made a much smaller contribution to GDP growth in the June quarter than in the March quarter. Even so, net exports are expected to continue making a positive contribution to growth over the period ahead, supported by the earlier exchange rate depreciation and the ramp-up in liquefied natural gas production. Mining investment still has further to fall as projects are progressively completed, although the effect of this on GDP growth should diminish noticeably over the next year or so. While there are signs that non-mining business investment is rising in some parts of the economy, most indicators of business investment intentions and non-residential construction activity suggest that overall non-mining business investment will remain subdued in the near term. At the same time, survey measures of business conditions and capacity utilisation are noticeably above their long-run averages. Non-mining business investment is expected to pick up in the latter part of the forecast period as demand strengthens.

The latest data on inflation and labour costs confirm that domestic cost pressures remain subdued. Measures of underlying inflation picked up to ½ per cent in the June quarter, to be around 1½ per cent over the year. This outcome was in line with the forecasts in the May *Statement*. Subdued domestic cost pressures reflect a number of factors, including the effect of the decline in the terms of trade and mining investment over recent years, and spare capacity in labour and a number of product markets. Low wage growth and a decline in margins contributed to non-tradables inflation remaining around its lowest level since the late 1990s in year-ended terms, and have largely offset the significant upward pressure on the prices of tradable items arising from the depreciation of the exchange rate over the past few years.

Underlying inflation is expected to remain around current rates in the near term, before picking up gradually to around 2 per cent by the end of the forecast period. The substantial depreciation of the exchange rate over recent years is expected to continue exerting upward pressure on the prices of tradable items for some time. Wage growth is expected to remain low in the near term, before rising modestly over the forecast period as labour market conditions improve and the adverse effects of the decline in the terms of trade and mining investment wane. There is, however, considerable uncertainty about the timing and the size of these effects. The outlook for the balance of supply and demand in the housing market is also an important source of uncertainty. Among other things, this will have a bearing on inflation given that housing costs make up a significant share of the CPI basket. While the exchange rate is assumed to remain around current levels over the forecast period, it may respond to any unanticipated changes to the outlook for growth in Australia or offshore, commodity prices or monetary policy decisions in Australia or elsewhere. It therefore represents a significant source of uncertainty for the forecasts of inflation, as well as for the outlook for growth in activity.

In May, with the outlook for economic activity and the unemployment rate little changed but the inflation outlook lower than previously anticipated, the Board decided to reduce the cash rate by 25 basis points. At the same time, the Board had taken careful account of developments in the housing market, noting the effects of supervisory measures to strengthen lending standards, the easing in housing credit growth and the abatement of strong price pressures.

The data coming to hand since then have not altered the outlook for output and unemployment, and confirm that inflation is likely to remain below 2 per cent over most of the forecast period. While the prospects for growth in economic activity are positive, there is room for even stronger growth. Also, recent information implies that dwelling prices have been rising modestly over the course of this year and confirms that growth in lending for housing purposes has slowed since last year. All this suggests that the risks associated with high and rising household sector leverage and rapid gains in housing prices have diminished.

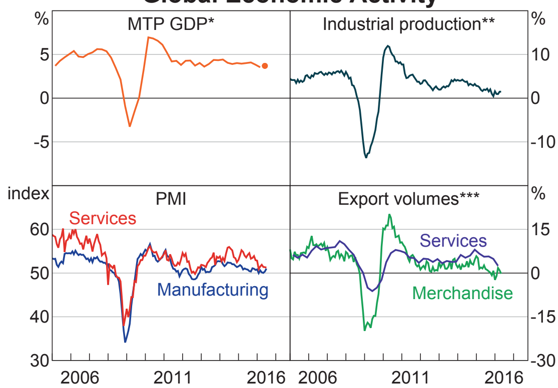
Given this background, the Board judged that prospects for sustainable growth in the economy, with inflation returning to target over time, would be improved by a further easing of monetary policy. Accordingly, the cash rate was reduced by 25 basis points at the August meeting.

1. International Economic Developments

GDP growth in Australia's major trading partners was a little below its decade average over the first half of 2016 (Graph 1.1). Growth in China continued to ease, while GDP growth rates in the major advanced economies have been around or above their decade averages over the past year. Expansionary monetary policy is continuing to support growth in most economies and fiscal policies have become less contractionary. The outcome of the United Kingdom's referendum to leave the European Union led to heightened uncertainty and is expected to lead to lower growth in the United Kingdom. The impact on the rest of the world is likely to be limited, absent any financial market dislocation or wider political instability in the European Union.[1]

Growth in global industrial production, manufacturing activity and trade has been below average for much of the period since the global financial crisis. Among other things, this has reflected the effects of heightened uncertainty and the slow recovery in economic activity on investment, particularly in the advanced economies.[2] Since mid 2014, weaker demand from commodity-exporting emerging market economies (where imports have declined over the past two years) and China has also restrained trade growth (Graph 1.2). The decline in export growth over the past couple of years has been pronounced for the

Graph 1.1
Global Economic Activity



* Major trading partner (MTP) GDP weighted using Australia's export shares; dot indicates RBA estimate; year-ended growth

** Industrial production is weighted by world industrial production shares at market exchange rates; year-ended growth

*** Service exports are for select MTPs and Australia; year-ended growth

Sources: ABS; Bloomberg; CEIC Data; CPB; IMF; Markit Economics; OECD; RBA; Thomson Reuters

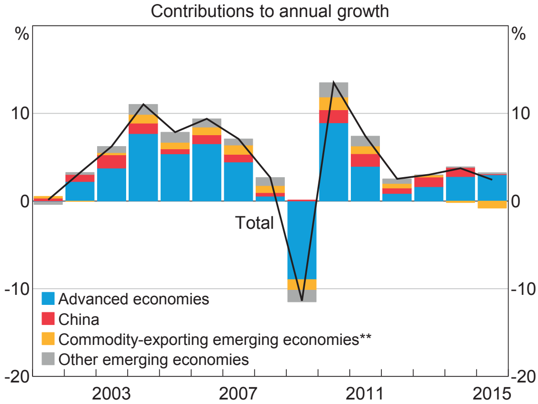
high-income east Asian economies, which have a high trade exposure to China and to other emerging market economies. While commodity prices remain low relative to recent years, they have increased over 2016 and are still well above the levels of a decade ago. Low oil prices should continue to support growth in Australia's major trading partners, which are generally net oil importers.

Labour market conditions in most advanced economies continue to improve and a number of these economies are close to full employment. Despite this, global inflation remains low and below most central banks' targets and longer-run averages (Graph 1.3). Year-ended headline inflation in advanced economies has picked up a little since late 2015, as the effect of earlier declines in oil prices

1 See, for example, Council of Financial Regulators (2016), 'Report on the Implications of Brexit', July, available at <http://www.cfr.gov.au/publications/cfr-publications/2016/report-on-the-implications-of-brexit/>.

2 See, for example, Jääskelä J and T Mathews (2015), 'Explaining the Slowdown in Global Trade', RBA *Bulletin*, September, pp 39–46.

Graph 1.2
Global Import Volumes*
Contributions to annual growth

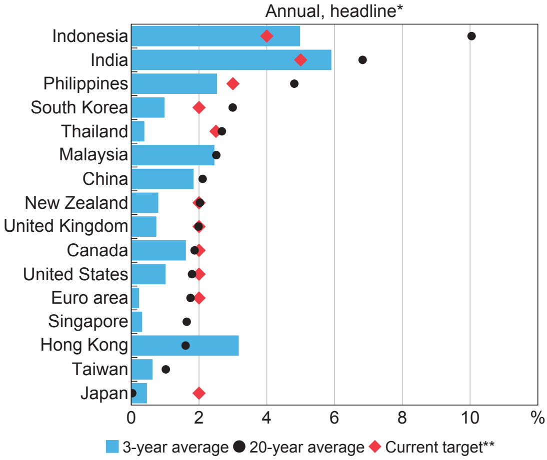


* Covers 87 per cent of global economies by PPP-weighted GDP, includes goods and services imports

** Economies for which gross commodity exports represent more than 35 per cent of total exports and net commodity exports represent more than 5 per cent of total trade, on average, between 1962 and 2014

Sources: OECD; RBA; Thomson Reuters

Graph 1.3
Major Trading Partners – Inflation
Annual, headline*



* The US measure is the personal consumption expenditure deflator. For Japan, the estimated effect of the 2014 consumption tax increase is excluded

** The mid-point is used for those economies with a target band

Sources: CEIC Data; central banks; IMF; RBA; Thomson Reuters

has moved out of the year-ended calculations. Core inflation has also increased in advanced economies over the past year, most notably in the United States, but has declined a little in emerging economies.

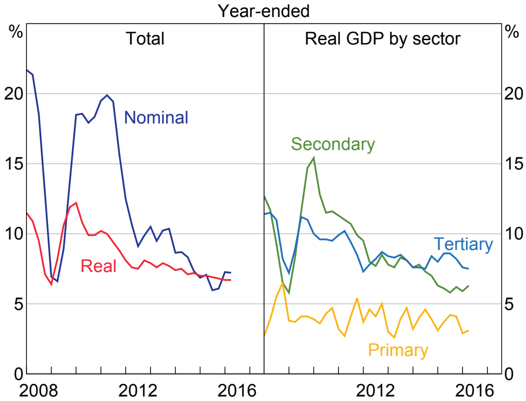
Asia-Pacific

In China, economic growth eased a little further in the first half of 2016 (Graph 1.4). Growth in the industrial (secondary) sector has declined considerably in recent years and subdued conditions in that sector have been associated with declining growth in private investment. Activity in the mining and manufacturing industries remains weak, although stronger conditions in the residential property sector in the first half of the year have supported the output of construction-related products, including steel.

Growth in Chinese private fixed asset investment has fallen sharply, although this has been partly offset by rapid growth in public investment spending over the past year, including on infrastructure (Graph 1.5). The Chinese Government has instructed relevant government agencies and local authorities to reduce impediments to private investment and facilitate increased bank lending to private sector firms.

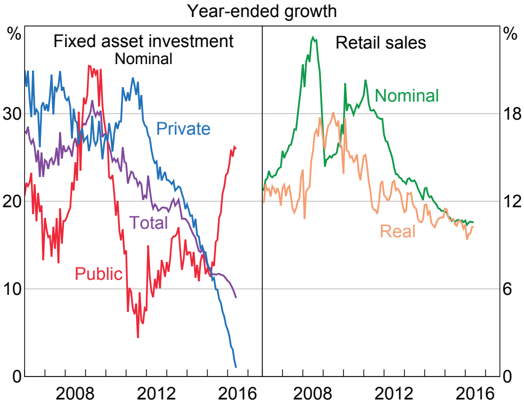
Overall growth in the Chinese economy has been supported by relatively strong growth in the services (tertiary) sector, notwithstanding slower growth in financial services of late. Indicators of consumption growth (including growth in retail sales) have been little changed in recent months.

Graph 1.4
China – GDP Growth
Year-ended



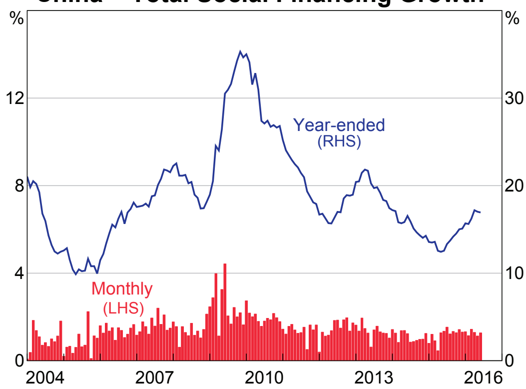
Sources: CEIC Data; RBA

Graph 1.5
China – Expenditure Indicators



Sources: CEIC Data; RBA

Graph 1.6
China – Total Social Financing Growth*



* Seasonally adjusted by RBA; upper bound estimate adjusting for impact of local government bond issuance to pay off debt previously included in TSF

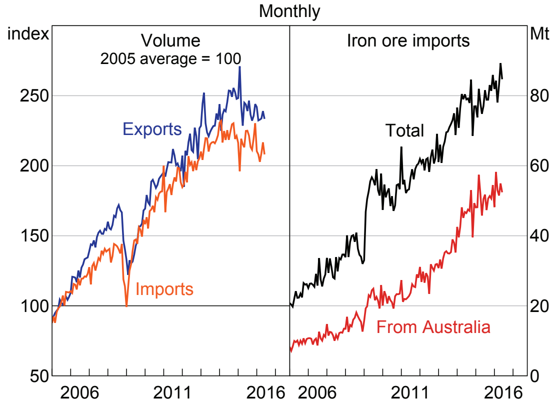
Sources: CEIC Data; People's Bank of China; RBA

Conditions in Chinese housing markets had strengthened since late 2015, in part reflecting earlier policy measures to support the market. More recently, however, conditions have moderated a little, including in some of the large and mid-sized cities where measures were recently introduced to restrain demand in response to very strong property price growth. In most cities, housing price growth has eased or remained little changed in recent months, while the volume of floor space sold and real estate investment have declined a little (see 'Box A: The Pick-up in the Chinese Housing Market').

Financial conditions in China remain relatively accommodative. Growth in total social financing has stabilised in recent months (after adjusting for the impact of the local government debt restructuring program) (Graph 1.6). The pace of corporate bond issuance has moderated, however, and growth in off-balance sheet lending has been low by historical standards.

Excess supply in the global industrial sector has contributed to weak global investment growth. Consistent with this, Chinese trade volumes have fallen over recent years (Graph 1.7). However, imports of iron ore, including from Australia, have risen in recent months, as Chinese iron ore production has declined further.

Graph 1.7
China – Merchandise Trade*



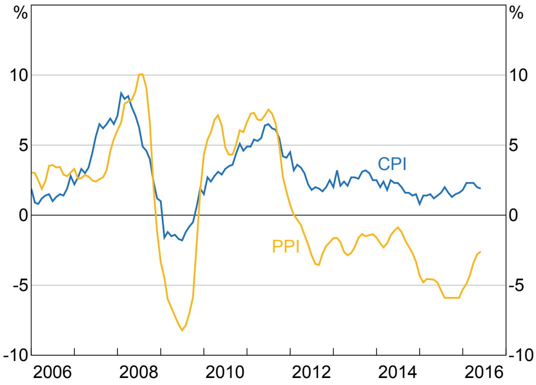
* Seasonally adjusted by RBA

Sources: CEIC Data; RBA

Inflationary pressures remain subdued in China. CPI inflation has been little changed in recent months as earlier increases in food prices have been unwound. Deflation in producer prices has continued to ease, consistent with increases in commodity prices (Graph 1.8).

In east Asia (excluding China and Japan), economic growth has slowed since late 2014, driven almost entirely by developments in the high-income economies. As these economies are quite reliant on trade, softer demand from China and other emerging economies has led to stagnant

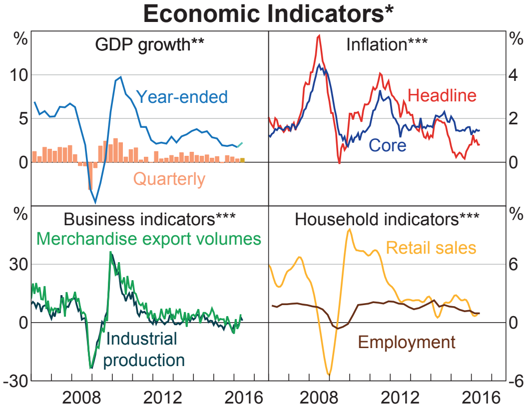
Graph 1.8
China – Inflation
Year-ended



Sources: CEIC Data; RBA

merchandise export volumes and industrial production (Graph 1.9).[3] Business investment has also been subdued over the past year. The exchange rate depreciations in the region over the past 1½ years should support net export volumes and economic activity more generally in the period ahead. Consumption growth in the high-income east Asian economies was resilient in 2015, but

Graph 1.9
High-income East Asia – Economic Indicators*

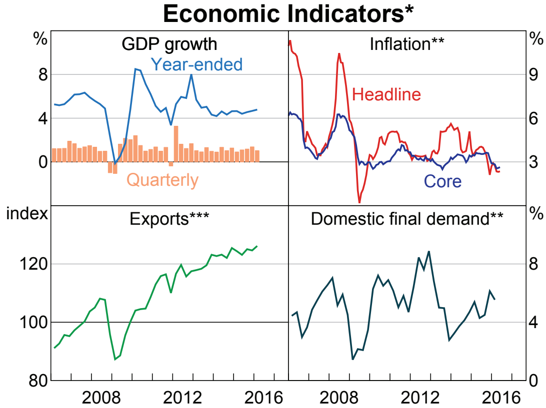


* Hong Kong, Singapore, South Korea and Taiwan
** June 2016 data are estimates
*** Year-ended growth; retail sales is a 13-term Henderson trend; employment is a quarter average
Sources: CEIC Data; IMF; RBA; Thomson Reuters; United Nations

looks to have moderated in 2016. This has coincided with a decline in employment growth and a slight increase in unemployment rates. Core inflation has eased since late 2014 and headline inflation remains low. A number of central banks in the region have eased monetary policy in the past year and several governments have increased spending and implemented temporary tax reductions. This includes the Korean Government, which is planning the third package of stimulus measures since 2015 (equivalent to around 1 per cent of GDP) aimed at supporting domestic consumption.

In contrast, GDP growth in the middle-income east Asian economies has been more resilient and remains around its decade-average (Graph 1.10). While these economies are also facing subdued external demand, they are less exposed to international trade than their high-income counterparts in the region. Domestic final demand in the middle-income economies has continued to be driven by moderate consumption growth and a marked increase in investment growth over the second half of 2015. Both headline and core inflation remain relatively low and have eased in recent months.

Graph 1.10
Middle-income East Asia – Economic Indicators*

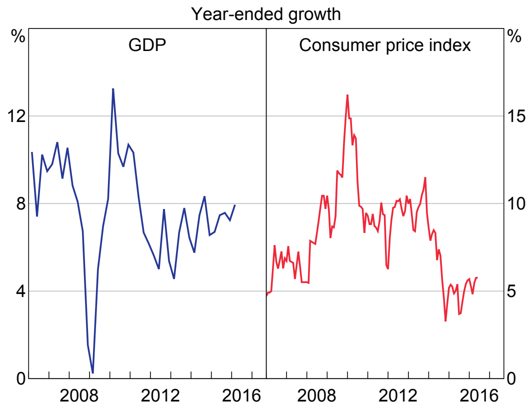


* Indonesia, Malaysia, Philippines and Thailand
** Year-ended growth
*** 2007 average = 100; exports are the national accounts measure
Sources: CEIC Data; IMF; RBA; Thomson Reuters

3 The ratio of exports to GDP in the high-income east Asian economies is around 80 per cent, compared with around 40 per cent in the middle-income east Asian economies.

In India, economic growth has continued to edge higher, as relatively strong consumption growth has more than offset weaker growth in investment (Graph 1.11). CPI inflation is currently a little above the Reserve Bank of India's interim goal of 5 per cent by March 2017. Rising food price inflation has contributed to the recent pick-up, although above-average monsoon rainfall has been forecast for 2016, which would support agricultural production and mitigate upward pressure on food prices.

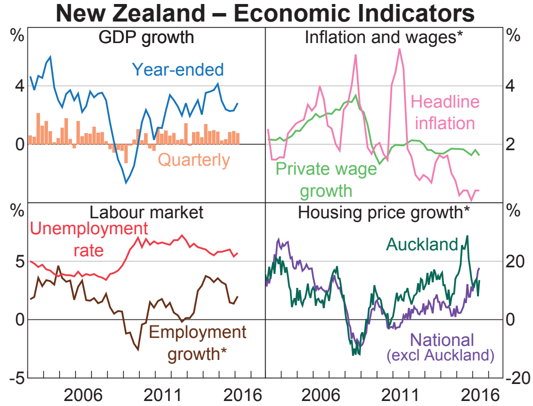
Graph 1.11
India – GDP Growth and Inflation



Source: CEIC Data

The New Zealand economy has grown at around its long-term average pace since mid 2015, supported by accommodative monetary policy and the earlier exchange rate depreciation (Graph 1.12). The unemployment rate is around its lowest level since 2009, as employment growth has been sufficient to absorb the record-high level of net immigration. Tax and regulatory changes aimed at curtailing investor activity in the housing market, particularly in Auckland, have seen housing price growth in Auckland moderate since October last year, although housing price growth has continued to increase in the rest of the country. The Reserve Bank of New Zealand has proposed new nationwide restrictions that will further limit high loan-to-valuation ratio lending and these are likely to come into effect in September this year. Headline consumer price inflation remains around historically

Graph 1.12
New Zealand – Economic Indicators



* Year-ended

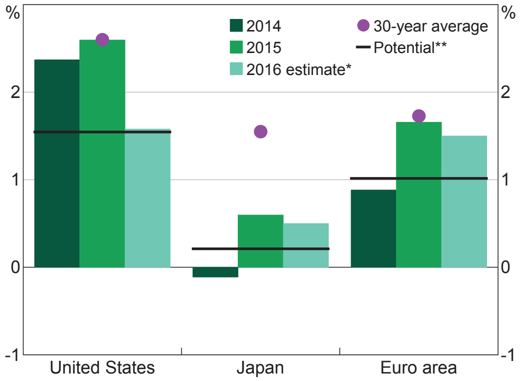
Sources: RBA; REINZ; Thomson Reuters

low levels, reflecting downward pressure from energy prices and subdued underlying inflationary pressures. Nominal wage growth has been low, although modest productivity growth implies that unit labour costs are growing at around their average rate of 2 per cent in year-ended terms.

Major Advanced Economies

GDP growth in the major advanced economies is around or a little above estimates of potential growth, which are generally lower than long-term average growth rates due to declining working-age population growth, weaker productivity growth and, in some cases, lingering effects from the global financial crisis (Graph 1.13). Growth in the United States picked up a little in the June quarter, but has declined in year-ended terms, while Japanese GDP was little changed over the past year. The euro area economy grew at an above-trend rate in the first half of 2016, although heightened uncertainty following the outcome of the United Kingdom's referendum could dampen output growth a little in the period ahead. At this stage, the referendum outcome seems to have had relatively little economic impact outside the United Kingdom. Consumer confidence and survey measures of business conditions remain at or above average levels in the three largest advanced economies (Graph 1.14).

Graph 1.13
Major Advanced Economies – GDP
Annual growth

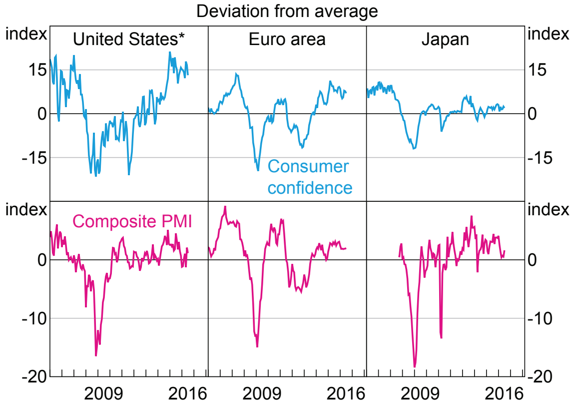


* US based on IMF forecast as at July 2016, adjusted for the June quarter GDP outcome; Japan and euro area based on Consensus Economics forecasts as at July 2016

** US and euro area estimates are for 2016; Japan estimate is for the six months ending March 2016

Sources: Bank of Japan; Congressional Budget Office; Consensus Economics; European Commission; IMF; RBA; Thomson Reuters

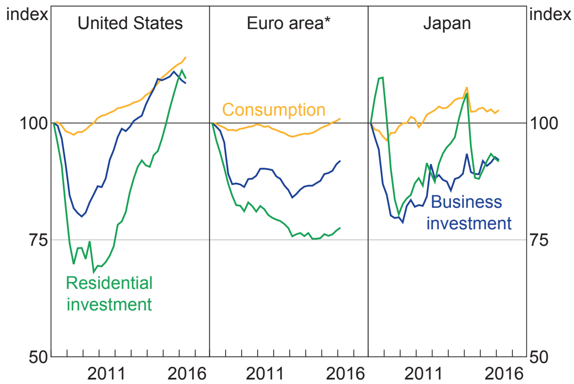
Graph 1.14
Major Advanced Economies – Survey Indicators
Deviation from average



* ISM surveys used to construct a composite survey index

Sources: RBA; Thomson Reuters

Graph 1.15
Major Advanced Economies – GDP Expenditure Components
March 2008 = 100



* Business investment in the euro area includes both public and private investment

Source: Thomson Reuters

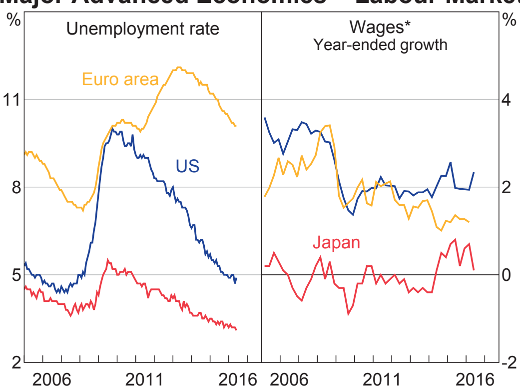
Over the past two years, private consumption has been the key driver of growth in the United States and the euro area (Graph 1.15). In contrast, consumption in Japan has remained subdued since the increase in the consumption tax in early 2014. This led the Japanese Government to postpone the next scheduled increase in the consumption tax from April 2017 to October 2019 and to pursue further fiscal stimulus measures. Consumption growth in the major advanced economies continues to be supported by: low borrowing rates owing to accommodative monetary policies; the boost to real incomes from low fuel prices; and increases in household wealth, including from rising housing prices. Working in the other direction, nominal wage growth remains low.

In the United States, the strength in business investment has waned since late 2014. Investment has declined in the oil & gas and manufacturing sectors, reflecting the fall in oil prices, weaker external demand and the appreciation of the US dollar. In contrast, residential dwelling investment has grown strongly over the past year and a half, supported by an increase in demand for higher-density dwellings and low residential mortgage rates, although there are some signs that it has eased of late. In the euro area and Japan, residential and business investment remain well below their pre-crisis levels. Nonetheless, euro area investment has grown at an above-average rate since early 2015. Business investment in Japan appears to have declined in the first half of 2016, which may, in part, reflect the effects of the appreciation of the yen since late 2015 and weaker external demand; however, survey measures of business investment intentions have held up and corporations still expect to increase investment over the year to March 2017.

Labour markets have improved considerably in recent years across the major advanced economies. Employment growth has been robust in all three economies, resulting in declining rates of unemployment and underemployment (Graph 1.16). Unemployment rates in the United States and Japan are now at or below their long-run averages and estimates of equilibrium levels, indicating that there is little spare capacity in the labour market. Consistent with this tightening, some labour compensation measures suggest a slight pick-up in wage pressures in these economies. Even though nominal wage growth remains low, productivity growth has been weak, such that unit labour costs in the US and Japanese economies have been growing at above-average rates (Graph 1.17). The unemployment rate in the euro area remains well above its long-run average level. Consistent with this, growth in compensation per employee in the euro area remains close to its historic low and unit labour cost growth has declined.

Inflation in the major advanced economies remains below the respective central banks' targets. While core inflation is above its 2015 lows, it has declined in the euro area and Japan over the past six months or so (Graph 1.18). Most measures of inflation expectations in the major advanced economies have declined in recent years to historically low levels. Much of the decline in longer-term market-based inflation expectations in the United States and the euro area has coincided with the decline in oil prices that has also contributed to low headline inflation. Japanese long-term inflation expectations have fallen sharply since late 2015 and have returned to where they were before the Bank of Japan renewed its quantitative easing program in early 2013.

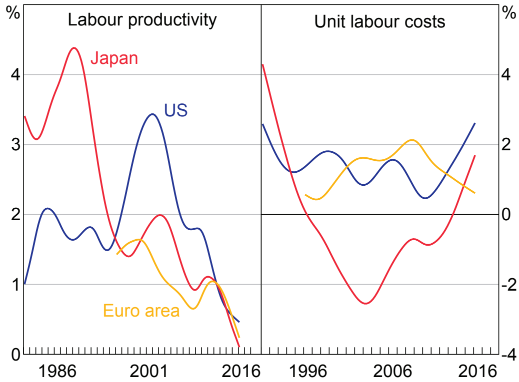
Graph 1.16
Major Advanced Economies – Labour Market



* Employment cost index for the US; compensation per employee for the euro area; average scheduled cash earnings for Japan

Sources: Eurostat; RBA; Thomson Reuters

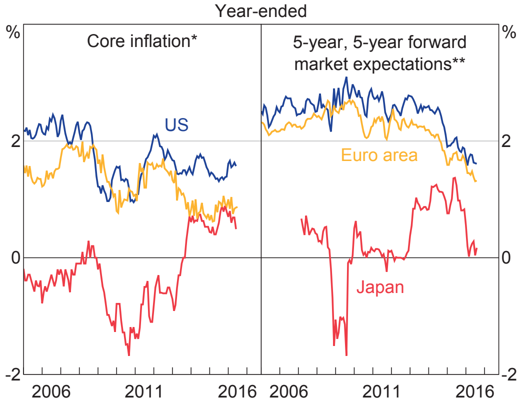
Graph 1.17
Major Advanced Economies – Productivity and Unit Labour Costs
Year-ended growth*



* HP filtered, with smoothing parameter set to 1600

Sources: Eurostat; RBA; Thomson Reuters

Graph 1.18
Major Advanced Economies – Inflation
Year-ended



* Personal consumption expenditures (PCE) inflation for the US; Japan data exclude the effects of the consumption tax increase in April 2014

** US expectations adjusted to be comparable to PCE inflation

Sources: Bloomberg; RBA; Thomson Reuters

United Kingdom

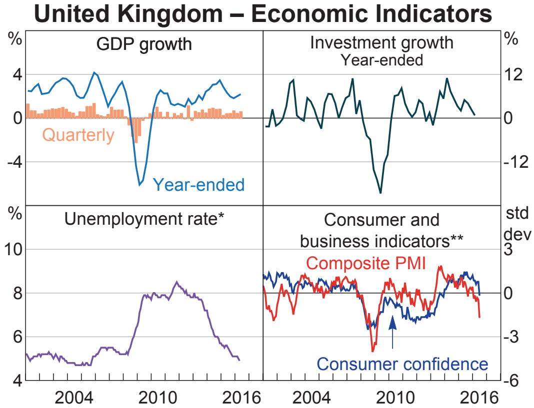
The United Kingdom voted to leave the European Union in a referendum held on 23 June. The formal notification of the decision will trigger a two-year period during which the terms of the United Kingdom's withdrawal from the European Union need to be negotiated.

Prior to the referendum, the UK economy had been growing at a moderate rate (Graph 1.19). Inflation had been below the Bank of England's target for some time, despite very stimulatory monetary policy and a tightening labour market. UK business investment had undergone a recovery, leading to the level of investment surpassing pre-global financial crisis levels in 2014. However, the increase in uncertainty in the lead up to the referendum may have dampened business investment more recently. Surveys of UK consumer confidence and business activity declined sharply after the referendum.

Leaving the European Union is likely to make it more costly and difficult for the United Kingdom to export goods and services to the region. This is important because the United Kingdom's international investment and trade flows, particularly with the European Union, are large. The United Kingdom's combined foreign assets and liabilities are equivalent to around 10 times its GDP;

Graph 1.19

United Kingdom – Economic Indicators



* Three-month moving average

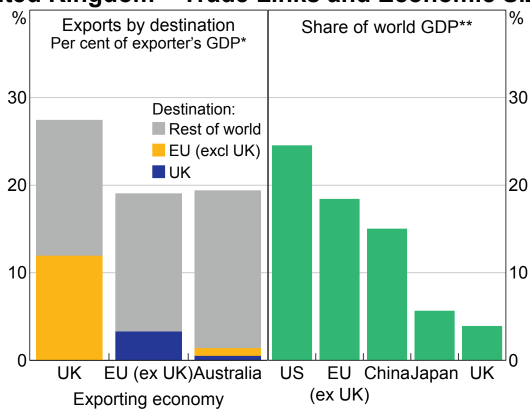
** Standard deviation from long-run average

Sources: Markit; RBA; Thomson Reuters

UK exports equate to around 27 per cent of GDP, nearly half of which are to the rest of the European Union (Graph 1.20). IMF and OECD estimates suggest that UK GDP could be between 1 and 5 per cent lower by the end of 2018, in the absence of any policy response.[4]

Graph 1.20

United Kingdom – Trade Links and Economic Size



* 2015 exports; excludes intra-European Union exports

** 2015 GDP at market exchange rates

Sources: IMF; Thomson Reuters

Commodity Prices

Commodity prices overall are above the lows reached around the turn of the year, but are about 50 per cent below their 2011 peak (Table 1.1; Graph 1.21). Those declines reflect both substantial increases in supply as resource projects have started production as well as weaker global demand, especially from Asia.

The spot price of iron ore has risen sharply in recent weeks, following declines over the previous couple of months (Graph 1.22). The spot price is now around 65 per cent below its 2011 peak, although it remains well above its mid-2000s level. The prices of iron ore and steel had been supported by the

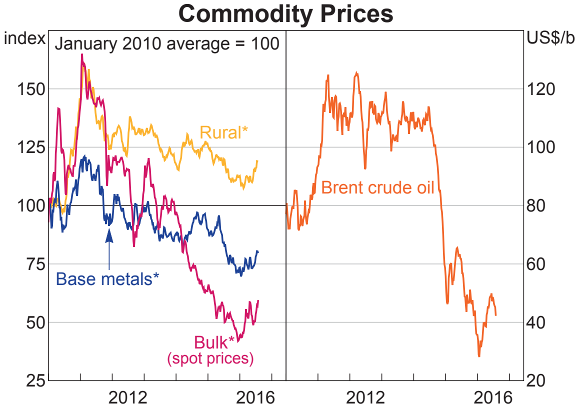
4 See IMF (2016), *'United Kingdom Selected Issues: Macroeconomic Implications of the United Kingdom Leaving the European Union'*, Staff Report on the 2016 Article IV Consultation, April, available at <http://www.imf.org/external/pubs/ft/scr/2016/cr16169.pdf> and OECD (2016), *'Box 1.1. Financial Market Shocks from Brexit'*, OECD Economic Outlook, 2016(1), available at <http://www.oecd.org/eco/outlook/OECD-Economic-Outlook-June-2016-general-assessment-of-the-macroeconomic-situation.pdf>.

Table 1.1: Commodity Price Growth[(a)]
SDR, three-month-average prices, per cent

	Since previous *Statement*	Over the past year
Bulk commodities	2	–2
– Iron ore	–4	–5
– Coking coal	9	7
– Thermal coal	9	–5
Rural	4	–3
Base metals	2	–11
Gold	4	11
Brent crude oil[(b)]	20	–22
RBA ICP	4	–7
– using spot prices for bulk commodities	2	–5

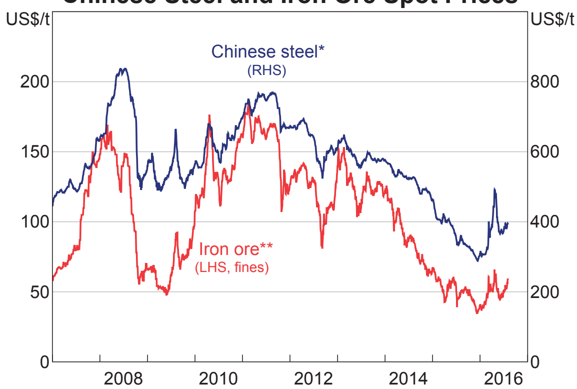
(a) Prices from the RBA ICP; bulk commodities prices are spot prices
(b) In US dollars
Sources: Bloomberg; IHS; RBA

Graph 1.21
Commodity Prices



* RBA Index of Commodity Prices sub-indices, SDR
Sources: Bloomberg; RBA

Graph 1.22
Chinese Steel and Iron Ore Spot Prices

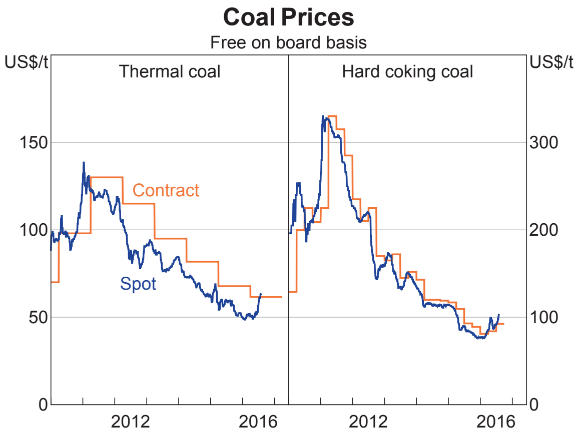


* Average of hot rolled steel sheet and steel rebar prices
** Free on board basis
Sources: Bloomberg; RBA

Chinese Government's announcement of its 2016 growth targets in early March, which improved the near-term outlook for steel demand. Speculative activity in derivative markets and restocking of iron ore inventories were also likely to have played a role in pushing prices higher for a time, but the prices of steel and iron ore declined following actions by the Chinese authorities to curb speculative activity. Chinese steel production is expected to moderate over the year ahead. At the same time, global supply of iron ore is expected to rise as increased supply from Australia and Brazil more than offsets the recent cuts to Chinese iron ore production. The combination of these factors is expected to exert downward pressure on prices.

After declining for much of the past five years, prices of thermal and coking coal have increased in recent months, and are now over 30 per cent above their lows earlier in the year (Graph 1.23). While thermal coal prices remain under pressure from weaker global demand, both thermal and coking coal prices have been supported by ongoing reductions in global supply, including from Chinese

Graph 1.23



Sources: Department of Industry, Innovation and Science; IHS; RBA

and Indonesian producers. Notwithstanding recent increases, at current prices a substantial share of global coal production, including in Australia, is estimated to be unprofitable.

Concerns about global demand, particularly subdued growth of global industrial production, have led to declines in the prices of base metals over the past year, although declines in the production of some of these commodities have supported prices in recent months.

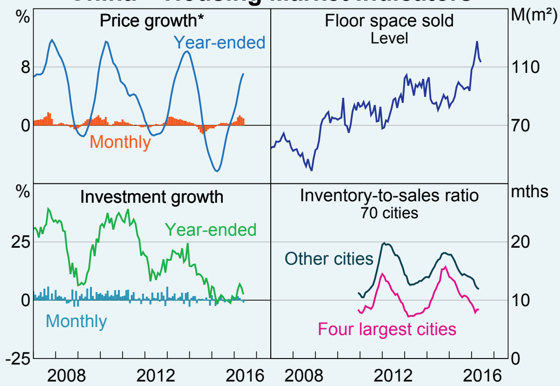
The Brent crude oil price has been higher in the past three months, following supply disruptions in several countries, including Canada and Nigeria (Graph 1.21). Prices have declined more recently, reflecting an increase in global supply and no indication that global production will be lowered. Regional liquefied natural gas (LNG) prices have been weak of late. This reflects the earlier decline in oil prices around the turn of the year, as changes in oil prices tend to affect LNG prices with a lag of a few quarters. The overall increase in the price of oil since then will flow through to the export price of contracted LNG volumes in coming quarters, but increased supply from Australian exporters is likely to place downward pressure on the regional LNG spot price over the next couple of years.

Box A

The Pick-up in the Chinese Housing Market

Dwelling investment has made a significant contribution to GDP growth in China over recent history. Developments in the Chinese housing market affect demand for Australia's exports of iron ore and coking coal owing to the steel-intensive nature of residential construction. Conditions in the Chinese housing market have picked up since the start of 2016 (Graph A1). Housing price inflation has risen, sales (measured as residential floor space sold) have grown rapidly and housing investment has strengthened after a period of weakness. The ratio of unsold inventory of developers to sales has declined, although the stock of unsold property remains high.

Graph A1
China – Housing Market Indicators



* Newly constructed property in 69 large and medium-sized cities

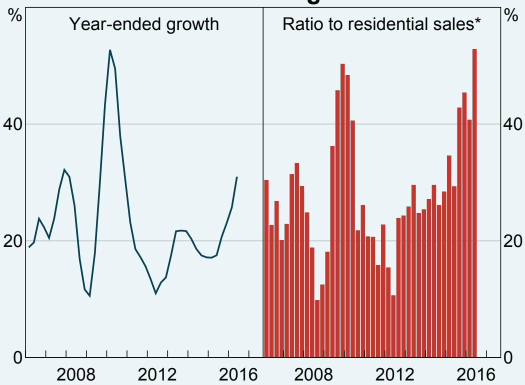
Sources: CEIC Data; CRIC; RBA; WIND Information

Government policy has played an important role in Chinese housing market cycles and a range of stimulus measures implemented since 2014 has contributed to the latest strengthening of conditions.[1] These policies have encouraged purchases of housing with the goal of reducing inventory levels, which have been high in many parts of the country (Graph A1). In September 2015, the minimum down payment for first-home buyers was lowered from 30 per cent to 25 per cent in most cities and a further discretionary 5 percentage point cut was authorised in February 2016. Minimum down payments on second properties were reduced from 60–70 per cent to 30 per cent over the same period. Benchmark lending rates have been cut by around 165 basis points since late 2014, and the estimated national average mortgage rate (a measure of rates actually paid) has fallen by an additional 70 basis points relative to these benchmarks. Property transaction taxes have been reduced and there have been targeted easing measures in some areas, such as subsidies for certain types of home buyers. However, local authorities in some areas have more recently introduced measures to temper strong housing price increases, as discussed in more detail below.

Following these earlier stimulatory measures, housing credit has grown rapidly, rising by more than 30 per cent over the year to June 2016 (Graph A2). Housing credit has also increased sharply relative to the value of property sales, suggesting that buyers are using more leverage to purchase property. Investor demand for housing appears to have contributed to the recent strength in many local housing markets. One likely reason for this is the perceived lack of alternative high-yielding investments, particularly given the unwinding of the equity market boom and declines in yields on wealth management products since mid 2015. While there are no reliable publicly available data that decompose housing purchases by investors

1 For further discussion of the Chinese housing market, see Cooper A and A Cowling (2015), 'China's Property Sector', RBA *Bulletin*, March, pp 45–54.

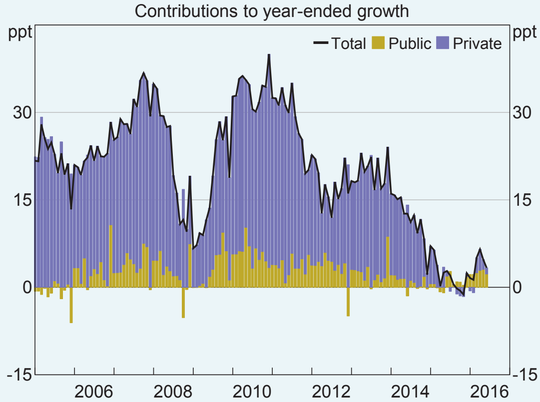
Graph A2
China – Housing Credit



* Seasonally adjusted; ratio of quarterly change in the stock of credit to quarterly residential sales

Sources: CEIC Data; RBA

Graph A3
Real Estate Development Investment



Sources: CEIC Data; RBA

and owner-occupiers, recent media reports suggest that investor demand for housing has accounted for an increasing share of purchases in housing markets that have experienced very strong demand, such as Shenzhen.

The pick-up in investment and sales is also likely to have been supported by policies targeted at property developers, including greater flexibility to alter project plans to satisfy evolving market demand more effectively (for example, allowing developers to change the configuration of rooms in a planned property). State-owned firms have contributed noticeably to the recent pick-up in real estate investment and there have been reports of some state-owned developers purchasing inventory from troubled private developers (Graph A3).

Despite the overall pick-up in housing market conditions, considerable differences across regions have persisted, reflecting differences in local economic conditions. Housing price growth has been weaker and inventory remains highest in smaller cities, reflecting more limited employment opportunities and high levels of dwelling construction relative to demand. In contrast, price growth has been stronger in larger cities, which are characterised by resilient labour markets and a relatively tight supply of housing and land. Many of those mid-sized or smaller cities experiencing rapid price increases, including Foshan, Huizhou, Langfang, Suzhou, Zhongshan and Zhuhai, are located close to one of China's four largest cities (commonly referred to as the 'Tier 1' cities), suggesting that demand may have spilled over from the larger city to the smaller neighbour.[2]

In some housing markets, price growth has been so substantial that the local authorities have responded with tightening measures. In March 2016, the Shanghai and Shenzhen municipal governments announced an increase in minimum down payment requirements for individuals with prior mortgages or existing property ownership and stricter regulations around property purchase for persons without local residency permits. Authorities in the mid-sized cities of Nanjing and Suzhou announced in May that price ceilings would be imposed on certain land purchases.

Given the large stock of unsold properties nationally, any slowing in demand from current levels would pose potential risks for property developers and upstream suppliers of raw materials to residential

2 China's 'Tier 1' cities are Beijing, Guangzhou, Shanghai and Shenzhen.

construction. The recent pick-up in sales has facilitated some reduction in developers' inventories. Yet land prices have been rising relative to housing prices in a number of cities, potentially squeezing developer margins, and the degree of gearing has continued to rise for mainland-listed developers. Developers have diversified their funding sources in recent years, decreasing their direct reliance on bank lending. Given the dominance of banks in China's financial system, it is likely that they are still indirectly exposed to much of this lending.[3] A downturn in market conditions, brought about either by a reduction in the degree of policy stimulus or a loss of confidence among home buyers, could therefore increase credit default risks for financial institutions.

The growth of credit and property prices in some cities has also prompted concerns about financial stability risks arising from the household sector directly. Chinese household indebtedness remains relatively low by international standards, and household mortgages account for only 17 per cent of bank lending. However, housing credit has been rising rapidly, and the recent upswing has been accompanied by reports of less creditworthy borrowers entering the housing market by obtaining credit through informal channels (such as peer-to-peer lending) to finance down payments. This raises both the risk of loan defaults and the potential size of any financial losses in the event that prices fall significantly. While it is difficult to quantify the extent of such practices, recent measures to reduce the incidence of borrowing for down payments indicates that the practice has been viewed with concern by the authorities. In March, the People's Bank of China announced that borrowing to finance down payments was not permitted and local authorities have subsequently increased efforts to rein in related activity.

In summary, despite the pick-up in housing market conditions since the start of 2016, there remains a significant stock of unsold housing in many cities and there may not be sufficient fundamental (owner-occupier) demand to support a reduction in that unsold stock. The apparent contribution of government stimulus measures to the recent strength in the Chinese housing market raises doubts about the sustainability of the recovery, particularly for investment. While there is a concern that the current strength in China's housing markets will not be sustained, the ability of municipal governments to introduce policies targeted to local conditions could help mitigate the risk of extreme fluctuations in regional housing markets.

3 Lending to developers amounts to around 7 per cent of total bank credit in China. Domestic bank loans account for around 15 per cent of developer funding for real estate investment; most funding is drawn from advance payments and self-raised funds.

2. International and Foreign Exchange Markets

Current and expected policies of the major central banks continue to be an important driver of developments in global financial markets. Financial markets had been volatile, both in the lead-up to and, in particular, in the period just after the United Kingdom's referendum on 23 June where a majority voted to exit the European Union (EU). The outcome surprised financial markets, resulting in large moves in bond yields, equity prices (especially those of banks) and exchange rates. The UK pound depreciated sharply following the referendum and reached a 31-year low against the US dollar. Despite considerable price movements, financial markets generally functioned in an orderly manner. Sovereign bond yields have subsequently fallen further and reached the lowest level on record in many countries. The Japanese yen has experienced sizeable swings in recent months and reached its highest level against the US dollar in several years.

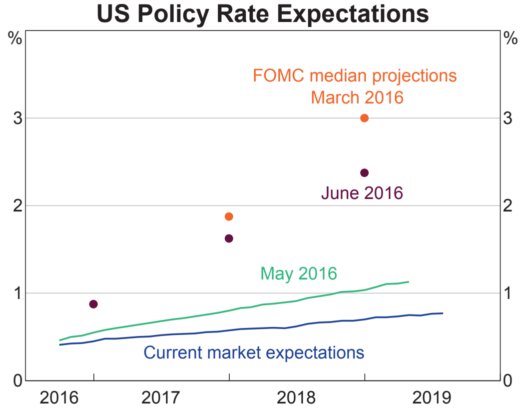
Central Bank Policy

The US Federal Open Market Committee (FOMC) left the target range for the federal funds rate at 0.25–0.50 per cent at both its June and July meetings. At the July meeting, the FOMC noted that household spending and the labour market had strengthened and the near-term risks to the outlook had diminished. Market-implied expectations for the next increase in the federal funds rate have been scaled back since May, with the next policy tightening currently not priced in until late 2017 (Graph 2.1).

The European Central Bank (ECB) has left policy unchanged since it announced additional stimulus measures at its March meeting. It commenced the second round of targeted longer-term refinancing operations (TLTRO II) as well as its purchases of corporate bonds in June. At the first TLTRO II allotment in late June, euro area banks obtained close to €400 billion in four-year term funding, which represents about a quarter of the amount they were eligible to draw from the facility. These banks used most of this funding to repay existing ECB long-term loans (that had less favourable interest rates), such that the net increase in term funding to banks was only €30 billion.

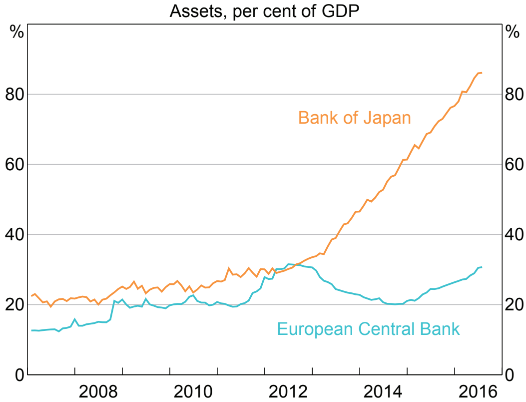
The ECB balance sheet now exceeds its previous peak in 2012. The ECB's outright purchases of public and private sector debt securities account for most of the €1.3 trillion increase in the ECB's balance sheet since mid 2014, which now stands

Graph 2.1
US Policy Rate Expectations



Sources: Bloomberg; Board of Governors of the Federal Reserve System; RBA at €3.3 trillion (or about 30 per cent of GDP; Graph 2.2). The UK vote to exit the EU raised expectations for further ECB stimulus, with markets now pricing in an additional reduction in the deposit rate over the coming year.

Graph 2.2
Central Bank Balance Sheets
Assets, per cent of GDP



Sources: Bank of Japan; European Central Bank; Thomson Reuters

The Bank of England (BoE) left its policy rate unchanged at 0.5 per cent at its July meeting but signalled that it expects to ease monetary policy at its August meeting. At the time of writing, markets had priced in a 25 basis point reduction of the policy rate at the BoE's meeting on 4 August with some expectations of a resumption of asset purchases.

Following the introduction of a negative interest rate on certain deposits in late January, the Bank of Japan (BoJ) has left monetary policy largely unchanged. At its July meeting, it increased the pace of annual purchases of exchange-traded funds from ¥3.3 trillion to ¥6 trillion, but maintained the overall pace of its balance sheet expansion at around ¥80 trillion annually. The BoJ announced that it will conduct a comprehensive assessment of its current policy measures, which will be deliberated at its next policy meeting in September.

The People's Bank of China (PBC) has held benchmark interest rates steady so far this year and left system-wide reserve requirement ratios unchanged since a 50 basis point reduction in February. Interbank interest rates have remained broadly stable over recent months, with the PBC actively managing liquidity conditions through open market operations and the use of its lending facilities.

A number of other central banks have eased policy in recent months (Table 2.1). The Bank of Korea lowered its policy rate by 25 basis points to 1.25 per cent, noting that while it expects a modest recovery in economic activity, the risks to growth have increased. Malaysia's central bank lowered its policy rate by 25 basis points to 3 per cent due to concerns that slower growth in major trading partners could weigh on growth. Bank Indonesia also reduced its policy rate by 25 basis points in

Table 2.1: Monetary Policy

	Policy rate Per cent		Most recent change
Euro area[(a)]	–0.40	↓	Mar 16
Japan[(a)]	–0.10	↓	Jan 16
United States[(b)]	0.375	↑	Dec 15
Australia	1.50	↓	Aug 16
Brazil	14.25	↑	Jul 15
Canada	0.50	↓	Jul 15
Chile	3.50	↑	Dec 15
India	6.50	↓	Apr 16
Indonesia	5.25	↓	Jun 16
Israel	0.10	↓	Feb 15
Malaysia	3.00	↓	Jul 16
Mexico	4.25	↑	Jun 16
New Zealand	2.25	↓	Mar 16
Norway	0.50	↓	Mar 16
Russia	10.50	↓	Jun 16
South Africa	7.00	↑	Mar 16
South Korea	1.25	↓	Jun 16
Sweden	–0.50	↓	Feb 16
Switzerland[(b)]	–0.75	↓	Jan 15
Thailand	1.50	↓	Apr 15
Turkey	7.50	↓	Feb 15
United Kingdom	0.50	↓	Mar 09

(a) Marginal rate paid on deposits at the central bank
(b) Midpoint of target range
Sources: Central banks; RBA; Thomson Reuters

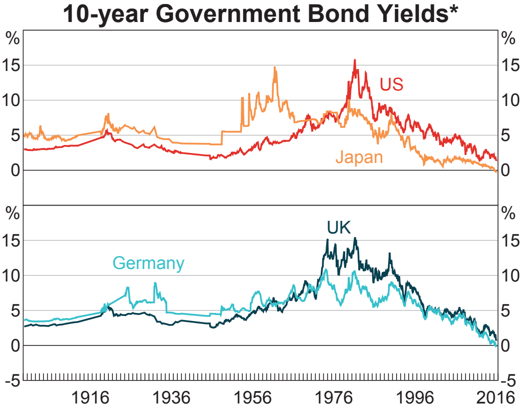
an effort to boost economic growth and domestic credit, while Russia's central bank lowered its policy rate by 50 basis points in response to easing concerns about high inflation and a further decline in inflation expectations. Following the attempted coup in Turkey, the central bank announced a number of measures to ensure the functioning of financial markets, including providing banks with unlimited liquidity. Mexico's central bank raised its policy rate by 50 basis points to 4.25 per cent, to counter the effects of the recent depreciation of the peso on inflation and inflation expectations.

Sovereign Debt Markets

Yields on major market sovereign bonds have been volatile in recent months. Major market sovereign bond yields fell sharply immediately following the UK referendum, with yields on 10-year UK, US and German government bonds declining by around 25–35 basis points intraday. Sovereign bond yields in major markets continued to decline over the following days to reach historical lows, including for Australia (Graph 2.3). Yields on UK sovereign bonds declined despite a ratings downgrade (by two ratings agencies) following the referendum.

Bond yields have at least partly reversed these falls over the past month, following generally stronger-than-expected US economic data and some reduction in UK political uncertainty, with

Graph 2.3
10-year Government Bond Yields*

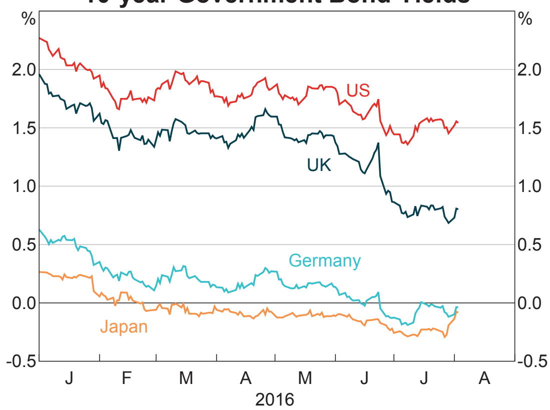


* Data interpolated during World War I and World War II; German data also interpolated between 1921 and 1924

Sources: Bloomberg; Global Financial Data; RBA

the appointment of a new prime minister and the announcement that the UK government would not trigger the start of the formal process to exit the EU this year (Graph 2.4).

Graph 2.4
10-year Government Bond Yields



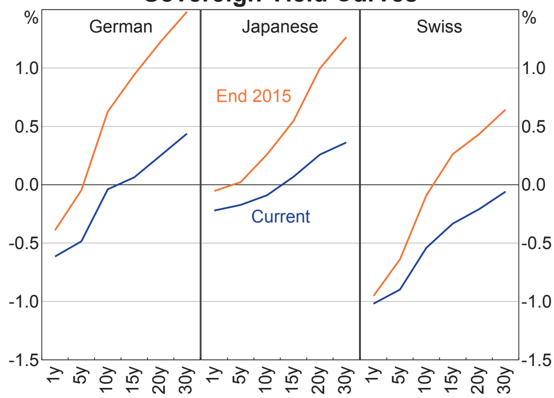
Source: Bloomberg

Japanese government bond yields have been particularly volatile over the past few months. Yields declined, in part owing to expectations of additional fiscal and monetary stimulus, but then rose significantly after the BoJ left its policy largely unchanged at its July meeting. Overall, since the previous *Statement* Japanese government bond yields have increased a little.

Looking through the volatility in recent months, most major market sovereign bond yields have declined markedly since the start of the year – with 10-year US, German and Japanese sovereign bond yields around 35–75 basis points lower. There has also been a material flattening of yield curves since the beginning of the year. German and Japanese government bonds with tenors up to 10 years are currently trading at negative yields, while Swiss government bonds trade at negative yields up to 30 years maturity (Graph 2.5).

Yields on 10-year bonds issued by governments in the euro area periphery have generally declined since the start of the year. Spreads of these bonds over German Bunds have generally narrowed slightly since early May, as the initial widening

Graph 2.5
Sovereign Yield Curves

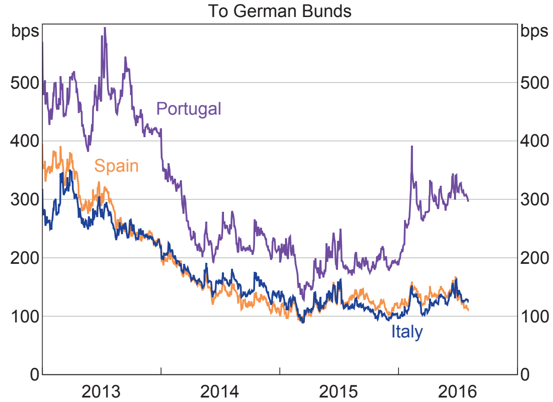


Source: Bloomberg

of spreads directly after the UK referendum was subsequently more than unwound (Graph 2.6). Since the start of the year, spreads on 10-year Italian sovereign bonds have widened amid investor concerns about the broader risks arising from non-performing loans of Italian banks and the upcoming Italian constitutional referendum in October.

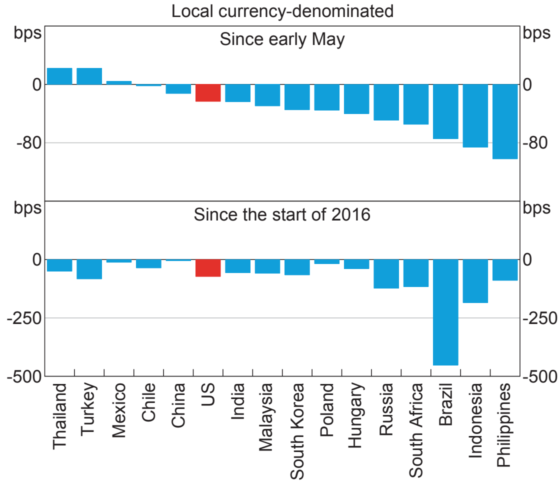
Yields on emerging market sovereign bonds denominated in local currency have generally declined in recent months, alongside falls in US Treasury yields (Graph 2.7). Local currency-denominated sovereign bond yields of a number of commodity exporters declined by up to 85 basis points, as commodity prices rose. The

Graph 2.6
Euro Area 10-year Government Bond Spreads
To German Bunds



Source: Bloomberg

Graph 2.7
Change in 10-year Government Bond Yields
Local currency-denominated



Sources: Bloomberg; Thomson Reuters

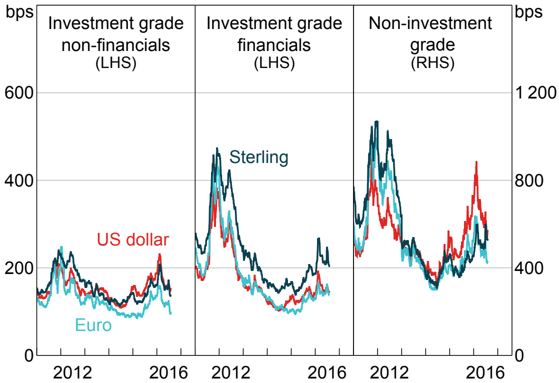
suspension of Brazilian President Rousseff's powers and duties and the appointment of an interim president as well as a recovery in commodity prices have contributed to a very large fall in 10-year Brazilian government bond yields since the start of the year. In contrast, yields on 10-year Turkish government bonds rose following the attempted military coup in mid July and have increased since early May.

Credit Markets

Yields on both investment grade and non-investment grade corporate bonds in US and euro area markets have fallen in recent months, as spreads have narrowed in combination with declines in sovereign yields. Spreads on non-investment grade bonds in the United States narrowed by as much as 100 basis points, before widening following a decline in oil prices (Graph 2.8). The fall in US investment grade bond spreads was relatively muted. Similar to other financial markets, conditions in corporate bond markets were volatile around the time of the UK referendum.

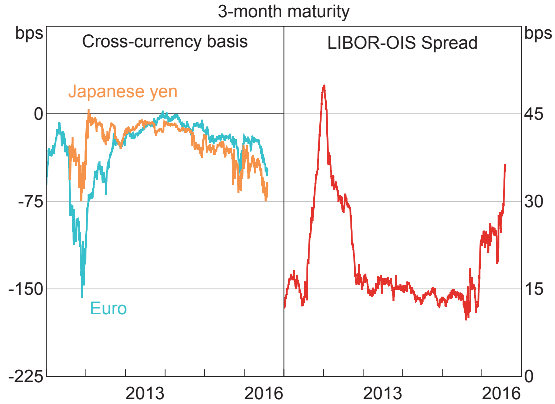
Moves in sterling markets were particularly pronounced following the referendum and in some

Graph 2.8
Corporate Bond Spreads
To equivalent government bonds



Sources: Bank of America Merrill Lynch; Bloomberg; RBA

Graph 2.9
US Dollar Funding Costs
3-month maturity



Source: Bloomberg

cases have been only partially unwound. Spreads on sterling non-investment grade bonds, which are primarily issued by UK corporations, rose by around 110 basis points after the referendum and have subsequently reversed only two-thirds of that. Spreads on bonds issued by financial corporations in the sterling market also rose by more than those in non-sterling markets; spreads on these bonds have since returned to around their pre-referendum levels, but these bonds have underperformed other sterling investment grade bonds. Spreads on short-term bank funding in the sterling unsecured market widened significantly after the UK referendum result, reaching their highest levels since 2012. These spreads remain elevated, but banks' borrowing costs have fallen in absolute terms due to a lower expected path of UK policy rates.

The cost of borrowing US dollars in exchange for yen and euros in short-term foreign exchange swap markets has increased; in late July, the cost of borrowing in exchange for yen reached its highest level in almost five years (Graph 2.9). This reflects an increase in demand from Japanese investors to reallocate to (hedged) US dollar-denominated assets where bond yields are higher.

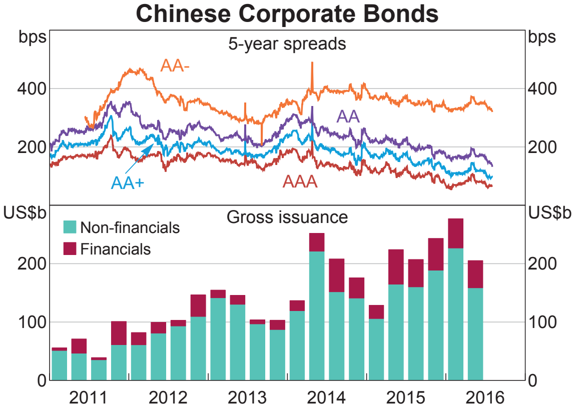
Spreads on short-term bank funding in US dollar markets have risen to their highest levels since 2012. Some part of this reflects the fact that the increased cost of borrowing US dollars in short-term foreign exchange swap markets has led to Japanese banks raising more funds in US short-term funding markets. The upcoming implementation of reforms to US money market funds (MMFs) in October is also reducing the number of such funds that lend to banks. Partly as a result of these reforms, prime MMFs' (that is, those MMFs that lend to banks) assets under management have fallen by over US$400 billion over the past year, as some prime funds switched their classification to government-only (which invest only in US government securities) and investors have begun to reallocate away from prime funds. Moreover, remaining prime funds have lowered the weighted-average maturity of their assets to increase their liquidity buffers ahead of the implementation date in October.

Bond issuance from US and euro area firms fell back to low levels in June and July amid uncertainty and volatility around the time of the UK referendum, after strong issuance from US firms in May. Issuance from firms incorporated in the euro area had previously increased following the ECB's announcement in March that its asset purchase program would be extended to include bonds issued by non-bank investment grade corporations. The ECB commenced purchases of these bonds in early June and currently holds a total of €13.2 billion.

Gross bond issuance by Chinese corporations slowed in the June quarter, following record high issuance in the March quarter (Graph 2.10). As a result, net corporate bond issuance in the June quarter was weak. Issuance of short-term corporate debt securities also declined in the quarter, and was less than the value of maturities during the period. The weaker corporate bond issuance coincided with a period of heightened investor caution towards the corporate bond market and an increase in the number of cancellations of planned bond issues, after a number of missed bond payments by some corporations over March and April. The increase in missed bond payments also contributed to an increase in local currency-denominated corporate bond spreads. Since May, these increases have been reversed, with spreads on highly rated bonds returning to around historical lows. Cancellations of bond issues have returned to normal levels, following a decline in the number of missed bond payments and the payment of bond obligations by some corporations that were expected to default (including a central government-owned enterprise). Local government bond issuance remained strong in the June quarter, supported by the ongoing local government debt swap program.

Since May, the first four issues of asset-backed securities with non-performing loans as underlying assets were sold as part of a pilot program involving the six largest Chinese banks. The program attempts to improve the quality of assets on banks' balance sheets in response to an increase in the proportion of non-performing loans.

Graph 2.10
Chinese Corporate Bonds



Sources: Bloomberg; CEIC Data; Dealogic; RBA

Spreads on US dollar-denominated bonds issued by other emerging market corporations mostly continued to narrow, consistent with developments in non-investment grade bonds in the United States. The narrowing in spreads was particularly pronounced for Brazilian corporations, consistent with falls in Brazilian sovereign yields. In contrast, spreads on bonds issued by Turkish corporates have widened sharply following the attempted coup. New issuance remains subdued, with cumulative gross issuance by emerging market corporations in the year to date continuing at its slowest pace since 2009.

Equities

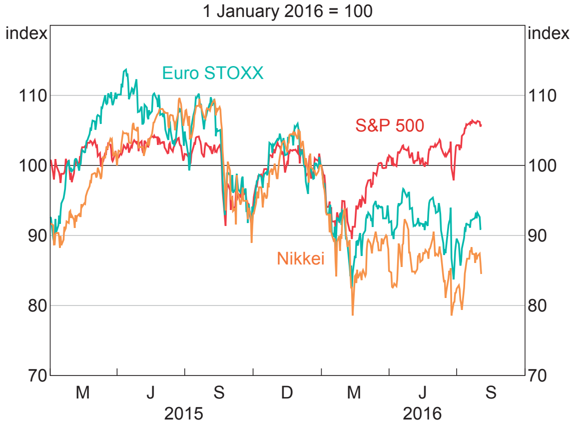
Global equity prices fell following the UK referendum but have since retraced most of these falls and, in some cases, exceed their pre-referendum levels (Table 2.2). The share price falls were particularly pronounced in Japan and the euro area (especially in the periphery countries) (Graph 2.11). While an appreciation of the Japanese yen (see Foreign Exchange) had contributed to

Table 2.2 Changes in International Share Prices
Per cent

	Over 2015	2016 to date
United States – S&P 500	–1	6
Euro area – STOXX	8	–9
United Kingdom – FTSE	–5	6
Japan – Nikkei	9	–16
Canada – TSE 300	–11	12
Australia – ASX 200	–2	3
China – MSCI All China	2	–12
MSCI indices		
– Emerging Asia	–8	3
– Latin America	–11	20
– Emerging Europe	–4	2
– World	**–1**	**1**

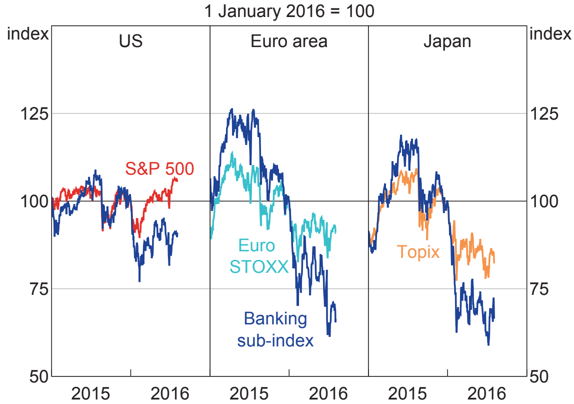
Source: Bloomberg

Graph 2.11
Major Share Price Indices



Source: Bloomberg

Graph 2.12
Major Market Bank Share Prices



Source: Bloomberg

the fall in Japanese stock prices, expectations of increased fiscal stimulus have since provided some support. In the United Kingdom, share prices of domestically focused firms fell significantly following the referendum and remain slightly below their pre-referendum levels. In contrast, share prices of more internationally focused UK firms fell by less than many other major markets immediately following the referendum and have since increased significantly, as the depreciation of the UK pound was seen as supporting these firms' earnings (see Foreign Exchange).

The US S&P 500 index has significantly outperformed the MSCI World index so far this year and has reached a record high. The UK referendum outcome had a less pronounced effect on US share prices, which were supported by expectations of a delay in policy tightening by the Federal Reserve, stronger-than-expected US payrolls data and better-than-expected corporate earnings.

Share prices of banks in the major markets fell following the UK referendum result (by around 10 per cent) and have underperformed the broader indices to be significantly lower over the year so far (Graph 2.12). A number of factors have contributed to the weakness in bank share prices: a general decline in bank earnings expectations, predominantly attributed to concerns about growing pressure on net interest margins resulting from lower risk-free rates and a flatter yield curve; ongoing concerns about Italian banks' non-performing loans; and the upcoming Italian constitutional referendum in October.

Reported net income of European banks has declined compared with the same period in 2015, but was generally above consensus expectations. Net interest income tended to be lower, while higher revenues from trading provided some support for the income of a number of banks. Headline profits of the major US banks declined in the June quarter compared with the same period last year, largely as a consequence of idiosyncratic factors (such as restructuring costs), most of which are not likely to be recurring. US banks benefited from a decline in expenses (largely a result of cost-cutting efforts), lower loan loss provisions and an increase in fixed income trading revenues amid higher client activity. However, net interest margins declined in the quarter.

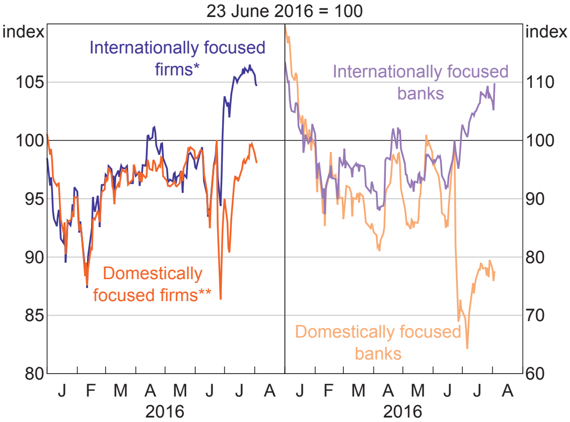
The stress tests by the European Banking Authority published in late July highlighted the progress of 51 of the largest European banks (covering around 70 per cent of banking assets in the European Union) in strengthening their capital. Only a small number of banks had their projected capital ratio fall below their respective regulatory minimums in the 'adverse' stress test scenario, although the sample was smaller than at the previous stress test in 2014.

Share prices of UK banks also fell immediately following the referendum, though there has been a large variance in outcomes (similar to the wide spectrum of outcomes for UK companies discussed above). The share prices of large UK banks with a more domestic focus (such as Lloyds and Royal Bank of Scotland) have fallen by around 25 per cent, reflecting concerns that weaker macroeconomic fundamentals could expose these banks to a decline in revenues and deteriorating asset quality (including in relation to the commercial property market). The BoE reduced the countercyclical capital buffer (which was scheduled to become effective from March 2017) from 0.5 per cent to 0 per cent in an effort to ease financial conditions for UK banks. In contrast to their domestically focused counterparts, share prices of more internationally focused UK banks have risen significantly (Graph 2.13).

Share prices of asset managers and insurance firms in the United Kingdom also fell immediately after the referendum. Six UK commercial property funds, representing a large proportion of the property fund market, have suspended redemptions temporarily due to exceptional liquidity pressures. Redemption requests had risen after the UK referendum as investors became concerned about a fall in UK commercial property prices. Other commercial property funds continued to allow redemptions but had significantly lowered the unit prices at which investor holdings could be redeemed.

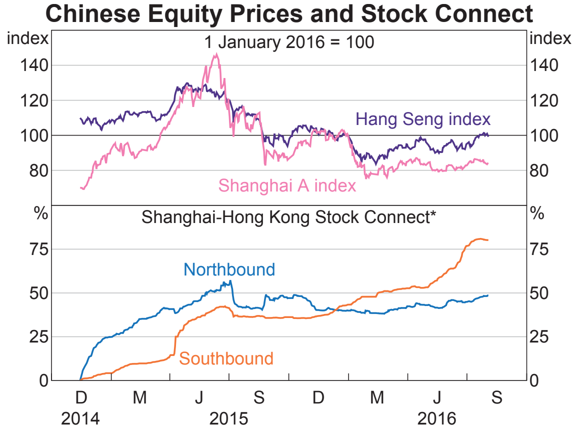
Share prices in emerging market economies have generally outperformed advanced economy equity prices since the beginning of the year, although performance has been mixed in recent months. Chinese equity prices, while still significantly lower than at the start of the year, have been little changed in recent months (Graph 2.14). Investments in Hong Kong-listed (and Hong Kong dollar-denominated) shares via the Stock Connect program have increased by around 50 per cent since early May (equivalent to an increase in the aggregate quota usage by 25 percentage points), alongside a decline in the renminbi's exchange rate against the US dollar. Equity prices in the Philippines rose by around 10 per cent following the presidential election in the beginning of May. Brazilian equity prices performed strongly alongside capital inflows and improved sentiment under the government led by the interim president. In contrast, Turkish equity prices fell sharply following the attempted military coup and announcement of a three-month state of emergency, reversing most of their gains since the start of the year.

Graph 2.13
UK Share Prices



* FTSE 100
** FTSE 250
Sources: Bloomberg; RBA

Graph 2.14
Chinese Equity Prices and Stock Connect

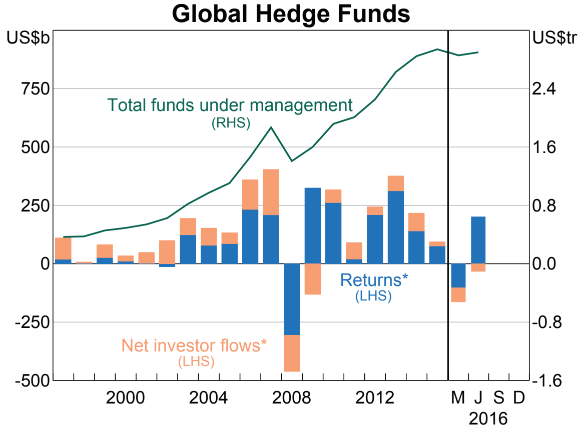


* Aggregate balance used as a share of total aggregate quota. Calculated on a 'net buy' basis after adjustments
Source: Bloomberg

Hedge Funds

Global hedge funds recorded an asset-weighted return on investment of 1.1 per cent over the June quarter. The return underperformed a balanced portfolio of global bonds and equities. The strongest performance came from funds that invest in emerging markets, particularly Latin America. Fixed income relative value funds also experienced strong gains amid declining interest rates (and rising bond prices) in the United States, Europe and Japan. Investors have made net withdrawals from hedge funds for the third consecutive quarter, but positive investment returns saw funds under management increase by over US$40 billion over the June quarter to US$2.9 trillion (Graph 2.15).

Graph 2.15
Global Hedge Funds

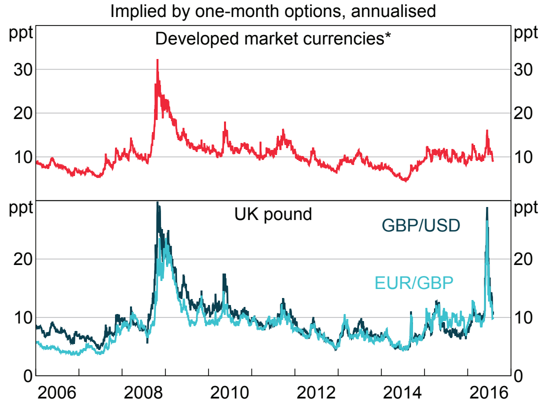


* Annualised for 2016 data
Sources: Hedge Fund Research, Inc.; RBA

Foreign Exchange

Foreign exchange markets have been primarily influenced by the UK referendum and evolving expectations about monetary policy in the major economies. Heightened uncertainty in the lead-up to the referendum contributed to a sharp increase in forward-looking measures of volatility in the main developed market currency pairs, particularly for the UK pound (Graph 2.16). Immediately following the referendum, the UK pound depreciated sharply, while the US dollar and yen appreciated

Graph 2.16
Volatility
Implied by one-month options, annualised



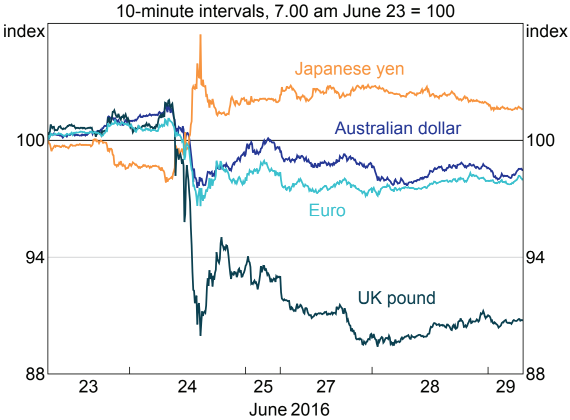
* EUR/USD, USD/JPY, GBP/USD, AUD/USD, USD/CAD, USD/CHF, EUR/JPY, EUR/GBP, EUR/CHF; weighted by share of foreign exchange turnover
Source: Bloomberg

markedly. Volatility eased in the days following the referendum and is currently around its long-run average.

Prior to the referendum, the UK pound moved within a relatively wide range alongside changes in the expected probability of the United Kingdom voting to exit the EU. The UK pound reached a high of US$1.50 per pound shortly after UK polls closed as markets expected a 'Remain' vote, but then depreciated by over 10 per cent to reach a low of US$1.32 per pound as it became likely that the referendum outcome would be a 'Leave' vote (Graph 2.17). Throughout this period, transaction volumes in foreign exchange markets were higher than usual and markets generally functioned well. The UK pound recovered slightly to US$1.37 by the close of the trading session on 24 June to finish the day 8 per cent lower; this was the largest daily move in the GBP/USD currency pair since the currency floated in 1971. Overall, the UK pound has depreciated by around 10 per cent against the US dollar from its level immediately prior to the referendum and is around its lowest level since 1985 (Graph 2.18). On the day of the referendum outcome, heightened risk aversion contributed to appreciation pressures on the Japanese yen, US dollar and Swiss franc. The euro also depreciated markedly against

Graph 2.17
Selected Currencies against the US Dollar*

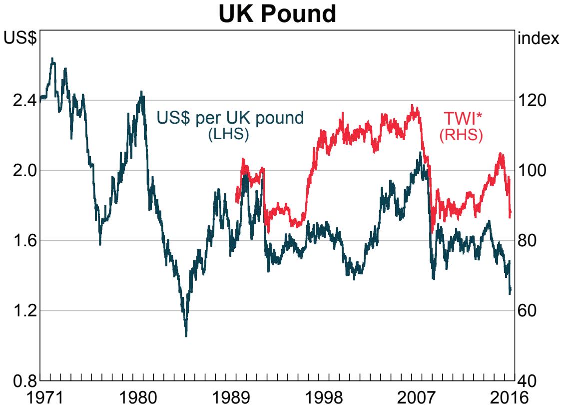
10-minute intervals, 7.00 am June 23 = 100



* Australian Eastern Standard Time (AEST)

Sources: EBS; Thomson Reuters

Graph 2.18
UK Pound



* 1990–2016 average = 100

Source: Bloomberg

the US dollar on the day of the referendum outcome, but recovered to settle around 2½ per cent lower over the day. Over the year to date, the euro has appreciated by around 2 per cent against the US dollar and on a trade-weighted (TWI) basis.

Since early May, the US dollar has appreciated by 3 per cent on a trade-weighted basis, despite market participants pushing back their expectations for the timing of the next policy rate increase by the FOMC (Table 2.3; Graph 2.19). The appreciation has been most pronounced against the currencies of European countries,

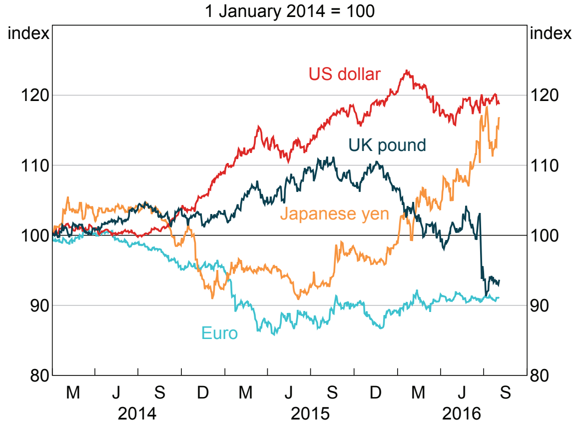
Table 2.3: Changes in the US Dollar against Selected Currencies
Per cent

	Over 2015	2016 to date
UK pound sterling	6	11
Mexican peso	17	10
Chinese renminbi	5	2
Swedish krona	8	1
Indian rupee	5	1
Philippine peso	5	0
European euro	11	–3
Thai baht	10	–3
Swiss franc	1	–3
New Taiwan dollar	4	–3
Australian dollar	12	–4
New Zealand dollar	14	–5
Indonesian rupiah	11	–5
South Korean won	8	–5
Singapore dollar	7	–5
Canadian dollar	19	–6
Malaysian ringgit	22	–6
Russian rouble	24	–8
Japanese yen	0	–16
Brazilian real	50	–18
TWI	**10**	**–1**

Sources: Bloomberg; Board of Governors of the Federal Reserve System

Graph 2.19
Nominal Trade-weighted Indices

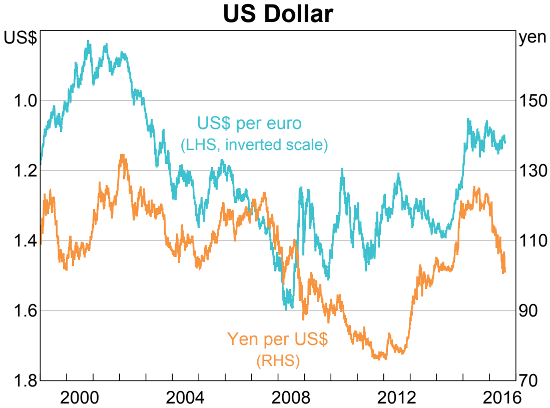
1 January 2014 = 100



Sources: BIS; Bloomberg; Board of Governors of the Federal Reserve System particularly the United Kingdom. Notwithstanding the recent appreciation, the US dollar remains around 4 per cent below its peak in late January on a trade-weighted basis.

The Japanese yen has traded in a wide range against the US dollar amid speculation of further macroeconomic policy stimulus in Japan (Graph 2.20). The Japanese yen experienced bouts of appreciation alongside the BoJ's decision to leave monetary policy largely unchanged at its June and July meetings and increased risk aversion associated with uncertainty around the UK referendum, but also depreciated significantly ahead of the BoJ's July meeting. Overall, the yen has appreciated by around 6 per cent against the US dollar and around 8 per cent in trade-weighted terms since the previous *Statement*. It reached its highest level against the US dollar in three years.

Graph 2.20
US Dollar

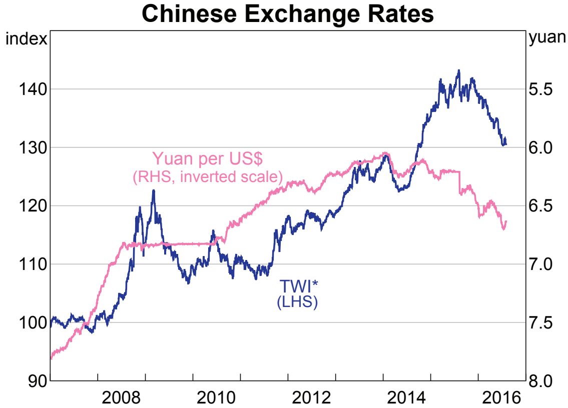


Source: Bloomberg

In the month leading up to the UK referendum, the Swiss franc appreciated by 3 per cent against the US dollar and by 2 per cent against the euro, reflecting safe-haven flows. Since the referendum, the Swiss franc has been little changed against the US dollar and the euro. The Swiss National Bank (SNB) intervened in the foreign exchange market following the UK referendum to mitigate appreciation pressure on the franc. Over the month of June, SNB's foreign currency reserves rose by 6.7 billion francs to 608.8 billion francs (equivalent to 95 per cent of GDP).

The Chinese renminbi (RMB) has continued to depreciate against a broad range of currencies, to be 6 per cent lower on a trade-weighted basis since the start of the year and 9 per cent lower since its early August 2015 peak (Graph 2.21). Against the US dollar, the RMB has depreciated by 2 per cent over the year to date and reached its lowest level since 2010. The RMB continues to trade in the offshore market at a discount to the onshore market; however, the level of the discount has remained small relative to that seen in December 2015.

Graph 2.21
Chinese Exchange Rates

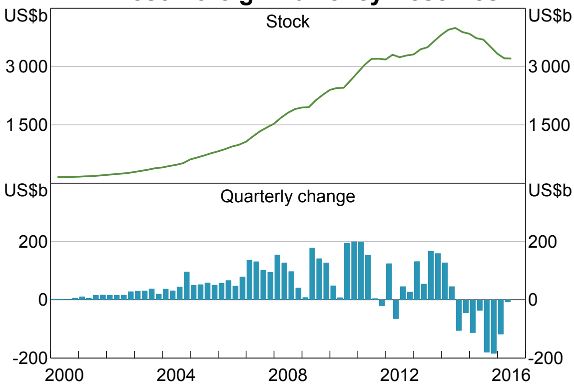


* Indexed to 2007 average = 100
Sources: BIS; Bloomberg; RBA

The PBC's foreign currency reserves decreased by only US$7 billion in the June quarter, which is likely to have reflected valuation effects (Graph 2.22). Overall, the value of reserves has been broadly stable since February, at around US$3.2 trillion (29 per cent of GDP). This suggests that net capital outflows have declined, following the large capital outflows in the year to the March quarter 2016.

In mid June, the Chinese authorities granted the United States a RMB250 billion quota under the RMB Qualified Foreign Institutional Investor scheme and committed to establish two RMB clearing banks in the United States. A commitment to establishing a clearing bank in Russia was also announced. The

Graph 2.22
Chinese Foreign Currency Reserves

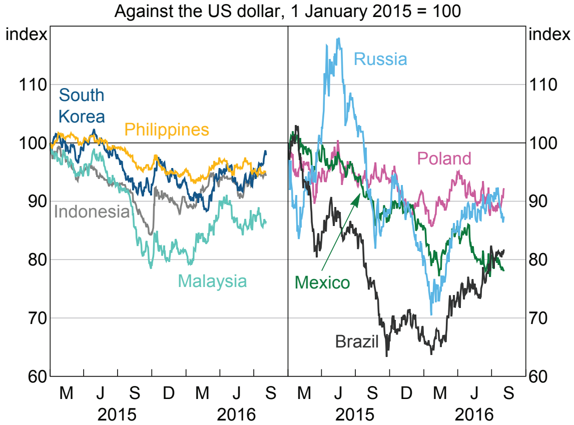


Source: CEIC Data

PBC also allowed the Korean won and the South African rand to trade directly with the RMB in the onshore foreign exchange market. There are now 14 currencies that trade directly with the RMB in the onshore market.

Over the past few months, most other Asian currencies have been little changed against the US dollar, while most other emerging market currencies have depreciated against the US dollar (Graph 2.23). In the lead-up to the UK referendum, most emerging market currencies appreciated against the US dollar but depreciated following the outcome – particularly the currencies of emerging European economies. Over the past few months,

Graph 2.23
Asian and Emerging Market Currencies
Against the US dollar, 1 January 2015 = 100



Source: Bloomberg

volatility in emerging market currencies has remained above its average level since 2010.

The Brazilian real has continued to appreciate against the US dollar over recent months alongside domestic political developments and increases in commodity prices, to be around 28 per cent above its trough in late January. In July, Brazil's central bank recommenced auctioning reverse foreign exchange swaps, which helped to curb appreciation pressure on the currency from late March through to mid May this year. In contrast, the Mexican peso has depreciated by 9 per cent since its peak in late April. Over recent months, the peso has depreciated by more than most other emerging market currencies; according to market participants, this is partly due to the peso being traded as a general proxy for risk in emerging market economies. Given the depreciation of the peso and concerns about its effect on inflation and inflation expectations, the Bank of Mexico increased its policy rate by 50 basis points at its June meeting.

The gross foreign currency reserves of most emerging market economies have been little changed or have increased slightly since the end of March (Table 2.4). The increase in Argentina's gross foreign currency reserves since the end of March has largely reflected the proceeds of bond sales.

Australian Dollar

The Australian dollar has appreciated a little against the US dollar and on a trade-weighted basis since the previous *Statement*, and appreciated by 11 per cent against the UK pound (Table 2.5; Graph 2.24). Throughout this period, the Australian dollar has been affected by changes in expectations for monetary policy in Australia and the United States, as well as the uncertainty surrounding the UK referendum. The Australian dollar was volatile on the day of the UK referendum outcome and bid-ask spreads in the AUD/USD currency pair increased for a time (see 'Box C: Australian Financial Markets and the UK Referendum'). The Australian dollar is

Table 2.4: Gross Foreign Currency Reserves[(a)]

	Percentage change since: End June 2015	End March 2016	Level US$ equivalent (billions)
China	–13	0	3 205
Saudi Arabia	–15	–3	560
Taiwan[(b)]	3	0	434
South Korea	–2	0	360
Brazil	–1	3	357
Hong Kong	7	1	351
India	2	1	338
Russia	5	0	318
Singapore	–2	1	246
Mexico	–8	–1	169
Thailand	12	2	169
Indonesia	1	2	103
Turkey	1	6	100
Malaysia	–8	0	89
Argentina	–8	10	26

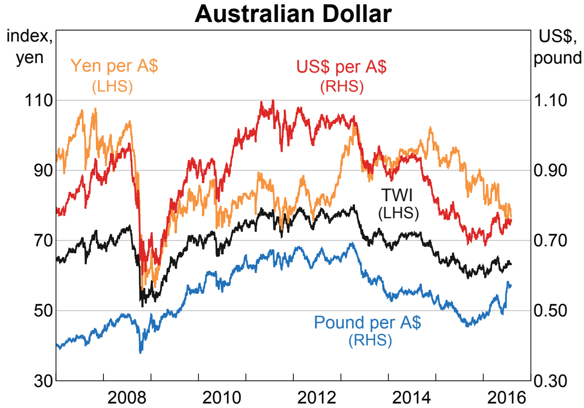
(a) Data to end June for China, Hong Kong, Indonesia, Mexico, Saudi Arabia, Singapore, South Korea, Taiwan and Thailand; to 15 July for Malaysia; to 22 July for India, Russia and Turkey; to end July for Argentina and Brazil.
(b) Foreign exchange reserves (includes foreign currency and other reserve assets).
Sources: Bloomberg; CEIC Data; central banks; IMF; RBA

Table 2.5: Changes in the Australian Dollar against Selected Currencies
Per cent

	Over 2015	2016 to date
UK pound sterling	–6	15
Chinese renminbi	–7	6
Indian rupee	–7	5
US dollar	–11	4
European euro	–1	1
Thai baht	–2	1
Swiss franc	–10	1
New Zealand dollar	2	–1
Indonesian rupiah	–1	–1
South Korean won	–4	–1
Singapore dollar	–5	–1
Canadian dollar	6	–2
Malaysian ringgit	9	–2
South African rand	19	–6
Japanese yen	–11	–12
TWI	**–6**	**1**

Sources: Bloomberg; RBA

Graph 2.24
Australian Dollar



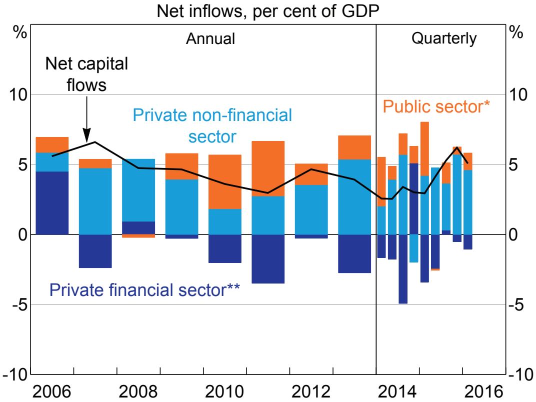
Sources: Bloomberg; RBA

currently around 10 per cent higher against the US dollar and 8 per cent higher on a TWI basis than the low it reached in September 2015. However, the Australian dollar is still around 20 per cent lower against the US dollar and around 12 per cent lower on a TWI basis than its peak in mid 2014.

Capital Flows

Net capital inflows to the Australian economy were equivalent to 5.1 per cent of GDP in the March quarter, around ½ percentage point higher than the average of net capital inflows over the past 10 years (Graph 2.25). Net capital inflows in the quarter largely reflected flows to the private non-financial sector, most of which were directed to the mining sector, while there were net outflows from the financial sector. There were modest net inflows to the general government and state and local government sectors in the March quarter. Notwithstanding this, the foreign ownership share of Australian Government Securities fell by 3 percentage points to 60 per cent as net issuance was larger than foreign purchases, while the foreign ownership share of state government debt increased slightly.

Graph 2.25
Australian Capital Flows
Net inflows, per cent of GDP



* Excludes official reserves and other RBA flows
** Adjusted for US dollar swap facility in 2008 and 2009
Sources: ABS; RBA

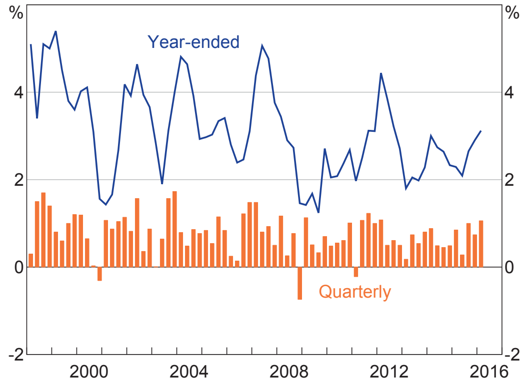
Australia's net foreign liability position increased to a little over 60 per cent of GDP at the end of the March quarter, in part because of exchange rate valuation effects. The net income deficit, which largely comprises payments made on Australia's net foreign liabilities, widened to 3.1 per cent of GDP in the March quarter, primarily reflecting operating losses on Australia's foreign direct equity assets.

3. Domestic Economic Conditions

Activity in the Australian economy grew by more than 3 per cent over the year to the March quarter, above estimates of the economy's potential rate of growth (Graph 3.1). GDP growth in the March quarter was stronger than expected, largely as a result of a significant expansion in the volume of resource exports, which benefited from unusually favourable weather conditions (Table 3.1). Indications are that growth in the June quarter was moderate. National income has been growing at a modest pace, owing to the decline in the terms of trade and low inflation.

The strong contribution of resource exports to GDP growth over the past year was offset by a further large fall in mining investment, such that mining

Graph 3.1
GDP Growth



Source: ABS

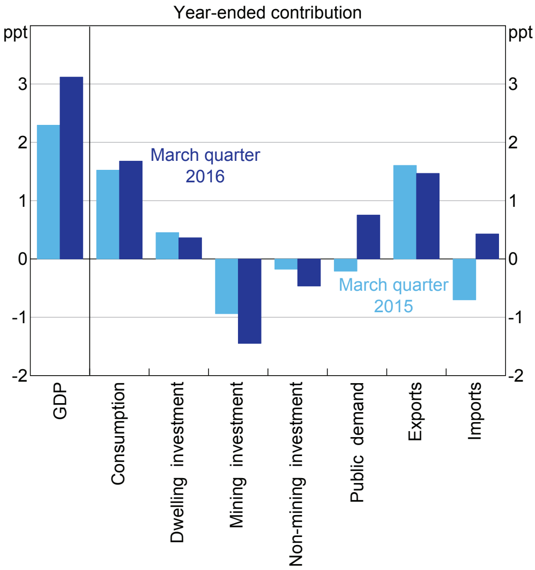
Table 3.1: Demand and Output Growth
Per cent

	March quarter 2016	December quarter 2015	Year to March quarter 2016
GDP	1.1	0.7	3.1
Consumption	0.7	0.8	3.0
Dwelling investment	1.4	2.8	7.0
Mining investment[(a)]	–2.5	–9.6	–26.7
Non-mining investment[(a)]	–3.7	1.0	–4.7
Public demand	0.6	1.4	3.5
Exports	4.4	0.4	6.6
Imports	-0.8	0.5	–2.0
Mining activity[(a)]	4.8	–3.7	0.7
Non-mining activity[(a)]	0.4	1.5	3.6
Nominal GDP	0.5	0.4	2.1
Real gross domestic income	0.5	0.1	0.6
Memo: Terms of trade	–1.9	–3.4	–11.5

(a) RBA estimates
Sources: ABS; RBA

activity was little changed (Graph 3.2). Meanwhile, non-mining activity has been growing at or above a trend pace for some time. Low interest rates and the depreciation of the exchange rate since early 2013 have supported this rebalancing, with solid growth evident in consumption, dwelling investment and most export categories. Public demand has also grown at a solid pace. However, non-mining business investment has declined, subtracting a little from growth.

Graph 3.2
GDP Growth



Sources: ABS; RBA

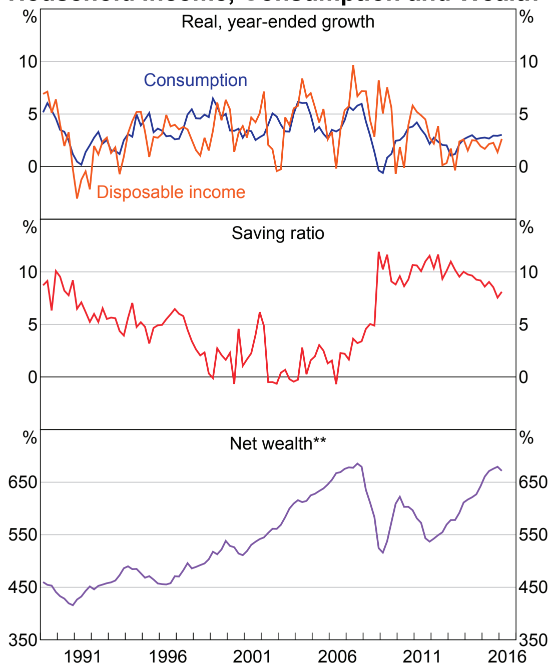
The unemployment rate has been steady at around 5¾ per cent. Employment growth has moderated somewhat since the start of 2016, following strong outcomes late last year. Average hours worked has declined a little and employment growth over recent months has been concentrated in part-time jobs. Indicators of future employment growth have been mixed of late. There is still evidence of spare capacity in the labour market, including low wage growth. While the protracted period of low wage growth has allowed for more employment than otherwise, it has also constrained growth in nominal household income in recent years.

Household Sector

Household consumption continued to grow at around its decade-average pace in early 2016. Low interest rates, employment gains and growth in household wealth have supported consumption in a period of below-average income growth. The saving ratio has declined further in line with the gradual trend of recent years (Graph 3.3). Consumption growth has remained strong in states with relatively little exposure to the resources sector, such as New South Wales and Victoria, but has been comparatively weak in the resource-rich states of Queensland and Western Australia.

Timely indicators of household consumption growth were mixed in the June quarter. Households' perceptions of their own finances have been above average in recent months, despite relatively weak income growth, and consumers' unemployment

Graph 3.3
Household Income, Consumption and Wealth*



* Household sector includes unincorporated enterprises; disposable income is after tax and interest payments; income level smoothed with a two-quarter moving average between March quarter 2000 and March quarter 2002; saving ratio is net of depreciation

** Per cent of annual household disposable income, before the deduction of interest payments

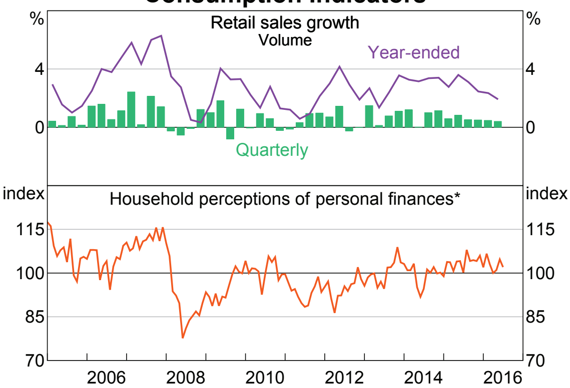
Sources: ABS; RBA

expectations are lower than in recent years. However, retail sales volumes increased at a slightly slower pace than in the March quarter (Graph 3.4).

A range of indicators suggest that conditions in the established housing market have eased this year from very strong conditions over recent years. Housing prices were little changed in the June quarter according to most published measures (Table 3.2; Graph 3.5). In contrast, the headline CoreLogic measure of housing prices recorded very strong growth in April and May in a number of cities, to be more than 5 per cent higher over the June quarter. Recent information suggests that the strong increases reported by CoreLogic were overstated as a result of methodological changes affecting growth rates for the June quarter. The most recent data suggest that housing prices declined in most capital cities in July.

Other timely indicators of conditions in the established housing market continue to point to weaker conditions than last year. Auction clearance rates and the number of scheduled auctions

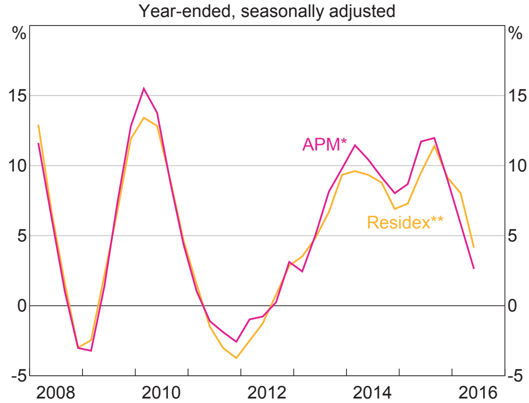
Graph 3.4
Consumption Indicators



* Average of the ANZ-Roy Morgan and Westpac-Melbourne Institute consumer sentiment measures of respondents' perceptions of their personal finances relative to the previous year; average since 1980 = 100

Sources: ABS; ANZ-Roy Morgan; RBA; Westpac and Melbourne Institute

Graph 3.5
Growth in National Housing Prices
Year-ended, seasonally adjusted



* APM is a quarterly stratified median price index

** Residex is a quarterly repeat sales price index

Sources: APM; RBA; Residex

Table 3.2: Housing Prices
Percentage change, seasonally adjusted

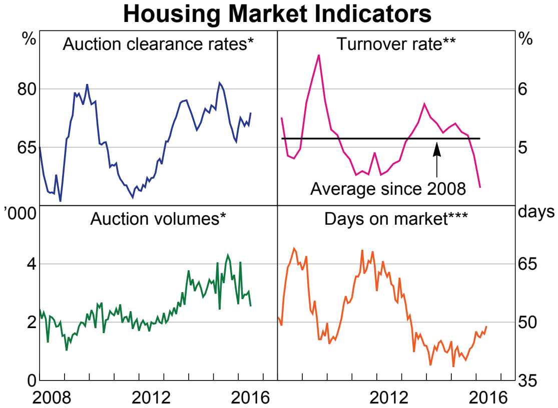
	APM *Stratified median*		Residex *Repeat sales*	
	June quarter 2016	Year to June quarter 2016	June quarter 2016	Year to June quarter 2016
Sydney	0.0	1.0	–0.1	3.7
Melbourne	3.2	8.6	–1.3	9.2
Brisbane	1.7	2.0	0.9	3.5
Adelaide	–2.2	2.2	0.5	2.1
Perth	0.3	–3.4	–0.2	–3.8
Canberra	2.0	2.6	0.5	4.3
Hobart	1.4	4.6	–1.5	2.1
Darwin	–	–	–0.5	–4.5
Australia[(a)]	**0.8**	**2.6**	**–0.1**	**4.1**

(a) Capital cities only

Sources: APM; RBA; Residex

are lower than a year ago and there has been a large decline in the number of transactions in the housing market, which is reflected in the turnover rate (Graph 3.6). In the private treaty market, the discount on vendor asking prices has been little changed of late, but the average number of days that a property is on the market has increased from the lows of last year.

Graph 3.6
Housing Market Indicators

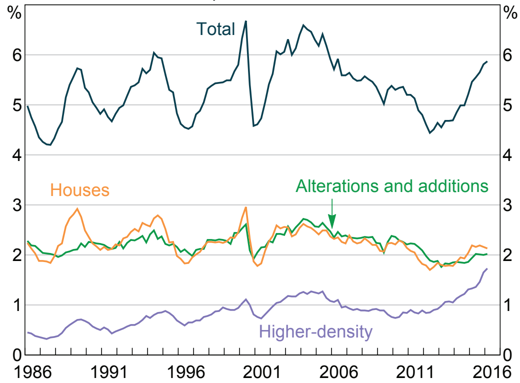


* Average of Melbourne and Sydney
** Share of dwelling stock, annualised
*** Capital city dwelling stock weighted median for private treaty sales only
Sources: ABS; APM; CoreLogic; RBA; Real Estate Institute of Victoria

Total housing loan approvals have been little changed in recent months. Meanwhile, housing credit growth has been steady in the first six months of the year but slower than in 2015, consistent with a relatively low level of turnover and the tightening of lending standards towards the end of 2015 (see 'Domestic Financial Markets' chapter for further details on the developments in housing finance).

The upswing in dwelling investment, particularly the construction of high-density dwellings, has continued, supported by low interest rates and earlier increases in housing prices (Graph 3.7). Residential building approvals are lower than their peak of mid 2015 but remain at high levels. Indeed, building approvals have continued to exceed completions, resulting in the number of dwellings under construction or yet to be completed reaching historically high levels. The work in the pipeline is sufficient to underpin dwelling investment activity for the next couple of years (see 'Box B: The Housing Market').

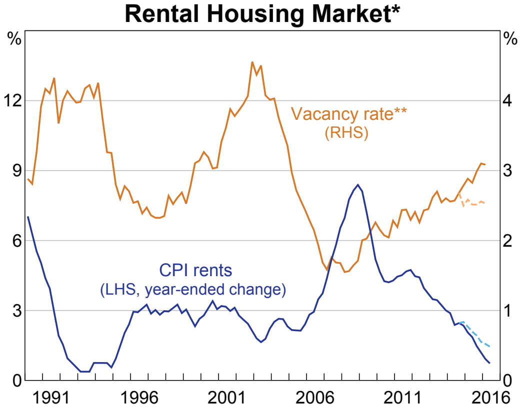
Graph 3.7
Dwelling Investment
Current prices, share of GDP



Sources: ABS; RBA

Conditions in the rental market have continued to soften over the past year. The aggregate rental vacancy rate has drifted higher to be close to its longer-run average of around 3 per cent and rental inflation is around multi-decade lows, having eased across most capital cities (Graph 3.8). The Perth rental market is particularly weak, reflecting the slowing in population growth combined with ongoing additions to the housing supply.

Graph 3.8
Rental Housing Market*

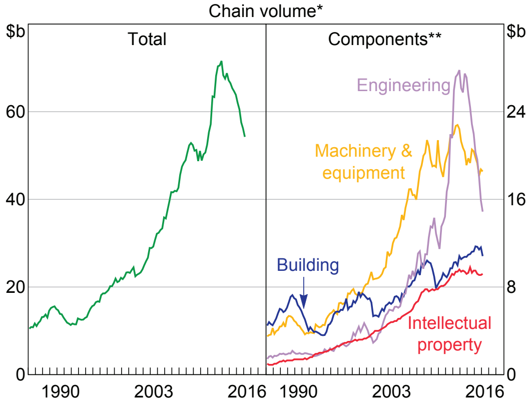


* Dotted lines exclude Perth
** Excludes Adelaide from March quarter 2015
Sources: ABS; RBA; Real Estate Institute of Australia

Business Sector

As expected, private business investment declined further in the March quarter and fell by 13 per cent over the year (Graph 3.9). The decline in the quarter was led by falls in engineering (which was largely related to the decline in mining investment) and building construction.

Graph 3.9
Private Business Investment
Chain volume*

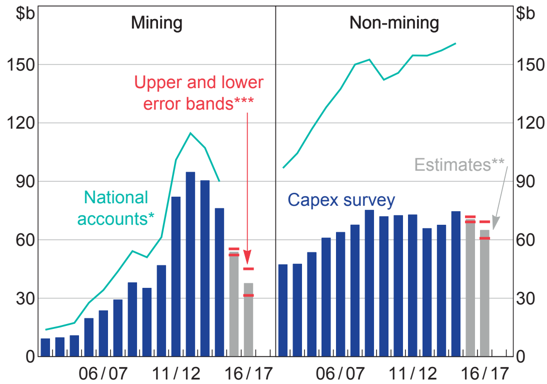


* Adjusted for second-hand asset transfers between the private and other sectors; reference year is 2013/14
** Excluding cultivated biological resources
Sources: ABS; RBA

Mining investment has fallen by around 45 per cent since its 2012 peak and is expected to fall further over the next couple of years as few new projects are expected to commence. The ABS capital expenditure (Capex) survey of investment intentions and Bank liaison suggest there will be a further large fall in mining investment in 2016/17, although the largest subtraction from GDP growth is likely to have occurred in 2015/16 (Graph 3.10).

In real terms, non-mining investment has been subdued for several years and indicators, such as the Capex survey, suggest that it will remain so for at least the next few quarters. The estimates from the Capex survey are, however, subject to considerable uncertainty. Moreover, the survey does not cover a large share of non-mining investment that is captured by the national accounts data, including investment in agriculture, education or healthcare, as well as intangible items, such as software

Graph 3.10
Measures of Private Business Investment
Nominal

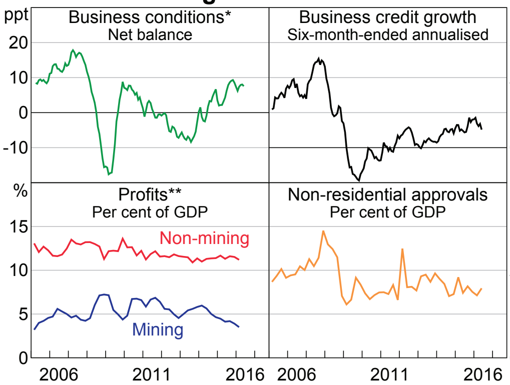


* Adjusted for second-hand asset transfers between the private and other sectors; excluding cultivated biological resources
** Estimates are firms' expected capital expenditure, adjusted for the past average difference between expected and realised spending
*** Error bands are based on the root mean square error of each adjusted estimate compared with the final outcome for investment in each year
Sources: ABS; RBA

development. Non-mining investment has been particularly weak in resource-rich states. In part, this is because many non-mining firms provide inputs and support to firms involved in either mining investment or resource extraction. More broadly, investment by non-mining firms is being adversely affected by weak demand growth overall in those states. In contrast, in New South Wales and Victoria, which are less resource intensive, the recovery in non-mining business investment appears to have begun, supported by very low interest rates and the depreciation of the Australian dollar over the past few years.

Although non-mining investment has been weak for some time, business surveys suggest that non-mining business conditions and capacity utilisation have been on an upward trend since 2013 and these survey measures are currently well above their long-term averages (Graph 3.11). Business credit growth has eased a little of late. At the same time, non-mining company profits have been little changed as a share of nominal GDP. While non-residential building approvals persist at relatively low levels, reflecting weak underlying conditions in the commercial property market, the Bank's liaison

Graph 3.11
Non-mining Business Indicators



* Deviation from long-run average; gross value added weighted; three-month moving average

** Inventory valuation adjusted gross operating profits

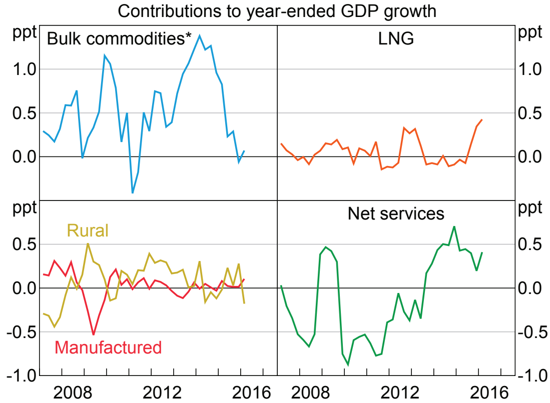
Sources: ABS; APRA; NAB; RBA

has suggested that the outlook for investment is relatively favourable in some commercial property sectors, including retail, hotels, student accommodation and aged care.

External Sector

Export volumes rose by 7 per cent over the year to the March quarter, largely driven by strength in resource and service exports (Graph 3.12). The ramp-up in liquefied natural gas (LNG) production has begun and LNG exports are expected to continue to grow rapidly over the next few years as further projects are completed. Both iron ore and coal exports grew strongly in the March quarter, supported by unusually favourable weather conditions. Looking ahead, iron ore export volumes are expected to be supported by increased production from Australia's large low-cost producers, while coal exports face headwinds from the relatively high cost of some Australian production and weak global demand. Net service exports have increased over the past year, although at a slower pace more recently, assisted by the improvement in competitiveness associated with the depreciation of the Australian dollar and relatively low labour cost growth; tourism, education and business service exports have all expanded.

Graph 3.12
Exports
Contributions to year-ended GDP growth

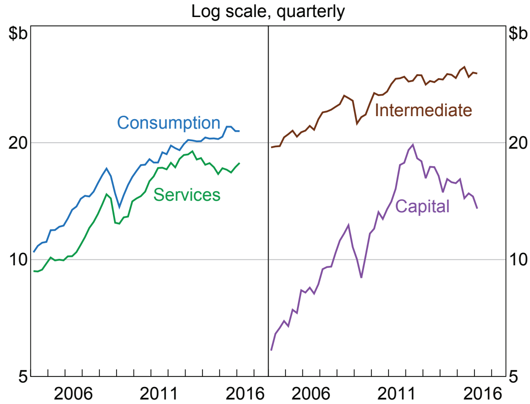


* Iron ore and coal

Sources: ABS; RBA

Import volumes decreased modestly over the year to the March quarter, reflecting declines in capital and intermediate imports (Graph 3.13). Imports of capital goods have been declining since 2012 when mining investment peaked.

Graph 3.13
Import Volumes*
Log scale, quarterly



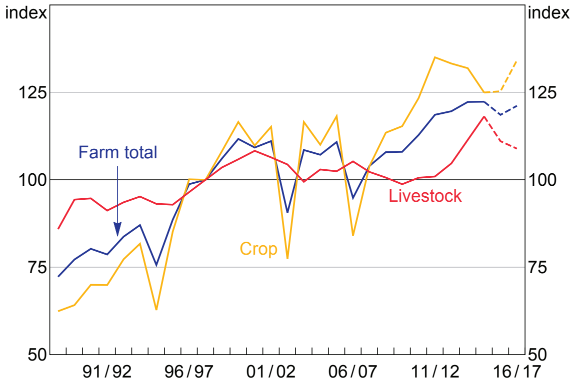
* Reference year is 2013/14

Source: ABS

Farm Sector

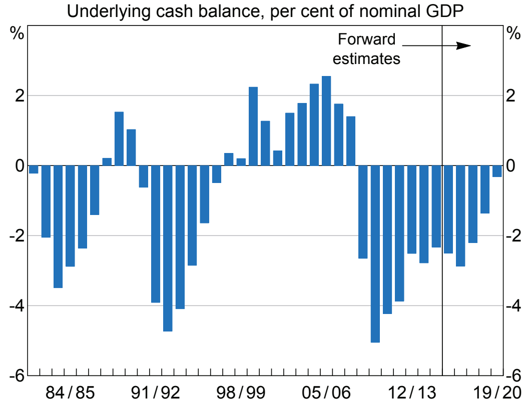
The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) estimates that the volume of farm production declined modestly in 2015/16 (Graph 3.14). In recent years, farm production has been supported by strong growth

Graph 3.14
Farm Production Volumes*
1997/98 = 100



* Dotted lines represents 2015/16 and 2016/17 forecasts
Source: ABARES

Graph 3.15
Consolidated Budget Balance*
Underlying cash balance, per cent of nominal GDP



* Federal, state and territory governments, based on 2016/17 budgets; excludes the effect of the federal grant to the RBA in 2013/14
Sources: ABS; Australian Treasury; RBA; State and Territory Treasuries

in livestock production, but this is expected to have moderated in 2015/16 as herds were being rebuilt. Farm production volumes are forecast by ABARES to increase in 2016/17 as the ongoing decline in livestock production is expected to be more than offset by strong growth in crop production, given above-average rainfall at the start of the winter crop-planting season.

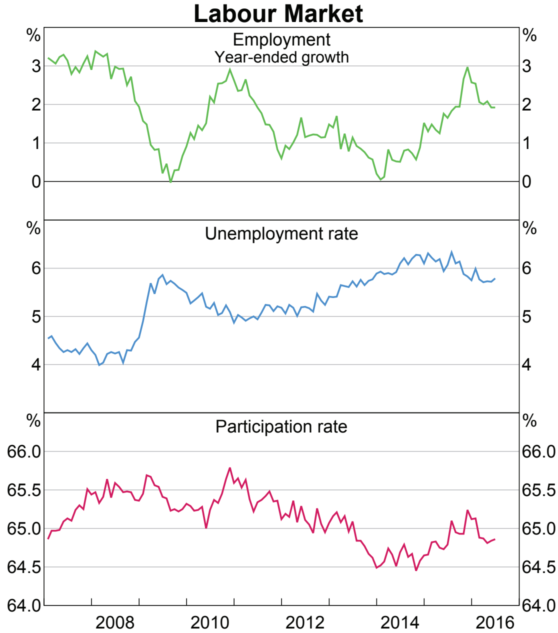
Government Sector

Recent federal and state government budgets suggest that the consolidated deficit will increase a little in 2016/17 to around 3 per cent of GDP, owing largely to lower revenue growth in the federal budget and higher capital expenditure by the New South Wales Government (Graph 3.15). Deficits are expected to be progressively lower over subsequent years; overall these deficits are slightly larger than previous budget estimates. The consolidated budget is expected to return to a balanced position by around 2019/20.

Labour Market

Employment growth has moderated, following strong growth late last year (Graph 3.16). The unemployment rate has been steady at around 5¾ per cent, having fallen by around ½ percentage point over 2015. The participation rate has also been little changed in recent months, although it is lower than it was late last year.

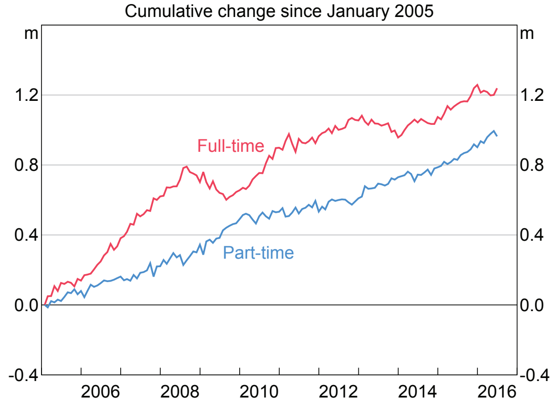
Graph 3.16
Labour Market



Source: ABS

Over the course of 2016, employment growth has been concentrated in part-time jobs, while full-time employment has been little changed until very recently (Graph 3.17). The share of part-time employment has trended higher over a number of decades to be close to one-third of total employment. This reflects increased participation by females, as well as labour market reforms that have provided firms with greater flexibility to adjust working hours rather than headcount in response to changes in demand.[1]

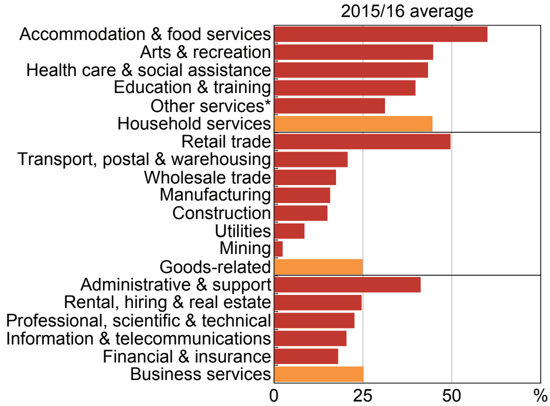
Graph 3.17
Employment
Cumulative change since January 2005



Sources: ABS; RBA

More recently, the shift in the composition of employment growth towards part-time employment appears to reflect two factors. First, employment growth has been stronger in industries that tend to have a higher proportion of part-time jobs, such as household services (Graph 3.18). In part, this reflects solid growth in household consumption and a pick-up in tourism, but also longer-run trends, such as increasing demand for aged and home-based care services as the population ages. Second, the recent growth in part-time employment may reflect a cautious approach by firms to hiring and/or a means for them to increase their use of labour in a way that contains costs. In particular, the Bank's liaison suggests that a broad range of businesses are seeking greater flexibility from employees through the use of part-time or casual work or temporary contracts, to improve productivity and minimise their labour costs. This might help to also explain the increase in part-time employment relative to full-time employment in a range of industries in the business service and goods-related sectors. Meanwhile, both full-time and part-time construction employment have grown strongly, underpinned by elevated levels of residential construction activity.

Graph 3.18
Part-time Share of Employment
2015/16 average



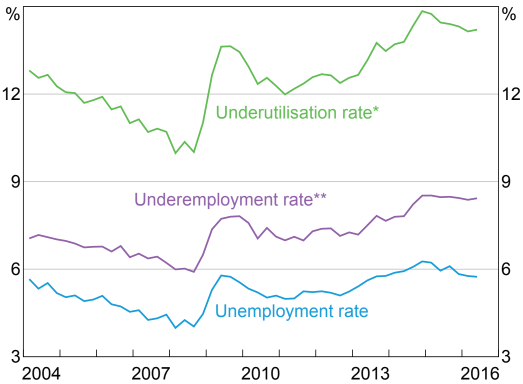
* Includes personal services; religious, civic, professional and other interest group services; repair and maintenance activities; and private households employing staff

Sources: ABS; RBA

The unemployment rate remains at a level consistent with there being spare capacity in the labour market. Furthermore, the share of workers who would like to work more hours has been little changed over the past two years and is at a high level. That is, the underemployment rate (which captures the number of workers who would like more hours, as a share of the labour force) has not fallen by as much as the unemployment rate over the past year (Graph 3.19). Low growth in a range of wage measures is also consistent with a degree of spare capacity in the labour market. At the same time, low wage growth may enable firms to employ

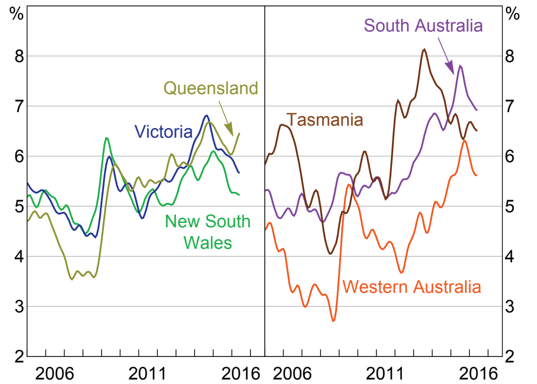
1 Bishop J and M Plumb (2016), 'Cyclical Labour Market Adjustment in Australia', RBA *Bulletin*, March, pp 11–20.

Graph 3.19
Labour Underutilisation Rates
Per cent of labour force



* Underutilisation rate is the sum of the underemployment and unemployment rates
** Full-time workers on reduced hours for economic reasons and part-time workers who would like, and are available, to work more hours
Source: ABS

Graph 3.20
Unemployment Rates by State
Trend



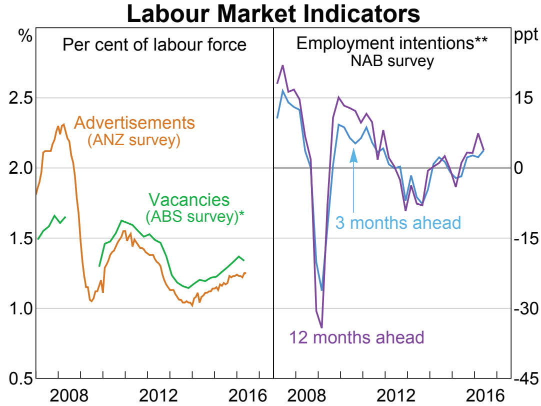
Source: ABS

more workers than would otherwise be the case (see 'Price and Wage Developments' chapter).

There appears to be somewhat less spare capacity in New South Wales and Victoria, where unemployment rates have declined noticeably over the past year and growth in full-time employment has been strongest (Graph 3.20). In contrast, Queensland's unemployment rate has ticked up recently and Western Australia's unemployment rate is much higher than it was a few years ago, although it is still a little below the national average. At the same time, population growth has moderated noticeably in the resource-rich states relative to the rest of the country, which has helped to limit the increase in their unemployment rates. Looking ahead, further mining-related job losses are expected as LNG-related construction projects reach completion.

Indicators of future employment growth have been mixed over recent months, following strong gains over the preceding year. Job advertisements as a share of the labour force had been little changed for some time, but increased slightly over the past couple of months (Graph 3.21). In contrast, the job vacancy rate declined a little over the three months

Graph 3.21
Labour Market Indicators



* This survey was suspended between May 2008 and November 2009
** Net balance of employment intentions for the following period; deviation from average; 12-months-ahead measure seasonally adjusted by the RBA
Sources: ABS; ANZ; NAB; RBA

to May. This appears to be consistent with weaker employment growth in the business service and goods-related sectors compared with household services, for which vacancies have continued to increase. The NAB survey measure of firms' hiring intentions remains above average. Overall, these indicators suggest employment growth in coming months will be consistent with a stable unemployment rate.

Box B

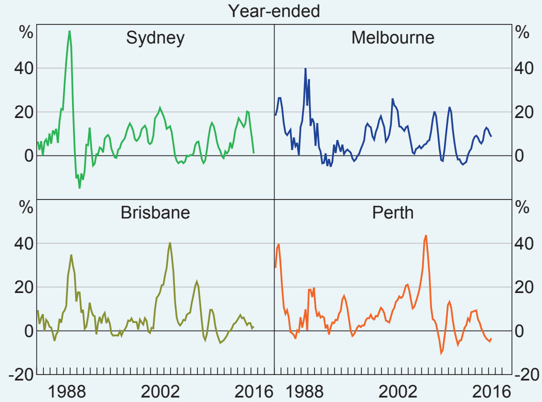
The Housing Market

Overall conditions in the housing market have been strong in recent years and have contributed to the rebalancing of economic activity towards the non-mining sectors of the economy. As expected, housing market activity has been relatively sensitive to the reduction in interest rates over recent years.[1] Population growth has also been an important driver of housing market trends across the country. Housing prices have increased and the construction of new dwellings has added to economic growth and employment.

Housing prices in Australia have increased at an average rate of around 7½ per cent per annum since mid 2012. This has been largely driven by developments in Sydney and Melbourne, with more modest price growth in other capital cities over this period, especially in those cities with larger exposures to the mining sector (Graph B1).

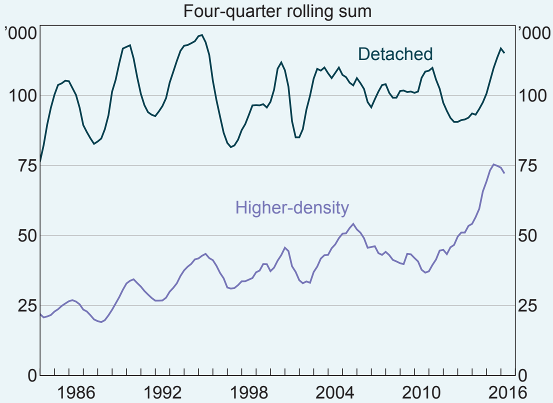
Residential building activity has increased as a share of GDP, from about 4½ per cent on average in 2012 to almost 6 per cent in the March quarter 2016. The number of new residential building completions in Australia was around 190 000 in 2015, an increase of almost 20 per cent compared with a decade ago when it was generally judged that supply had not been keeping up with demand. Apartments have accounted for most of the increase in housing supply, although detached dwelling completions have also picked up over the past couple of years (Graph B2).[2]

Graph B1
Housing Price Growth
Year-ended



Sources: APM; RBA; REIA

Graph B2
Private Dwelling Completions
Four-quarter rolling sum



Sources: ABS; RBA

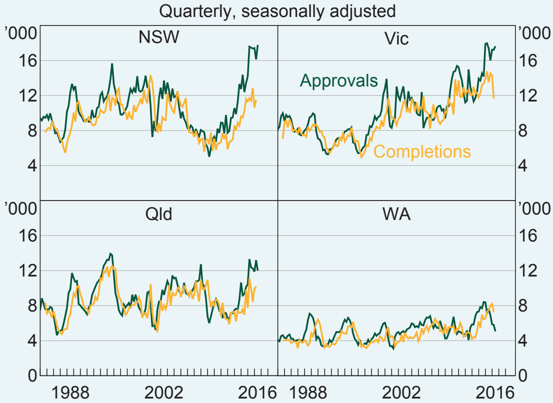
Since 2012, the supply of housing has increased in all Australian states, but activity has been concentrated in the four largest states of New South Wales, Victoria, Queensland and Western Australia, which together account for more than 90 per cent of Australia's total building activity. Building

1 See RBA (2015), 'Box C: The Cycle in Dwelling Investment', RBA *Statement on Monetary Policy*, May, pp 43–45.

2 See Shoory M (2016), 'The Growth of Apartment Construction in Australia', RBA *Bulletin*, June, pp 19–26.

approvals data suggest that there will be a further expansion of supply in these states over the next year or two (Graph B3).[3] The number of newly approved dwellings has been above completions for some time, leading to a build-up in the pipeline of work yet to be done to historically high levels. In part, this reflects a shift in the composition of approvals towards higher-density dwellings, which typically take longer to complete than detached dwellings. This build-up in dwellings under construction or yet to be commenced is particularly apparent in New South Wales and Victoria (Graph B4).[4]

Graph B3
Private Dwelling Activity
Quarterly, seasonally adjusted



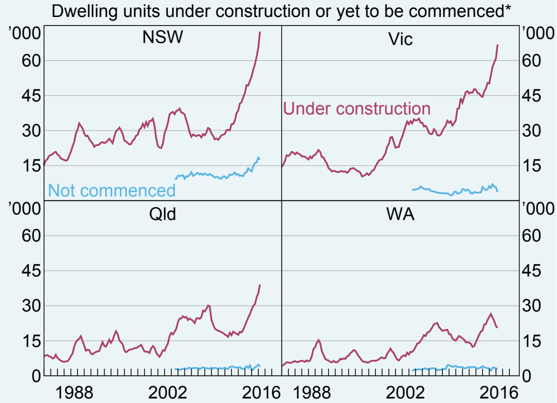
Sources: ABS; RBA

In addition to interest rates, growth in the number of households is a key determinant of housing demand. This in turn is a function of population

3 Building approvals are generally sought just prior to the commencement of construction work. These are separate from planning approvals, which can potentially precede building by many years.

4 Information from liaison suggests that residential construction activity is operating at close to capacity in those markets where demand is strong. There may be some capacity to accommodate a further pick-up in the construction of detached houses in south-east Queensland and apartments in Melbourne (outside the inner city). In markets operating close to capacity, such as Sydney and the greenfield market in Melbourne, further increases in land and dwelling sales may lead to activity remaining at high levels for longer, but are unlikely to add to the level of activity in the near term.

Graph B4
Dwellings Pipeline
Dwelling units under construction or yet to be commenced*



* Dwelling units under construction are private sector projects only; work yet to be commenced includes public sector projects

Sources: ABS; RBA

growth and changes in the average size of households.[5] In New South Wales and Victoria, relatively strong population growth has supported underlying demand over the past few years (Graph B5). However, in Western Australia and to a lesser extent Queensland and South Australia, population growth has slowed following the end of the mining investment boom.

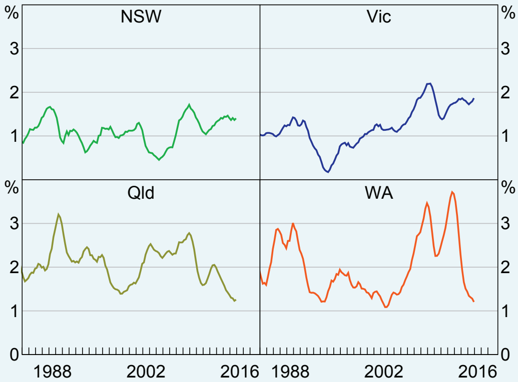
The balance between supply and demand for housing is ultimately reflected in housing prices, vacancy rates and rents. In Perth, the combination of slower-than-expected population growth, weaker household income growth and a high level of dwelling completions in recent years has placed downward pressure on housing prices. Rental vacancy rates in Perth have risen sharply to be more than double the average of all other capital cities, which is around 2½ per cent (Graph B6). Consistent with this, rents in Perth declined by 5¼ per cent over the year to the June quarter 2016 (Graph B7).

Despite the substantial increase in supply in recent years, vacancy rates in Sydney, Melbourne and

5 Average household size tends to change slowly. Between 1911 and 2001 average household size decreased by about 2 persons per household, from 4½ to 2½, but has since been little changed.

Graph B5
Population Growth

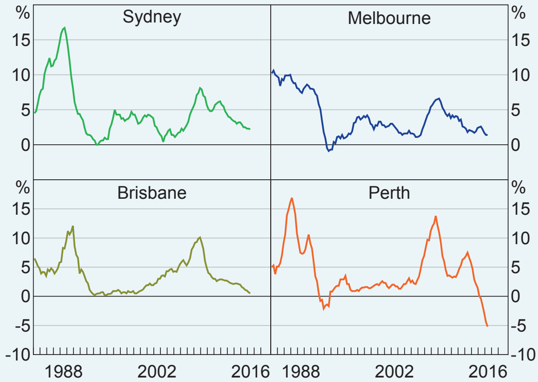
Year-ended



Sources: ABS; RBA

Graph B7
Capital City Rent Inflation

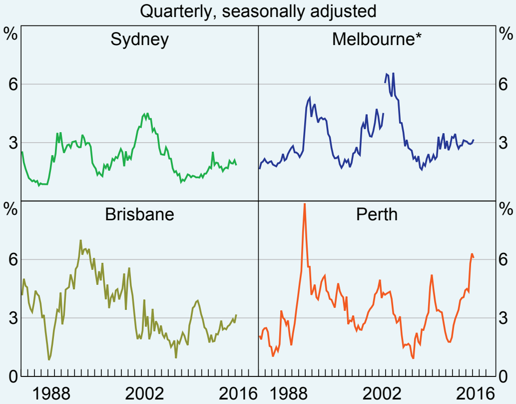
Year-ended



Source: ABS

Graph B6
Rental Vacancy Rates

Quarterly, seasonally adjusted



* Series break December quarter 2002

Sources: RBA; REIA; REIV

Brisbane have only risen a little, to be around their long-run average levels. That said, rent inflation in these cities has been declining, and has also been a little weaker than suggested by its historical relationship with the vacancy rate.

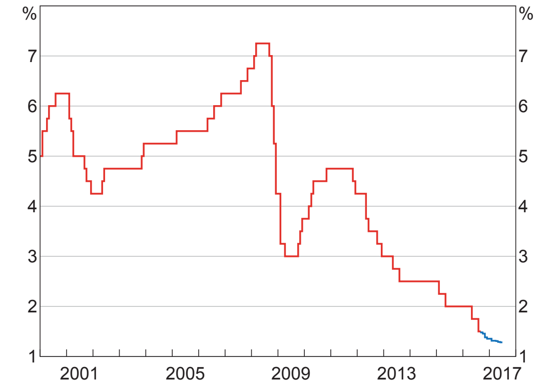
There are some concerns about the concentration of new supply in areas such as some parts of inner-city Melbourne and Brisbane. Downward pressure on prices from large increases in supply relative to demand for apartments in some areas could increase the risk of off-the-plan purchases failing to settle.[6] More generally, a further increase in the supply of apartments is scheduled over the next couple of years. While this will continue to support economic activity over this period, it will tend to constrain growth in housing prices and rents, at least in some markets. ✠

6 See RBA (2016), *Financial Stability Review*, April.

4. Domestic Financial Markets

Conditions in domestic financial markets continue to support the financing of the household and business sectors. The cash rate target was reduced at the August Board meeting, and housing and business lending rates have declined. Australian government bond yields have fallen to historic lows in line with global developments. Yields on bonds issued by domestic banks and non-financial corporations have also declined, and banks have been able to raise ample funding in wholesale debt markets. In contrast, non-financial corporate bond issuance has remained subdued, particularly in the resources sector. Despite historically low interest rates, growth in credit extended to households and businesses has slowed in recent months. Equity prices have picked up from their lows earlier in the year, with resources sector share prices rising in response to higher commodity prices.

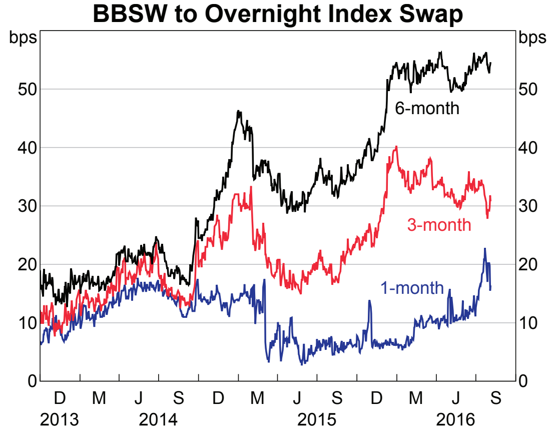
Graph 4.1
Cash Rate*



* Data from September 2016 onwards are expectations derived from interbank cash rate futures

Sources: ASX; Bloomberg

Graph 4.2
BBSW to Overnight Index Swap



Sources: AFMA; Tullett Prebon (Australia)

Money Markets and Bond Yields

The Reserve Bank Board lowered its target for the cash rate to 1.50 per cent at its August meeting. Rates on overnight indexed swaps (OIS) suggest that the cash rate is expected to be reduced again in the year ahead (Graph 4.1).

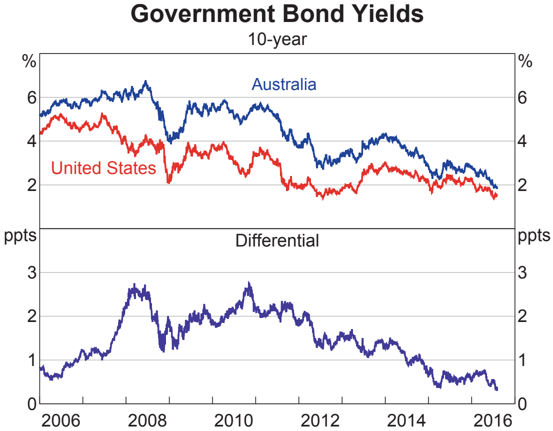
Since the start of the year, 3- and 6-month bank bill rates (BBSW) have moved broadly in line with OIS rates (Graph 4.2). In contrast, the spread between 1-month bank bill rates and OIS rates has risen. However, the 1-month bank bill market has become a less significant source of bank funding since the introduction of the Liquidity Coverage Ratio in 2015, which reduces the attractiveness to banks of very short-term wholesale funding.

Secured rates in the repurchase agreement (repo) market have also risen relative to OIS rates in recent months. This widening appears to reflect heightened demand for secured funding from market participants responding to arbitrage opportunities in the bond futures and foreign exchange (FX) swap markets. Bond futures have been trading at higher implied prices than the basket of bonds that underlie the futures and, in response, some investors have sold the futures and bought the bonds using repo funding. In the FX swap market, Australian dollars can be lent against yen at a relatively high implied Australian dollar interest rate; in response, some investors have been borrowing Australian dollars under repo to lend against yen in the swap market at a higher interest rate.

Yields on 10-year Australian Government Securities (AGS) reached a historic low of 1.82 per cent in early August alongside the decline in global bond yields. AGS yields have continued to be largely influenced by movements in US Treasuries, although the spread between the two has narrowed in recent months (Graph 4.3). Despite large intraday movements in prices on the day of the UK referendum result, and much greater than normal volumes, market functioning was very orderly (see Box C: 'Australian Financial Markets and the UK Referendum').

Standard & Poor's (S&P) revised its outlook on Australia's AAA sovereign credit rating from stable to negative, reflecting its view that prospects for fiscal consolidation have weakened. There was minimal market reaction to S&P's announcement.

Graph 4.3
Government Bond Yields



Sources: Bloomberg; RBA

In line with the negative outlook S&P placed on Australia's sovereign credit rating, the AAA ratings of New South Wales, Victoria and the Australian Capital Territory were revised to a negative outlook. S&P also announced that the major banks' credit ratings would be lowered by one notch in the event that Australia's sovereign rating was downgraded, since the banks benefit from S&P's assumption of implicit government support.

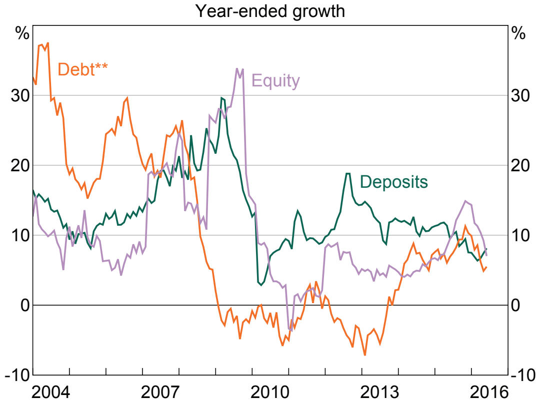
The Australian Office of Financial Management (AOFM) has announced plans to issue around $60 billion of AGS in the 2016/17 financial year in net terms, which would see total AGS rise to around $430 billion (25 per cent of GDP) at the end of June 2017. Recent AGS auctions have been well received and there appears to be considerable offshore demand for Australian bonds. State and territory governments ('semis') issued around $35 billion in bonds in the 2015/16 financial year. Taking into account the $40 billion in maturities over the same period, the stock of semis bonds outstanding fell to $237 billion at the end of June. Funding requirements for the 2016/17 financial year are expected to be modest compared to recent years, although this depends on the timing and realised prices of planned asset sales.

Bond issuance by non-residents in the domestic market ('Kangaroo' issuance) has totalled $20 billion in the year to date. In addition to ongoing issuance by supranational institutions, foreign sovereigns and agencies, US corporations have been able to issue large deals, with Apple and Coca Cola raising a combined $2.4 billion this year. Secondary market spreads to AGS for AAA rated issuers are slightly wider than in late 2015.

Financial Intermediaries

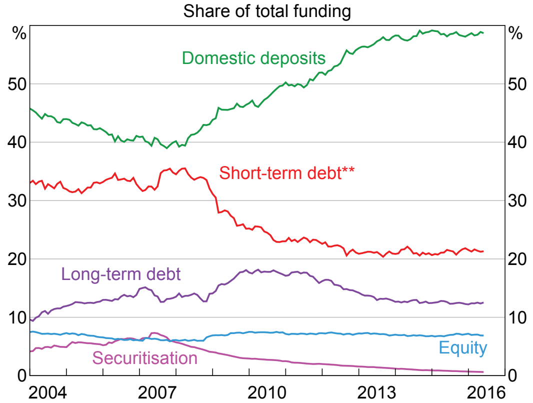
Growth in banks' balance sheets has slowed over the past 6 months, mainly reflecting a slowing in deposit growth. Growth in wholesale debt and equity also declined following a pick-up in these funding sources last year (Graph 4.4). Deposits have remained close to 60 per cent of total funding (Graph 4.5).

Graph 4.4
Banks' Funding Liabilities*
Year-ended growth



* Adjusted for movements in foreign exchange rates
** Includes long-term debt, short-term debt and securitisation
Sources: APRA; RBA

Graph 4.5
Funding Composition of Banks in Australia*
Share of total funding

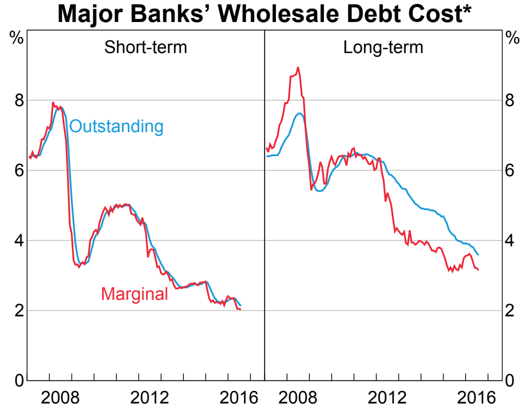


* Adjusted for movements in foreign exchange rates; tenor of debt is estimated on a residual maturity basis
** Includes deposits and intragroup funding from non-residents
Sources: APRA; RBA; Standard & Poor's

A factor that is likely to influence the composition of banks' balance sheets over the period ahead is the introduction in January 2018 of the Net Stable Funding Ratio (NSFR) as part of the Basel III liquidity reforms. The NSFR is designed to encourage banks to maintain a stable funding profile in relation to the composition of their assets and off-balance sheet activities. This may encourage banks to utilise more stable sources of funding such as retail deposits and long-term debt and encourage less use of short-term wholesale debt. Consistent with this, some banks recently announced increases in term deposit rates for terms over 12 months. The NSFR may also influence the composition of banks' assets, given that unsecured lending to businesses and households generally requires more stable funding than housing-secured lending.

Estimates of the major banks' average debt funding costs declined following the May cash rate reduction, but by a little less than the cash rate, mainly reflecting upward pressure on wholesale funding costs. There had also been some upward pressure on the cost of term deposits. Nevertheless, the cost of new issuance by banks of both short- and long-term debt has recently been below the cost of outstanding debt (Graph 4.6).

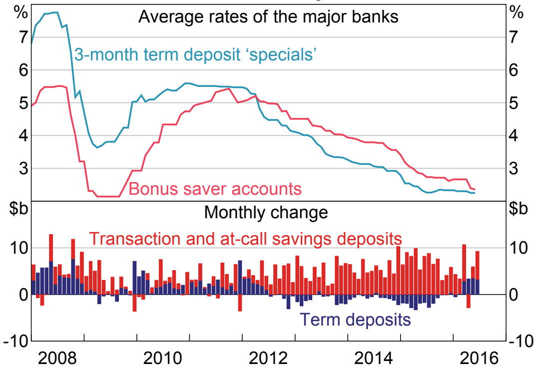
Graph 4.6
Major Banks' Wholesale Debt Cost*



* Funding costs model estimates; rates do not include interest rate hedges
Source: RBA

Competition for term deposits has increased a little in the past few months. The May cash rate reduction was largely reflected in lower advertised deposit rates, but term deposit rates remained little changed. Following the August cash rate reduction, the average interest rate banks will be offering on term deposit 'specials' for terms of 12–36 months will increase to around 3 per cent. Deposits of this maturity currently account for less than 2 per cent of total funding. With the interest rates on term deposits not declining in line with other deposit rates, strong growth has been recorded in term deposits more recently (Graph 4.7).

Graph 4.7
Household Deposits

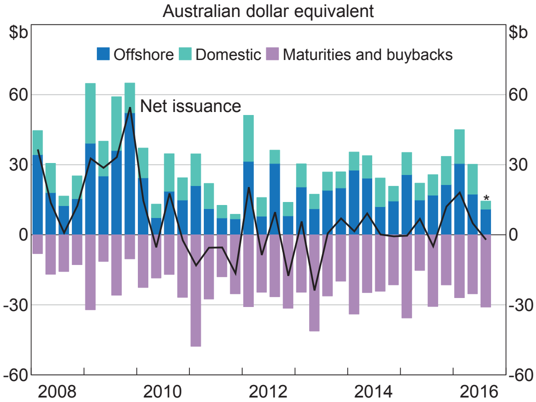


Sources: APRA; Canstar Cannex; RBA

Australian banks have issued a relatively large amount of debt this year (Graph 4.8). In the year to date, $90 billion of bank bonds have been issued; taking bond maturities into account, net bank bond issuance has been $21 billion. Bank bond yields in the secondary market are around historical lows, while spreads to benchmark rates are a little wider than at the start of the year (Graph 4.9).

Graph 4.8
Australian Banks' Bond Issuance

Australian dollar equivalent



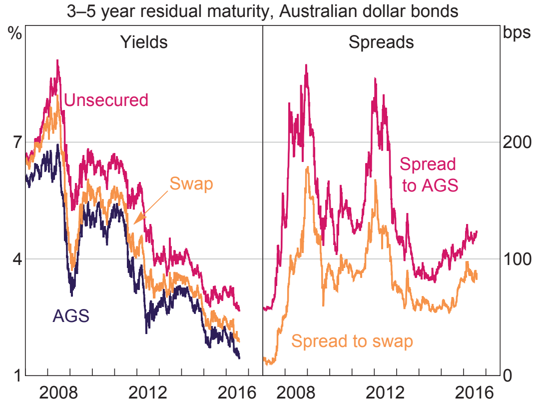
* Latest quarter issuance to date

Source: RBA

Hybrid issuance by Australian financial companies was large in the June quarter, driven by issuance by the major banks (Graph 4.10). The four major banks have each issued Basel III-compliant Additional Tier 1 (AT1) hybrids in 2016. This included the issuance by a major bank of an AT1 hybrid into the offshore market for the first time since 2009. The AT1 hybrid issuance

Graph 4.9
Major Banks' Bond Pricing

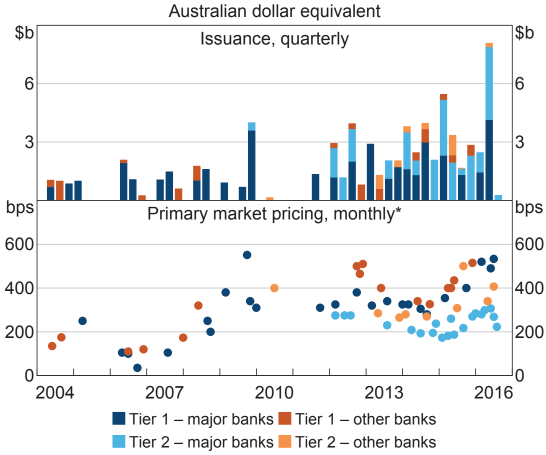
3–5 year residual maturity, Australian dollar bonds



Sources: Bloomberg; UBS AG, Australia Branch

Graph 4.10
Hybrid Issuance by Australian Banks

Australian dollar equivalent



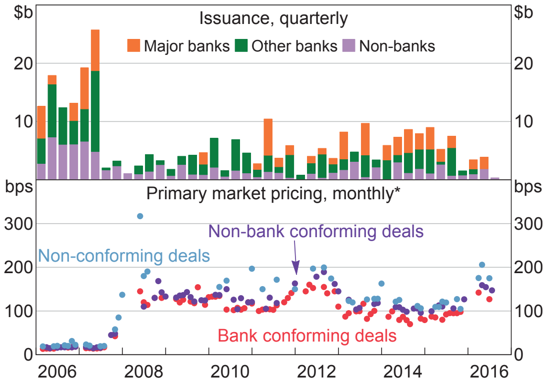
* Face-value weighted monthly average of the primary market spread to bank bill swap rate; foreign currency hybrids hedged back to Australian dollars assuming redemption on the first call date

Source: RBA

has been used by the major banks to replace existing hybrids. Tier 2 hybrids have been issued by a wide range of banks and insurance companies.

Activity in the asset-backed securities market remains low and primary market spreads to bank bills continue to be elevated (Graph 4.11). Recent issuance has included a large residential mortgage-backed securities (RMBS) deal from a major bank, and several deals from non-bank originators. There has been no issuance of other asset-backed securities since April.

Graph 4.11
Australian RMBS

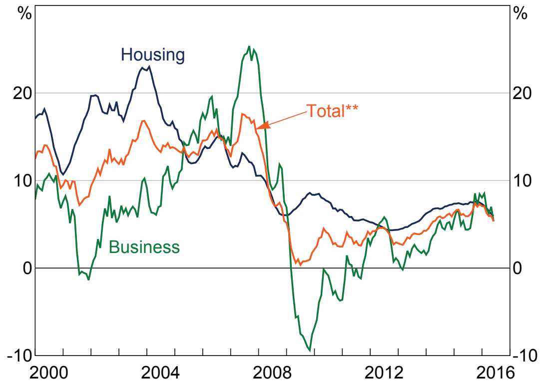


* Face-value weighted monthly average of the primary market spread to bank bill swap rate

Source: RBA

Graph 4.12
Credit Growth by Sector*

Six-month-ended annualised



* Seasonally adjusted and break-adjusted; including securitisation

** Includes housing, personal and business credit

Sources: ABS; APRA; RBA

Financial Aggregates

Total credit growth has eased a little in recent months (Graph 4.12). Growth in housing credit has been below the pace seen in 2015, while business credit growth has moderated following strong growth earlier in the year. Credit has been growing at around the same pace as broad money (Table 4.1).

Household Financing

Housing credit growth has been steady at an annualised pace of around 6 per cent over the first six months of the year, which is a little slower than in 2015. Growth in credit to investors has remained around 4 per cent, while growth in credit to owner-occupiers has slowed a little. Net housing debt has continued to grow around 1¼ percentage points slower than housing credit due to ongoing rapid growth in deposits in mortgage offset accounts (Graph 4.13).

After falling through late 2015 and early 2016, the flow of new housing loan approvals has stabilised in recent months and is consistent with housing credit growth continuing at around its current pace (Graph 4.14). Some lenders have placed restrictions on lending to non-residents or borrowers reliant on foreign income, while some state governments have increased taxes and duties for foreign buyers. These changes will likely have only a small impact

Table 4.1: Financial Aggregates

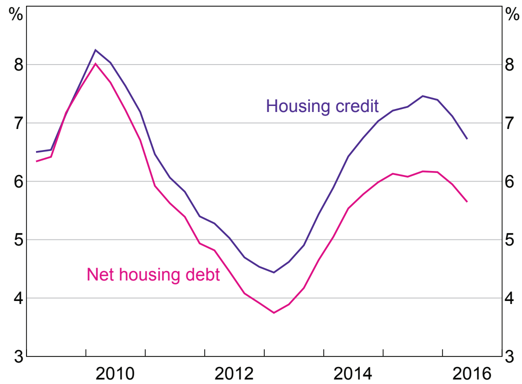
Percentage change[(a)]

	Three-month ended		Year-ended
	March 2016	June 2016	June 2016
Total credit	1.5	1.1	6.2
– Housing	1.5	1.4	6.7
– Owner-occupier	1.8	1.6	7.7
– Investor	1.1	1.1	5.0
– Personal	–0.3	–0.3	–0.8
– Business	1.7	0.8	6.6
Broad money	2.1	1.1	6.0

(a) Growth rates are break adjusted and seasonally adjusted

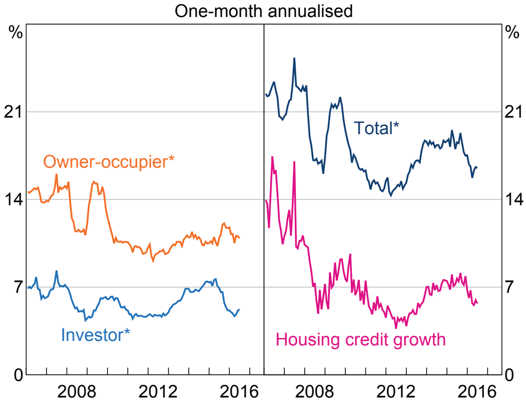
Sources: APRA; RBA

Graph 4.13
Housing Credit Growth*
Year-ended



* Seasonally and break-adjusted
Sources: ABS; APRA; RBA

Graph 4.14
Housing Loan Approvals and Credit
One-month annualised



* Seasonally adjusted and break-adjusted; net of refinancing; as a share of housing credit
Sources: APRA; RBA

on housing credit growth, as lending to this cohort represents a small share of total housing lending.

The slowing in housing loan approvals over the past year is consistent with the decline in turnover in the housing market. It also reflects slower growth in the average size of new loans and a decrease in the average loan-to-valuation ratio. This follows various measures introduced by the Australian Prudential Regulation Authority (APRA) to strengthen lending standards.

Some of the recent decline in the value of housing loan approvals may also reflect an increase in off-the-plan purchases. These transactions do not involve a mortgage at the time the dwelling is purchased off the plan, but add to the stock of housing credit when a mortgage is taken out by the purchaser upon the completion of the dwelling. Loans for the purpose of constructing new dwellings may be taken out by both households and businesses, although loans for the purpose of constructing large apartment blocks are typically undertaken by businesses. Loans drawn down by businesses for the purpose of constructing residential dwellings have grown very rapidly in recent years, consistent with the strong growth in building approvals for apartments.

The May cash rate reduction was passed through to most advertised housing lending rates. A number of lenders reduced fixed rates by more than variable rates, and some fixed rates have been lower than variable rates since the middle of last year (Table 4.2). Consistent with this, the share of loans being taken out at fixed interest rates has been elevated. The average outstanding housing interest rate declined by around 20 basis points and will decrease further following the August cash rate reduction and as fixed rate loans roll over to lower interest rates. The major banks have announced that they will pass through around half of the August cash rate reduction to their standard variable housing lending rates.

Business Financing

Over recent months, business credit growth has moderated and the issuance of debt securities by Australian companies has remained low, as reflected in the slowing in a broad measure of business debt growth (Graph 4.15). The easing in business credit growth is consistent with the decline in business loan approvals (Graph 4.16). This has been driven by slower growth in lending to some larger businesses and follows some lenders reporting an increase in non-performing large business loans. The reduction in business loan approvals has been apparent across

Table 4.2: Intermediaries' Fixed and Variable Lending Rates

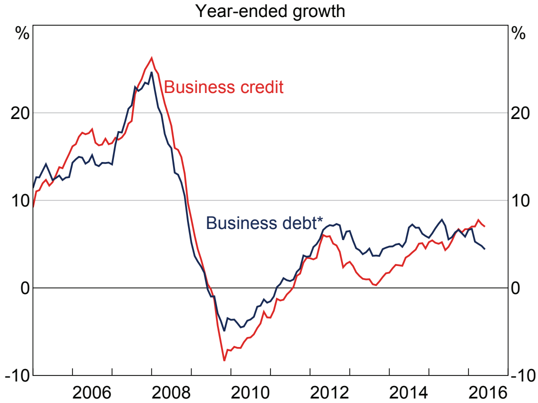
Prior to the August cash rate reduction

	Interest rate Per cent	Change since April 2016 Basis points	Change since July 2015 Basis points
Housing loans			
– Standard variable rate[(a)(d)]			
– Owner-occupier	5.39	–24	–7
– Investor	5.63	–24	17
– Package variable rate[(b)(d)]			
– Owner-occupier	4.59	–24	–8
– Investor	4.83	–24	16
– Fixed rate[(c)(d)]			
– Owner-occupier	4.27	–16	–39
– Investor	4.48	–18	–18
– Average outstanding rate[(d)]	4.64	–22	–6
Personal loans			
– Variable rate[(e)]	11.32	–5	0
Small business			
– Term loans variable rate[(f)]	6.50	–25	–10
– Overdraft variable rate[(f)]	7.38	–25	–10
– Fixed rate[(c)(f)]	5.38	–6	0
– Average outstanding rate[(d)]	5.51	–19	–20
Large business			
Average outstanding rate[(d)]	3.76	–21	–20

(a) Average of the major banks' standard variable rates
(b) Average of the major banks' discounted package rates on new, $250 000 full-doc loans
(c) Average of the major banks' 3-year fixed rates
(d) RBA estimates
(e) Weighted average of variable rate products
(f) Residentially secured, average of the major banks' advertised rates
Sources: ABS; APRA; Canstar Cannex; RBA

Graph 4.15
Business Debt

Year-ended growth

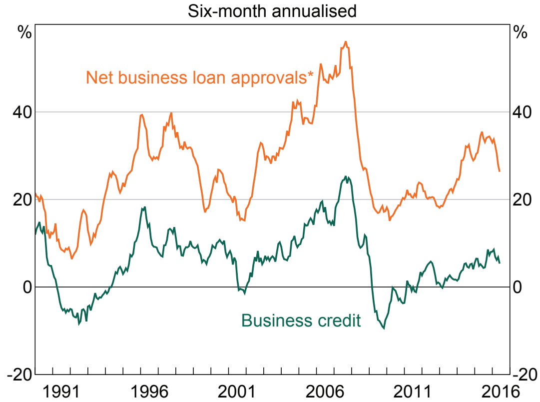


* Non-seasonally adjusted and non-break adjusted; includes RFI business credit, non-intermediated debt and an estimate of cross-border syndicated lending

Sources: ABS; APRA; Bloomberg; RBA; Thomson Reuters

Graph 4.16
Business Credit Growth and Approvals

Six-month annualised



* As a share of business credit

Sources: ABS; APRA; RBA

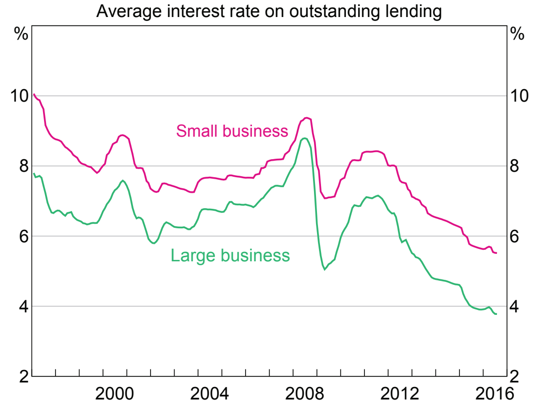
most industries, although it has been more prevalent in sectors in which lending grew more quickly in 2015, such as finance and insurance, manufacturing, and utilities and telecommunications. Some segments of lending remain strong, particularly fixed-term loan approvals for property and construction purposes. Both foreign and domestic banks have contributed to the easing in business credit growth, with the foreign bank share of business credit remaining steady in recent months.

Prior to the August cash rate reduction, business lending rates had declined by less than the cash rate. For large businesses, the pass-through of the cash rate reduction in May followed increases in business lending rates earlier in the year in response to higher spreads in non-intermediated credit markets (Graph 4.17). The average outstanding small business lending rate declined by around 15 basis points over the first half of the year; advertised small business lending rates were generally reduced by 25 basis points in May, partly offsetting increases in small business lending rates earlier in the year.

Bond issuance by Australian corporations remains relatively low with $11 billion issued in the year to date (Graph 4.18). This mostly reflects the continued absence of issuance by resource-related corporations. Spreads to AGS for resource-related corporations increased significantly through 2015 and early 2016; while spreads have eased in recent months, they remain elevated compared to the first half of 2015, when these corporations last engaged in substantial issuance (Graph 4.19). Spreads for other non-financial corporations have reversed the widening seen earlier in the year.

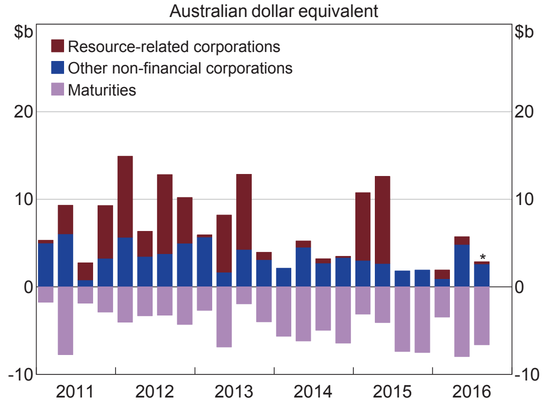
Equity raisings by non-financial corporations (including real estate companies) increased in the June quarter following limited activity earlier in the year. Mergers and acquisitions (M&A) activity has been elevated over the past 18 months, with around $27 billion in deals announced by listed companies so far this year.

Graph 4.17
Australian Business Lending Rates*
Average interest rate on outstanding lending



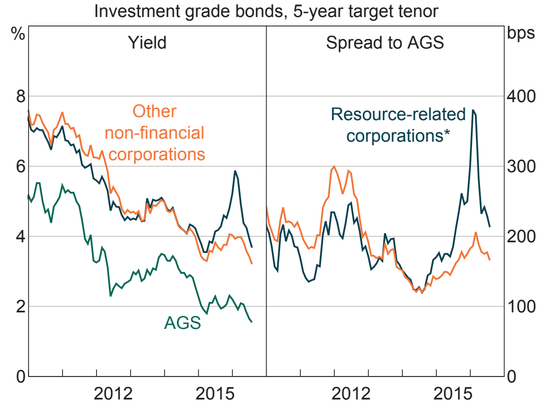
* RBA estimates
Sources: APRA; RBA

Graph 4.18
Australian Corporate Bond Issuance
Australian dollar equivalent



* Latest quarter issuance to date
Source: RBA

Graph 4.19
Australian Corporate Bond Pricing
Investment grade bonds, 5-year target tenor

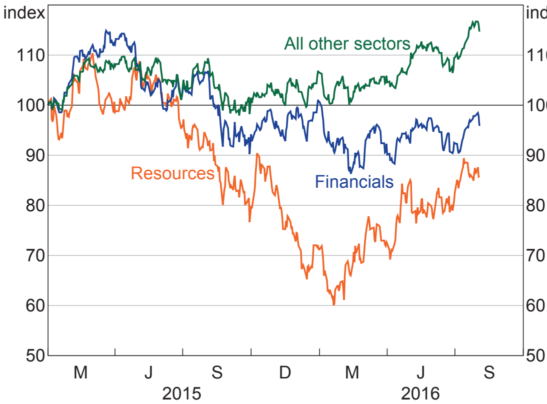


* Includes Origin Energy
Sources: Bloomberg; RBA; S&P Capital IQ

Equity Markets

Australian equity prices have largely followed movements in global share prices in recent months, falling following the UK referendum vote before recovering to be 3 per cent higher than at the start of the year. The rise in equity prices was broad based across sectors, although financials continue to underperform (Graph 4.20).

Graph 4.20
Australian Share Price Indices
End December 2014 = 100



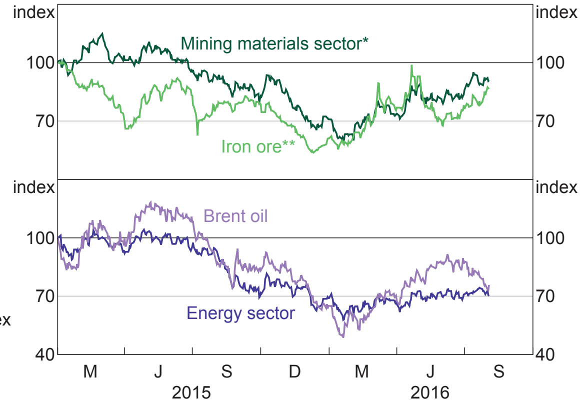
Source: Bloomberg

The resources sector has outperformed throughout the year to date as commodity prices have traded at higher levels compared with late 2015 (Graph 4.21). More recently, gold miners have been buoyed by higher gold prices amid heightened demand for safe haven assets.

Share prices for companies outside the financial and resources sectors are generally higher; utilities, healthcare, industrials and consumer discretionary have outperformed the broader market, while consumer staples were affected by earning downgrades and impairments.

Analysts' earnings expectations for the 2016/17 financial year have generally been revised lower over the past few months. However, resources sector earnings expectations have been revised higher alongside a sustained recovery in commodity prices.

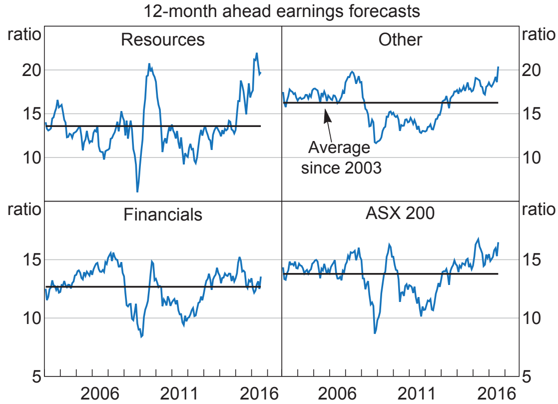
Graph 4.21
Resources Share Prices and Commodity Prices
End December 2014 = 100



* Derived from resources sector share prices
** Qingdao import iron ore spot price
Sources: Bloomberg; RBA

Valuations of Australian equities, as measured by forward price-earnings ratios, remain at or above their long-term averages across all broad sectors (Graph 4.22). Resources sector valuations remain well above long-term averages, reflecting low analysts' earnings expectations over the next 12 months. However, analysts are expecting an improvement in resources sector earnings over the coming years. ✠

Graph 4.22
ASX 200 Forward Price-earnings Ratios
12-month ahead earnings forecasts



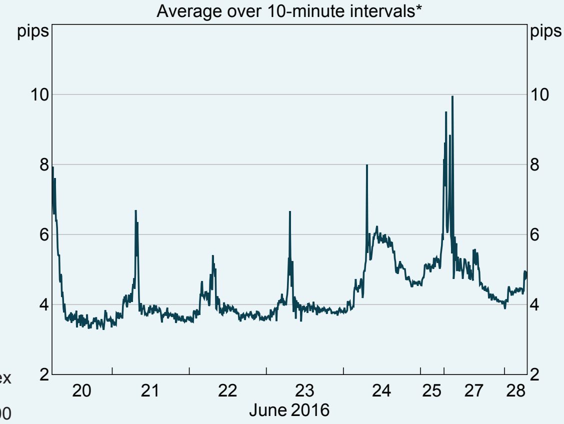
Source: Thomson Reuters

Box C

Australian Financial Markets and the UK Referendum

There were large movements in financial markets on 24 June as it became apparent that the UK referendum would result in a majority voting for the option to leave the European Union. In Australia, as in other countries, there were large movements in exchange rates, government bond yields and equity prices over the trading session as results from the ballot count were announced (Graph C1). Amid the increase in market volatility, there was a substantial pick-up in market turnover and the key markets where price discovery takes place functioned well and remained highly liquid.

For a couple of days following the referendum, transaction volumes in foreign exchange markets were higher than normal. There was no material impact on price discovery, although bid-ask spreads (the difference between the best quoted prices for buying and selling) rose in currency markets for a short period of time.[1] Consistent with this, bid-ask spreads for the Australian dollar against the US dollar increased immediately after the referendum (Graph C2). However, spreads returned to their usual size over the next few days. (Spreads in early morning trades on Mondays are usually wider than those on other weekday mornings.)



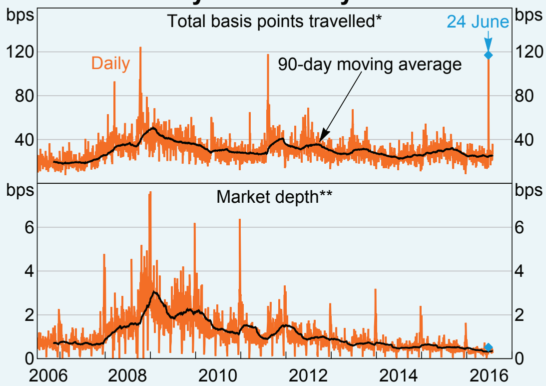
In Australia, much of the price discovery in fixed income markets occurs in the Treasury bond futures market.[2] On 24 June, the net fall in 10-year bond yields, as measured by the change in yield on the 10-year Treasury bond futures contract, was about 25 basis points. Over the course of the day, however, bond yields moved considerably in both directions. Aggregated over 5-minute intervals during each

1 Bid-ask spreads are typically measured in 'pips' in foreign currency markets. For example, the AUD/USD bid-ask spread for a bid price of 0.7510 US dollars and an ask price of 0.7511 US dollars is 1 pip.

2 For a discussion of market liquidity see Cheshire J (2016), 'Liquidity in Fixed Income Markets', RBA *Bulletin*, June, pp 49–58.

trading session (excluding after hours trading), yields moved a total of 120 basis points on the day (top panel of Graph C3). This is similar to price movements recorded during the global financial crisis in 2008 and the concerns around European sovereign debt in 2011.

Graph C3
Australian 10-year Treasury Bond Futures



* Aggregated basis point movement in bond yields over 5-minute intervals during the day session

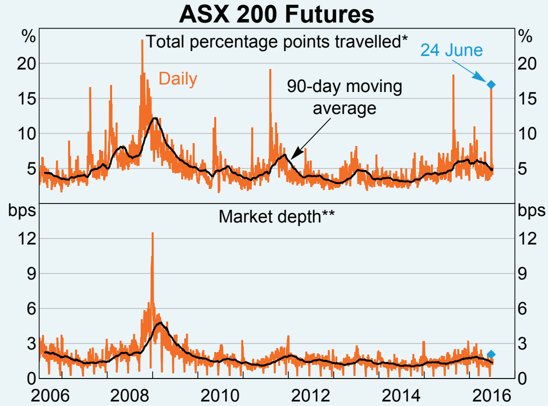
** Basis point movement per $100 million of contracts at market value

Sources: ASX; RBA; Thomson Reuters

However, in contrast to those earlier periods, liquidity in bond futures markets on 24 June did not appear to be adversely affected as it was underpinned by a substantial increase in turnover. In the Australian 3-year Treasury bond futures contract, turnover during the day session was around $31 billion, while turnover in the 10-year bond futures contract was around $23 billion. This compares with daily averages over the previous year of around $11 billion and $8 billion, respectively. Market depth, as measured by the distance yields moved per $100 million of futures contracts transacted, remained near its recent average, suggesting that transactions were able to be executed with limited price impact despite the increased volatility (bottom panel of Graph C3).

A similar pattern was evident in equity markets. On 24 June, the ASX 200 and corresponding equity futures fell by around 3 per cent during the day session. This was smaller than losses seen in other periods of heightened risk aversion, although in the futures market the intraday movements were as large as those observed in the global financial crisis and aggregated to over 15 per cent of the ASX 200's index value (top panel of Graph C4). Notwithstanding the intraday volatility, liquidity in the equity market did not appear to diminish during the trading session, as turnover rose and market depth remained near its recent average (bottom panel of Graph C4). Turnover in ASX 200 equity futures on 24 June was around $8 billion, compared with a daily average of around $4 billion over the previous year.

Graph C4
ASX 200 Futures



* Aggregated percentage point movement in ASX 200 index value over 5-minute intervals during the day session

** Basis point movement per $10 million market value of contracts

Sources: ASX; RBA; Thomson Reuters

It is more difficult to assess intraday liquidity in credit markets because almost all activity occurs over the counter (OTC), which doesn't have the same level of transparency as activity in exchange-traded markets. Credit markets are typically much less liquid than government bond markets, but they are an important source of finance for corporations. Over the day, there was a rise in spreads on corporate securities relative to government bonds and an increase in credit default swap (CDS) premia, which was consistent with moves in credit markets overseas. This occurred alongside an increase in trading activity in CDS markets. There has been little lasting impact from the event, and credit spreads and yields have subsequently declined.

Primary market bond issuance by Australian resident issuers slowed ahead of the UK referendum, but, after a brief pause, has resumed. In particular, Australian banks have issued securities in the domestic and offshore markets at similar spreads to those seen prior to the UK referendum.

The infrastructure that underpins the Australian financial market operated smoothly throughout this period. For example, the central clearing counterparties (CCPs) that are responsible for the clearing of exchange-traded products (such as bond and equity futures) and OTC derivative instruments in Australia had established plans to ensure uninterrupted operation and adequate financial cover in the event that market volatility increased around the UK referendum. In the event, the heightened market volatility and elevated turnover on 24 June prompted the CCPs to process a large volume of intraday margin calls. This included additional initial margin calls in the afternoon of the Australian trading day on 24 June, to increase collateral held to cover forward-looking volatility ahead of the European and US trading days. These calls were met on time.

5. Price and Wage Developments

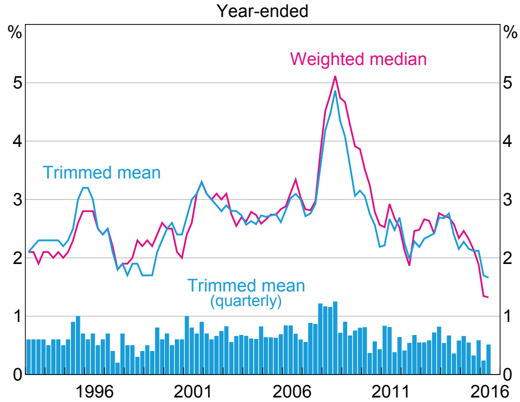
Inflation

Inflation has been low. A confluence of factors is contributing to weakness in domestic cost pressures. This includes spare capacity in labour and a number of product markets, which has been associated with low wage growth and pressures on costs and margins. Some of the weakness in domestic cost pressures also reflects the adjustment to the decline in the terms of trade and mining investment over recent years, while the depreciation of the Australian dollar over the past few years has put upward pressure on the costs of tradable items.

The June quarter inflation data were broadly in line with the forecast in the May *Statement*. Following the very low March quarter outcomes, measures of underlying inflation picked up to ½ per cent in the June quarter, to be around 1½ per cent over the year (Graph 5.1; Table 5.1). After falling in the March quarter, the headline consumer price index (CPI) increased by 0.6 per cent (in seasonally adjusted terms) to be 1.0 per cent higher over the year (Graph 5.2). Price inflation for volatile items such as fuel and fruit & vegetables boosted headline inflation in the June quarter but remained lower over the year.

The prices of tradable items (excluding volatile items and tobacco) declined slightly in the June quarter and were little changed over the year (Graph 5.3). The final prices of tradable items depend on the world market price and exchange rate movements, although there is still a significant domestic cost component. The substantial

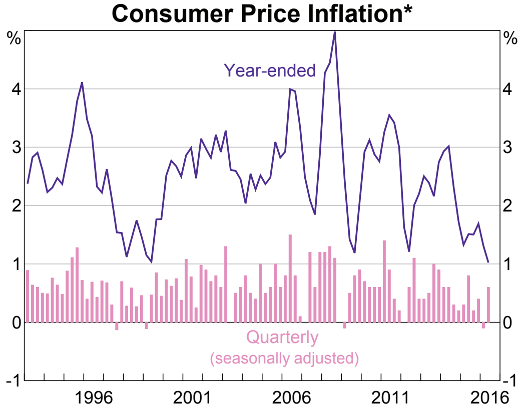
Graph 5.1
Measures of Underlying Inflation*
Year-ended



* Excludes interest charges prior to the September quarter 1998; adjusted for the tax changes of 1999–2000

Sources: ABS; RBA

Graph 5.2
Consumer Price Inflation*



* Excludes interest charges prior to the September quarter 1998; adjusted for the tax changes of 1999–2000

Sources: ABS; RBA

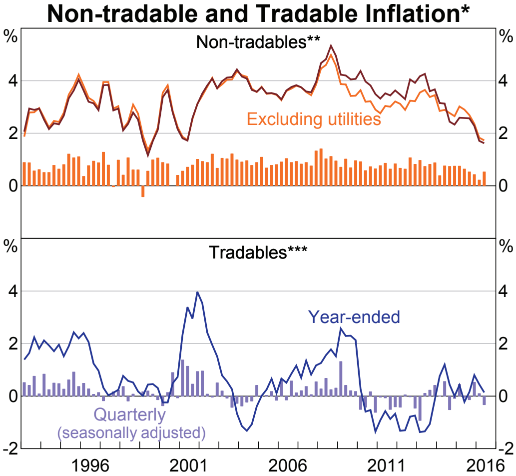
depreciation of the exchange rate over the past few years has increased import and export prices in Australian dollar terms (Graph 5.4). However,

Table 5.1: Measures of Consumer Price Inflation
Per cent

	Quarterly[(a)]		Year-ended[(b)]	
	June quarter 2016	March quarter 2016	June quarter 2016	March quarter 2016
Consumer Price Index	0.4	–0.2	1.0	1.3
Seasonally adjusted CPI	0.6	–0.1	–	–
– Tradables	0.6	–0.6	0.0	0.6
– Tradables (excl. volatile items and tobacco)[(c)]	–0.3	0.1	0.1	0.5
– Non-tradables	0.6	0.2	1.6	1.7
Selected underlying measures				
Trimmed mean	0.5	0.2	1.7	1.7
Weighted median	0.4	0.1	1.3	1.3
CPI excl. volatile items[(c)]	0.4	0.3	1.6	1.7

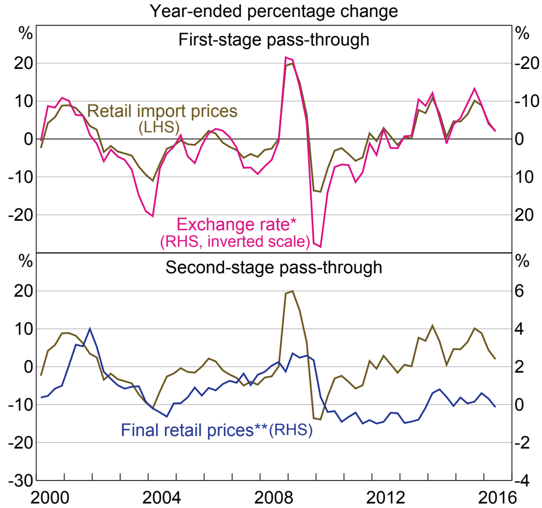
(a) Except for the headline CPI, quarterly changes are based on seasonally adjusted data; those not published by the ABS are calculated by the RBA using seasonal factors published by the ABS
(b) Year-ended changes are based on non-seasonally adjusted data, except for the trimmed mean and weighted median
(c) Volatile items are fruit, vegetables and automotive fuel
Sources: ABS; RBA

Graph 5.3
Non-tradable and Tradable Inflation*



* Adjusted for the tax changes of 1999–2000
** Excluding interest charges prior to the September quarter 1998 and deposit & loan facilities to June quarter 2011
*** Excluding volatile items (fruit, vegetables and automotive fuel) and tobacco
Sources: ABS; RBA

Graph 5.4
Retail Prices and the Exchange Rate



* Import-weighted index, quarter average
** Adjusted for the tax changes of 1999–2000
Sources: ABS; RBA

heightened retail competition over recent years, including from new foreign entrants, has placed downward pressure on retail prices.[1] The net effect has been further declines in prices of consumer durables, though the extent of the declines is less than a few years ago, and low growth in the prices of food and alcohol.

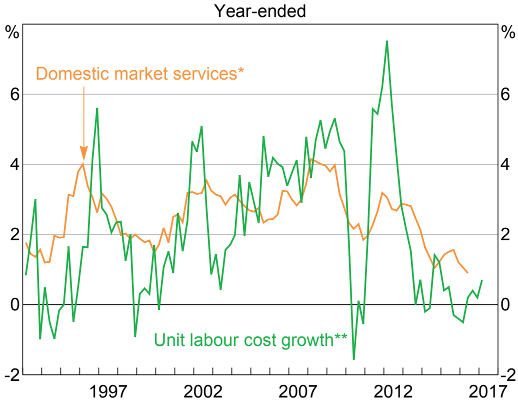
Non-tradables inflation picked up a little in the June quarter but, in year-ended terms, remained

1 For a more detailed discussion, see Ballantyne A and S Langcake (2016), 'Why Has Retail Inflation Been So Low?', RBA *Bulletin*, June, pp 9–17.

around its lowest level since the late 1990s. A number of factors have contributed to the relatively broad-based decline in non-tradables inflation over recent years, including spare capacity in much of the economy and the associated low growth in labour costs.

Market services inflation has been particularly low (Graph 5.5). As labour costs account for around half of final prices for market services, inflation in this component is consistent with low growth in unit labour costs. This weakness has been particularly pronounced in household services inflation, which includes further large falls in prices of telecommunication equipment and services due to heightened competition. Prices of domestic holiday travel and accommodation were also lower over the year.

Graph 5.5
Market Services Inflation



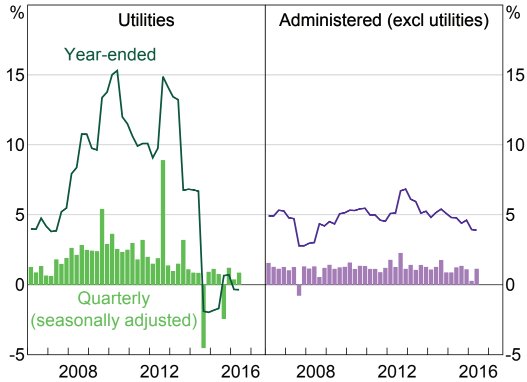
* Excludes interest charges prior to the September quarter 1998, deposit & loan facilities prior to the June quarter 2011, housing services and domestic travel; adjusted for the tax changes of 1999–2000

** Non-farm, moved forward by four quarters

Sources: ABS; RBA

Administered prices picked up (in seasonally adjusted terms) in the June quarter, following unusually low outcomes in the March quarter in part due to temporary factors (Graph 5.6). Utilities inflation has been low since 2014, following a period of high inflation that was driven by a variety of factors not closely linked to the business cycle, including: a move towards cost-based pricing; an increase in investment to replace ageing infrastructure and

Graph 5.6
Administered Prices

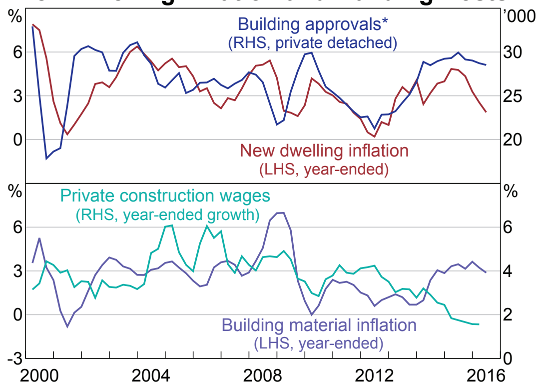


Sources: ABS; RBA

improve capacity; and higher wholesale prices. Many of these pressures have now dissipated and there has been a broad-based decline in inflation in electricity, gas & other household fuels, and water & sewerage. Inflation in other administered items has declined in recent years and was a little below its inflation-targeting average over the past year.

Inflation in the housing-related components of the CPI has been mixed. Inflation in the cost of new dwellings picked up to be around average in the June quarter, following surprisingly weak outcomes in the previous two quarters. New dwelling costs are currently measured by the ABS as the cost of building a new detached house in a capital city, excluding the price of the land; as such, it does not (directly) capture the cost of building an apartment, where a large proportion of building activity has been concentrated of late. The June quarter outcome is broadly consistent with the level of detached housing construction activity in many capital cities and elevated inflation in the cost of building materials (Graph 5.7). While measures of construction wage growth are low, they will also include wage growth in the non-residential and mining construction industries. Furthermore, the residential building industry has a large share of subcontractors, rather than wage earners. According to the Bank's liaison, earnings growth for many residential building subcontractors remains relatively high. New dwelling costs remain weak

Graph 5.7
New Dwelling Inflation and Building Costs



* Three-month rolling sum

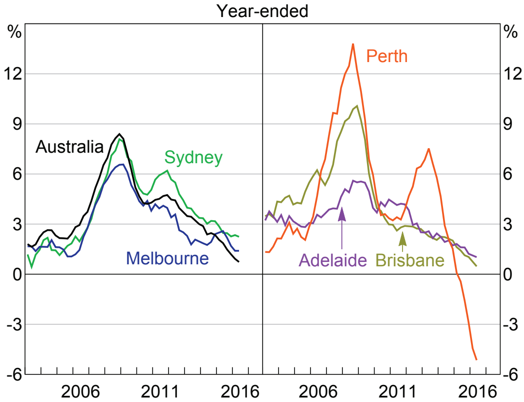
Sources: ABS; RBA

in Perth, reflecting reduced demand for housing following the end of the mining investment boom and the large decline in commodity prices over recent years.

In Perth, rents have declined sharply, reflecting slower population growth and ongoing additions to the housing supply (Graph 5.8; see 'Box B: The Housing Market'). More generally, residential rent inflation has declined across all capital cities over the year. Developments in rent inflation are fairly persistent over time because the CPI captures all rents, not just the small proportion of agreements that are renegotiated each quarter.

Graph 5.8
Rent Inflation

Year-ended

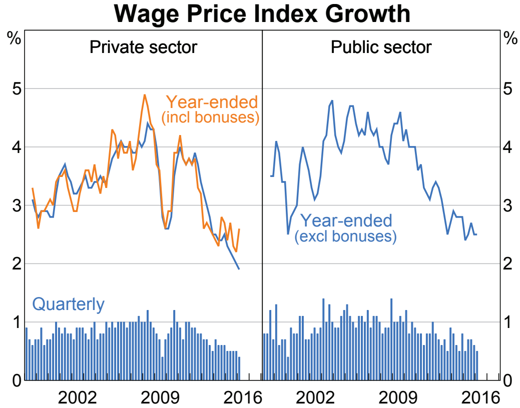


Source: ABS

Labour Costs

Labour cost pressures remain weak, reflecting spare capacity in the labour market, a decline in inflation expectations and the moderation in firms' profits due to the decline in the terms of trade. The wage price index (WPI), which is designed to abstract from changes in the type and quality of jobs, rose by 0.4 per cent in the March quarter and by 2.1 per cent over the year. Growth in private sector wages edged down further over the year to March (Graph 5.9). However, when bonuses are included, private sector wage growth has been little changed for the past two years. Public sector wage growth has also been fairly stable over most of the past two years. While wage growth has been low recently, it is around average in real terms (deflated by headline CPI).

Graph 5.9
Wage Price Index Growth



Source: ABS

WPI growth has been low in every industry and across all states. However, private sector wage growth is currently lowest in Western Australia and Queensland, and total wage growth is lowest in industries that are more exposed to the end of the mining investment boom, such as mining, construction and professional, scientific & technical services (Graph 5.10).

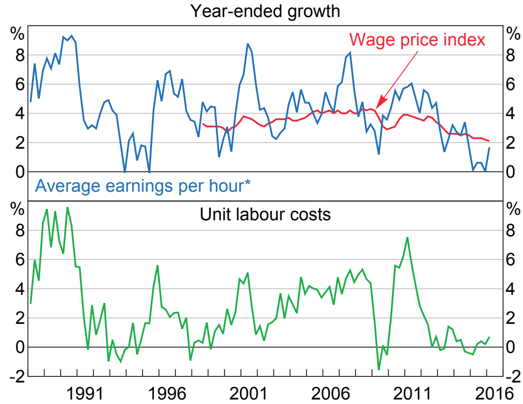
Growth in average earnings per hour from the national accounts (AENA) – which captures a broader range of payments to labour as well

Graph 5.10
Wage Growth by Industry Group
Seasonally adjusted, year-ended

* Includes: mining; construction; rental, hiring & real estate; professional, scientific & technical services; and administrative & support services

Sources: ABS; RBA

Graph 5.11
Labour Costs
Year-ended growth



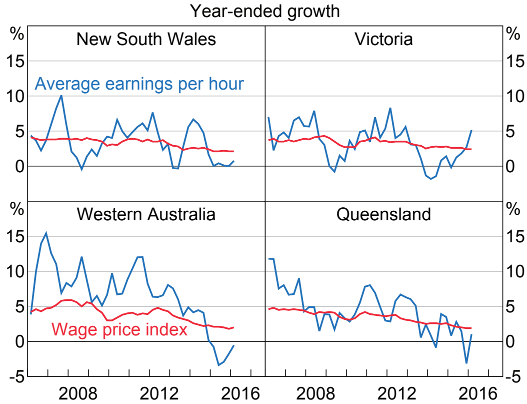
* Average earnings per hour for the March quarter 2016 are calculated using hours worked from the labour force survey

Sources: ABS; RBA

as the effects of changes in the composition of employment – picked up in the March quarter to be 1.7 per cent higher over the year (Graph 5.11). Growth in AENA had been noticeably weaker than growth in the WPI over 2015, which partly reflects the movement of some workers from high-paying jobs in mining-related activities to similar work in lower-paying positions in the non-mining economy. For example, Bank liaison suggests that many workers employed in mining construction during the mining investment boom have returned to jobs in civil and residential construction at lower wage rates. In addition, liaison reports that spare capacity in the labour market more generally is leading some firms to replace workers who are leaving with new employees on lower salaries. Also, promotion rates may be below average and non-wage payments, such as allowances, are likely to be growing slowly or even declining. Nevertheless, AENA growth picked up to be closer to WPI growth in the March quarter 2016. This may just reflect the usual volatility in this series, but the expectation is that AENA growth will eventually pick up in a durable way as the effects of the weakness in resource sector employment wane and there are further cyclical improvements in labour market conditions more broadly.

The difference between AENA and WPI growth has been largest in Western Australia, where the shift away from highly paid mining-related positions is most pronounced (Graph 5.12). Indeed, in Victoria AENA growth is outpacing growth in the WPI, which may reflect a shift in employment towards more highly paid positions, a rise in promotion rates or increases in bonuses and other non-wage payments.

Graph 5.12
Labour Costs by State
Year-ended growth



Sources: ABS; RBA

While low wage growth is consistent with a degree of spare capacity in the labour market, wage growth has been lower than implied by its historical relationship with the unemployment rate.[2] Several

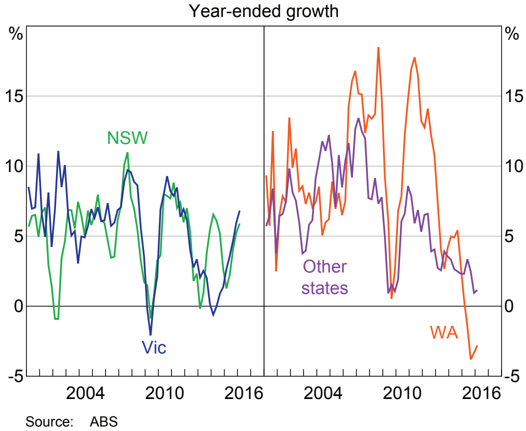
2 For a more detailed discussion of these factors, see Jacobs D and A Rush (2015), 'Why is Wage Growth So Low?', RBA *Bulletin*, June, pp 9–18.

factors are likely to have contributed to this. The decline in inflation expectations and lower CPI outcomes over recent years may have influenced wage negotiations. The Bank's liaison suggests that a large proportion of firms benchmark average wage rates to consumer price inflation and survey evidence suggests union officials commonly consider inflation when negotiating wage increases. It is also possible that other measures of spare capacity in the labour market that have not moved in line with the unemployment rate are more relevant for wage developments. For example, the participation rate remains well below its previous peak, which could signal that some people who would like to work have given up searching for a job, but could re-enter the labour force if employment prospects improve. Also, the underemployment rate remains elevated, as the share of workers who would like to work more hours has not declined (see 'Domestic Economic Conditions' chapter). Finally, increased labour market flexibility may have provided firms with greater scope to adjust wages in response to a given change in demand for their goods and services, and in response to lower income growth, partly due to the significant fall in the terms of trade.

Overall, the cost of a unit of labour from a firm's perspective (unit labour costs) has been little changed for around four and a half years, as low growth in AENA has been matched by low growth in labour productivity (output per hour worked). Productivity growth ticked up a little over the year to March 2016, in part reflecting an increase in LNG exports that made a significant contribution to output but required little additional labour input. Nevertheless, labour productivity growth remains relatively weak in Australia, as it does in many advanced economies (see 'International Economic Developments' chapter). Together with the depreciation of the nominal exchange rate over recent years, low unit labour cost growth is helping to improve international competitiveness, following a period of relatively strong growth in unit labour costs during the large run-up in commodity prices and mining investment.

Lower growth in labour costs may have encouraged firms to employ more people than otherwise, thereby supporting growth in overall household spending. At the same time, low wage growth has directly contributed to low growth in household disposable income. Overall, growth in total compensation of employees – which reflects growth in both average earnings per hour and the number of hours worked by employees – has picked up to be a little above its long-run average in New South Wales and Victoria over the past year (Graph 5.13). In contrast, compensation of employees has declined in Western Australia over recent years, after growing strongly during the terms of trade and mining investment boom. Growth has also been low in the other states over recent years.

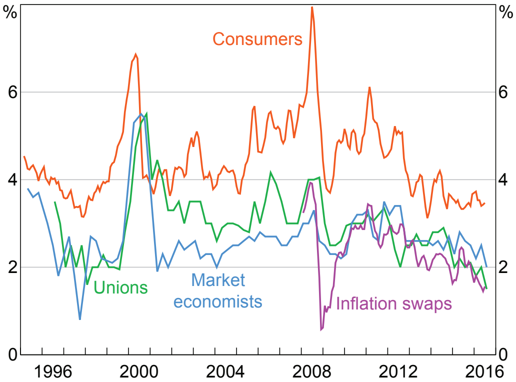
Graph 5.13
Compensation of Employees
Year-ended growth



Inflation Expectations

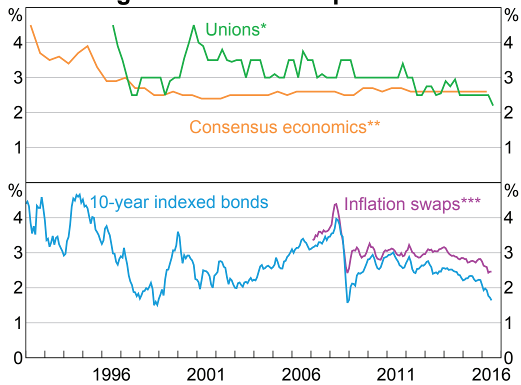
Short-term measures of inflation expectations remain low, consistent with the low inflation outcomes of late (Graph 5.14). Consumers' inflation expectations have been little changed over the past year, while union officials' expectations have

Graph 5.14
Short-term Inflation Expectations
Over the next year



Sources: Australian Council of Trade Unions; Bloomberg; Melbourne Institute of Applied Economic and Social Research; RBA; Workplace Research Centre

Graph 5.15
Long-term Inflation Expectations



* Average over the next five to ten years
** Average over six to ten years in the future
*** Five-to-ten-year forward

Sources: Australian Council of Trade Unions; Bloomberg; Consensus Economics; RBA; Workplace Research Centre; Yieldbroker

drifted down a little. Union officials' and consumers' expectations for inflation over the next year are around the levels seen in the late 1990s. Near-term inflation expectations based on inflation swaps have declined further in recent months; however, some part of this may reflect a change in investors' assessment of, and willingness to bear, inflation risk.

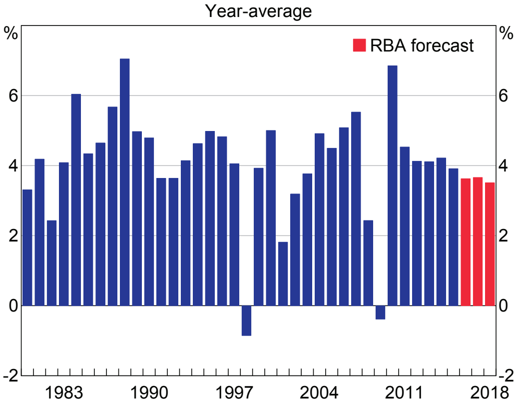
The long-term expectations of union officials have moved a little lower more recently, though both the long-term expectations of market economists and union officials have remained between 2 and 3 per cent (Graph 5.15). Five-to-ten year inflation swaps, which capture expected average inflation between five and ten years ahead, remain within the range of 2–3 per cent, although they have declined since the beginning of the year. Inflation expectations based on 10-year indexed bonds have also fallen noticeably over the first half of the year to be less than 2 per cent, and are now around late 1990s levels. This is partly because the bond-based measure of inflation expectations is the expected average over the next 10 years and is, therefore, affected by expected near-term low rates of inflation. Swaps and bonds may have also been affected by other developments such as changes in the premium that investors demand to bear inflation and liquidity risks. ✠

6. Economic Outlook

The International Economy

The GDP growth of Australia's major trading partners overall is expected to be a bit below average over the next few years, which is unchanged from the May *Statement* (Graph 6.1).

Graph 6.1
Australia's Trading Partner Growth*
Year-average



* Aggregated using total export shares
Sources: ABS; CEIC Data; RBA; Thomson Reuters

Growth in China is expected to moderate gradually over the next few years, largely as forecast previously. Weakness in the growth of private investment is expected to be partly offset by the effects of recent policy stimulus aimed at achieving the authorities' economic growth targets. Japanese GDP growth is expected to pick up to be slightly above its potential growth rate over the next couple of years. This is slightly stronger in the near term than previously expected given that the next consumption tax increase has been postponed from early 2017 to late 2019 and additional fiscal stimulus has been announced. However, there has been no change to the longer-term outlook for the Japanese economy, which is facing a significant drag on growth associated with population ageing.

In other east Asian economies, the ongoing weakness in external demand conditions is likely to continue to dampen export and investment growth for a time. Consumption growth, especially in the high-income economies, is also likely to be more subdued than in recent years. Accommodative monetary policies and supportive fiscal policies in some of these economies, together with some recovery in external demand conditions from commodity-exporting emerging economies, are expected to see GDP growth in the region recover to around estimates of the potential growth rate by 2018.

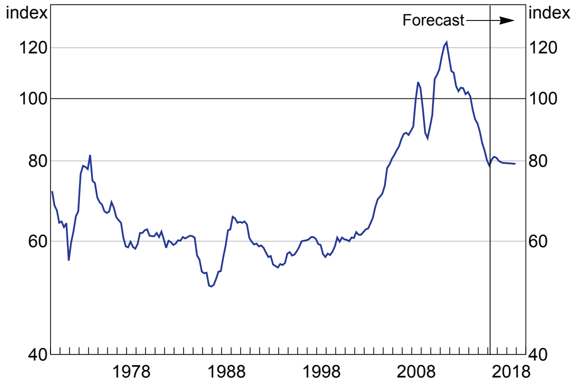
The US economy is expected to grow at an above-trend rate over the next couple of years. US monetary policy remains very accommodative and, after a few years of consolidation, fiscal policy has become less of a drag on growth. Conditions in the US labour market remain strong and should continue to support growth of consumption. This is likely to offset the ongoing weakness in overall business investment, much of which reflects the decline in oil-related investment.

There is considerable uncertainty around how the outcome of the UK referendum will affect the UK economy, although it is expected to restrain UK business investment in the near term. At this stage, the effect of these developments on Australia's major trading partners as a group is expected to be limited. Outside the United Kingdom itself, the largest impact, although still relatively small, is expected to be on growth in the rest of the European Union. GDP growth in the euro area over the next 2–3 years has been revised slightly lower but is still expected to remain above trend, supported by accommodative monetary policy, less drag from fiscal consolidation and further gradual improvements in labour market conditions.

Globally, core inflation has been low for some time, reflecting spare capacity in many labour, product and commodity markets. However, the ongoing decline in spare capacity in the major advanced economies, particularly in labour markets, is expected to place some upward pressure on core inflation over time. While headline inflation rates are likely to remain below central bank targets for some time yet, the drag from the earlier fall in oil prices should dissipate. On the other hand, there are indications that inflation expectations have declined in some advanced economies since late 2014, which could dampen inflationary pressures.

Australia's terms of trade have declined by about 35 per cent since their peak in late 2011 but remain well above levels that prevailed prior to the mining boom (Graph 6.2). They are forecast to remain close to current levels over the course of the forecast period. This outlook is little changed from that presented three months ago. The outlook for coal prices is slightly more positive than previously thought, reflecting supply cuts in China and elsewhere. Iron ore prices are still expected to fall from current levels over the forecast period. Chinese steel demand is projected to ease over the next few years, largely as previously forecast, and the total supply of iron ore is expected to increase, despite a rapid reduction in supply from high-cost producers, particularly those in China.

Graph 6.2
Terms of Trade
2013/14 average = 100, log scale



Sources: ABS; RBA

Domestic Activity

The domestic forecasts are conditioned on a number of technical assumptions. The cash rate is assumed to move broadly in line with market pricing as at the time of writing. This assumption does not represent a commitment by the Reserve Bank Board to any particular path for policy. The exchange rate is assumed to remain at its current level over the forecast period (trade-weighted index (TWI) at 63 and A$ at US$0.76). The TWI is 1½ per cent higher than the assumption underlying the forecasts in the May *Statement*. The forecasts are based on the price of Brent crude oil being US$45 per barrel over the forecast period, which is 3 per cent lower than the assumption used in May and in line with futures pricing for the near term. The working-age population is still assumed to grow by 1.5 per cent over 2016 and by 1.6 per cent over 2017 and 2018, drawing on forecasts from the Department of Immigration and Border Protection.

Overall, the forecasts for GDP growth are little changed from those presented in the May *Statement*. The year-ended growth rate in the near term is slightly higher given the unexpected strength in the March quarter data, but recent indicators are consistent with a more moderate pace of growth in the June quarter 2016. Growth is forecast to be around 2½–3½ per cent over the year to the December quarter 2016, before increasing to around 3–4 per cent over the year to the December quarter 2018, which is above estimates of potential growth in the Australian economy (Table 6.1).

Table 6.1: Output Growth and Inflation Forecasts[(a)]
Per cent

	Year-ended					
	Jun 2016	Dec 2016	Jun 2017	Dec 2017	Jun 2018	Dec 2018
GDP growth	3¼	2½–3½	2½–3½	2½–3½	3–4	3–4
CPI inflation	1.0	1½	1½–2½	1½–2½	1½–2½	1½–2½
Underlying inflation	1½	1½	1½–2½	1½–2½	1½–2½	1½–2½
	Year-average					
	2015/16	2016	2016/17	2017	2017/18	2018
GDP growth	3	2½–3½	2½–3½	2½–3½	2½–3½	3–4

(a) Data are quarterly; technical assumptions include A$ at US$0.76, TWI at 63.5 and Brent crude oil price at US$45 per barrel; shaded regions are historical data

Sources: ABS; RBA

The starting point for the forecasts is that the Australian economy grew by more than estimates of potential over the year to the March quarter 2016. This was stronger than expected at the time of the May *Statement* and was largely the result of a significant expansion in the volume of resource exports due to unusually favourable weather conditions. At the same time, there were further large falls in mining investment, such that mining activity overall was little changed over the year. Meanwhile, the non-mining sectors of the economy grew at an above-average pace over the year to the March quarter 2016, supported by low interest rates and the ongoing effects of the exchange rate depreciation since early 2013. Solid growth was evident in consumption, dwelling investment and most export categories. Public demand grew at close to its average pace, while non-mining business investment declined over the year.

Low interest rates and gains to employment are expected to continue supporting household demand, despite relatively modest growth in household income over the next year or so. Consumption growth is projected to remain close to its long-term average over the forecast period, consistent with the forecasts in the May *Statement*. Meanwhile, growth in real household disposable income is expected to gradually increase to around average levels by the end of the forecast period.

Together, these forecasts imply that the household saving ratio will decline gradually for a time, extending the downward trend of the past few years.

The outlook for dwelling investment is little changed. The substantial amount of residential construction work in the pipeline increased a little further in the March quarter, and it is sufficient to underpin dwelling investment growth for the next year or so. However, the modest decline in dwelling approvals from the high levels observed at the beginning of 2015 is consistent with the pace of growth in dwelling investment moderating towards the end of the forecast period.

The outlook for the level of resource exports is a little higher than previously expected by the end of the forecast period. The liquefied natural gas (LNG) export profile has been revised higher, reflecting a modest increase in capacity at some LNG projects. Coking coal exports are also expected to be slightly higher as Australian miners respond to the improvement in coking coal prices. However, the scope for additional growth in thermal coal exports appears to be limited given weak global demand and the relatively high cost of some Australian production. More generally, the depreciation of the Australian dollar over the past few years is assisting domestic producers of tradable items, and net service exports are forecast to continue growing.

As before, mining investment is expected to continue to fall over the forecast period, as large resource-related projects are completed and few new projects are expected to commence. This forecast reflects existing capacity in conjunction with expectations for some moderation in growth in global demand for commodities. However, the subtraction from GDP growth from lower mining investment looks to have peaked in the 2015/16 financial year.

The outlook for non-mining business investment remains subdued in the near term, consistent with the ABS capital expenditure survey of firms' investment intentions and the low level of non-residential building approvals. However, investment is being supported, especially in non-resource-rich states, by very low interest rates, the gradual pick-up in demand growth and the depreciation of the Australian dollar over the past few years. Moreover, survey measures of capacity utilisation have been increasing over the past couple of years and are currently above their long-term averages. Stronger growth in public investment is expected to support public demand over the forecast period.

Consistent with the outlook for output, the labour market forecasts are little changed from the May *Statement*. Following strong growth in late 2015, employment growth has moderated over the first half of the year, which had been expected. Near-term indicators, such as job advertisements and job vacancies, suggest continued modest employment growth over the second half of 2016. Employment growth is then expected to pick up over the forecast period, supported by rising GDP growth and relatively subdued wage growth. The participation rate is expected to increase as more people enter the labour force in response to the improvement in employment growth. In combination, this implies that the unemployment rate will move only a little lower over the forecast period, and that there is likely to be a degree of spare capacity in the labour market for some time.

Inflation

The June quarter underlying inflation outcome was broadly in line with expectations at the time of the May *Statement*. As a result, there has been little change to the forecast that underlying inflation will remain around 1½ per cent in year-ended terms over 2016 and pick up to around 1½–2½ per cent by the end of the forecast period.

The large exchange rate depreciation since early 2013 is likely to continue boosting the prices of tradable items as increases in import prices are gradually passed through to the prices paid by consumers. However, domestic factors, such as heightened competitive pressure in retail markets and low wage growth, have put downward pressure on retail inflation over recent years and are expected to persist for some time.

Wage growth is low, reflecting spare capacity in the labour market, a decline in near-term inflation expectations and downward pressure on firms' profits as a result of the decline in the terms of trade. Growth in the wage price index (WPI) is expected to remain around its current levels over the rest of the year and to pick up gradually over the forecast period as labour market conditions improve and firms' output prices rise. However, broader measures of labour costs also influence inflation. One such measure is average earnings per hour from the national accounts, which captures the effects of non-wage costs, such as allowances, as well as changes in the composition of the labour force. Growth in average earnings per hour has been weaker than growth in the WPI over the past year or so, reflecting, in part, the usual cyclical effects arising from spare capacity in the labour market that lead to subdued growth in non-wage costs and enable firms to hire new workers on lower wages. In addition, average earnings appear to have been affected by workers moving from high-paying mining jobs to similar types of work at lower levels of pay, as mining investment and the terms of trade decline. The combination of these effects is expected to wane over the forecast period because the transition from mining employment is well advanced and labour market conditions are expected to improve. As a result, the national accounts measure of average earnings is expected to grow at a faster pace than the WPI towards the end of the forecast period.

When considering labour cost pressures, the output that can be produced for each additional hour worked also matters. Unit labour costs, which combine average earnings with labour productivity, are expected to rise gradually over the next few years. This will contribute to a pick-up in non-tradable inflation. Working in the opposite direction, further additions to housing supply are expected to keep rental growth low over the next few years.

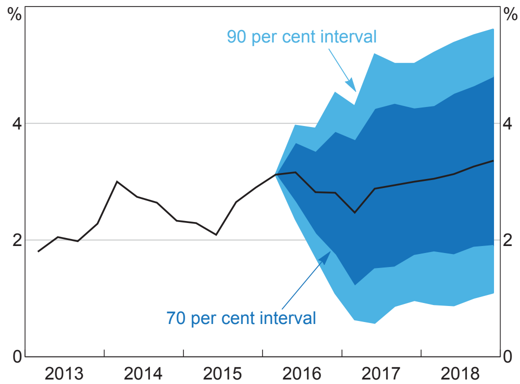
There have also been a number of temporary factors that have subtracted from headline inflation that are expected to dissipate, such as the sharp decline in fuel prices over recent years and the effects of regulatory changes to some utilities prices. In addition, the tobacco excise is scheduled to rise by 12.5 per cent in September 2016. As a result, headline inflation, which has been lower than underlying inflation over the past two years, is expected to pick up to be around 1½–2½ per cent by early 2017.

Key Uncertainties

The forecasts are based on a range of assumptions about the evolution of some variables, such as the exchange rate and population growth, and judgements about how developments in one part of the economy will affect others. One way of demonstrating the uncertainty surrounding the central forecasts is to present confidence intervals based on historical forecast errors (Graph 6.3; Graph 6.4; Graph 6.5).

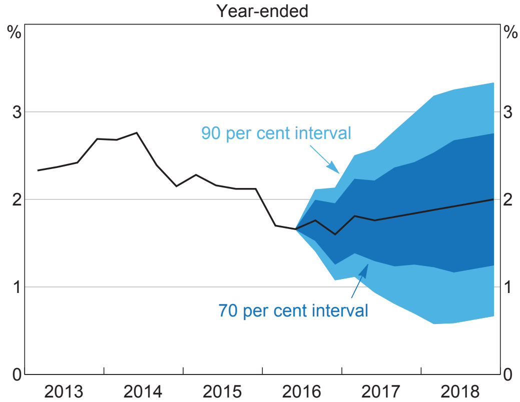
It is also worth considering the consequences that different assumptions and judgements might have on the forecasts and the possibility of events occurring that are not part of the central forecast. There continue to be a number of geopolitical and economic risks that could materialise in the global economy for which the consequences are difficult

Graph 6.3
GDP Growth Forecast*
Year-ended



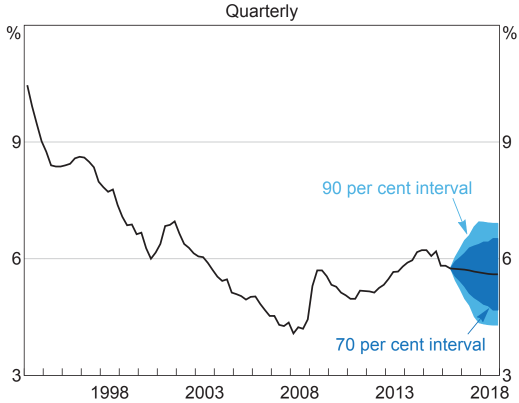
* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

Graph 6.4
Trimmed Mean Inflation Forecast*
Year-ended



* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

Graph 6.5
Unemployment Rate Forecast*
Quarterly



* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

to predict. For example, there may be a larger-than-expected increase in inflation in the United States, which could lead the Federal Reserve to tighten monetary policy by more than market participants expect. In that case, a range of financial prices are likely to respond, including the Australian dollar, which would be likely to depreciate. Relative to the constant exchange rate assumption that underlies the forecasts, this would imply a boost to domestic activity and a pick-up in tradable price inflation in Australia.

Another key source of uncertainty for the central forecasts continues to be the outlook for the Chinese economy, the reaction of Chinese policymakers to slowing growth and the risks created by high and rising levels of debt. In turn, uncertainty about the outlook for China has implications for commodity demand and ultimately for the forecasts for Australia's terms of trade. Domestically, there is considerable uncertainty about the degree of spare capacity in the labour market currently and over the forecast period, and the extent to which wage growth will pick up over the next few years. The underlying balance of demand and supply in the housing market are also difficult to project. Both of these raise uncertainty about the outlook for inflation and activity.

The Chinese economy

The outlook for commodity prices and resource exports continues to be sensitive to demand fluctuations in the Chinese construction and manufacturing sectors. Accordingly, China's growth outlook remains an important source of uncertainty for the Australian economy. A key uncertainty is the sustainability of the recovery in the Chinese property market, which has provided considerable support to upstream suppliers of construction-related manufacturing items and raw materials (see 'Box A: The Pick-up in the Chinese Housing Market'). Recent falls in residential floor space sold and the slowing in residential construction investment raise some doubts about the durability of the pick-up in demand earlier in the year. A substantial slowing in demand would pose risks for property developers and related industries, including the steel industry.

There is also uncertainty related to how policymakers will respond to the continued rise in corporate and local government debt amid deteriorating conditions in some industries and regions. Chinese financial conditions have been accommodative so far this year, but recent data indicate a modest slowing in broad credit growth. Moreover, the authorities have expressed concern regarding the build-up in leverage in the economy, which may foreshadow greater caution in the application of stimulus policies. The authorities face a difficult trade-off between supporting growth and avoiding financial disruption in the near term, while achieving more financial discipline and broader economic reforms over the longer term.

Momentum in the labour market

It is currently difficult to gauge the momentum in the labour market. A decline in employment growth over 2016 was expected and followed particularly strong growth in employment late last year. Leading indicators of employment, such as job advertisements, vacancies and hiring intentions, have been mixed of late. It is possible that the recent decline in employment growth was temporary, in which case, employment growth would recover more quickly than is currently forecast. However, to the extent that gains in employment continue to be mostly in part-time employment and among workers who would like more hours, there could be more spare capacity in the labour market than implied by the forecast for the unemployment rate. In addition, the past relationship between employment and GDP growth may be less useful as a guide in the coming years because an increasing share of GDP growth is expected to come from LNG production, which is less labour intensive than most other activities. While the forecasts take this into account, it is possible that a given rate of GDP growth will generate less employment growth than currently anticipated.

The participation rate is currently forecast to increase as the labour market recovers. However, there is some uncertainty around whether the recent fall in the participation rate primarily occurred for cyclical reasons, such as an increase in discouraged workers (who have given up searching for work due to perceived poor employment prospects), or owed more to structural factors, such as the ageing of the population. If the decline in the participation rate has been driven by structural factors, it may not increase over the forecast period, and rising demand for workers may lead to a more pronounced decline in the unemployment rate than is currently forecast.

Domestic cost pressures

As has been the case for some time, there is considerable uncertainty around the extent to which domestic inflationary pressures will pick up over the next few years. Wage growth has been lower than implied by historical relationships between wage growth and measures of spare capacity in the labour market. One explanation is that the low growth of labour costs, and low inflation more generally, has been a more important part of the economy's adjustment to large swings in the terms of trade than in the past. During the large run-up in commodity prices and mining investment, growth in Australian unit labour costs outpaced that in many comparable economies, resulting in a decline in the international competitiveness of Australian labour. However, since the terms of trade have been declining, low growth of unit labour costs has played the reverse role of improving international competitiveness, in conjunction with the depreciation of the exchange rate. It is also likely that relatively low wage growth has assisted the transition of workers from the mining sector as the mining boom moves to the relatively capital-intensive production phase. The forecast for a pick-up in wage growth is based on the observation that the rebalancing of the economy is already well advanced and so these downward pressures will gradually ease, but there is significant uncertainty around how long this process will take.

The forecast rise in wage growth and inflation implicitly assumes an increase in expectations of future inflation. Various measures of inflation expectations are lower than their long-run averages, but most are still consistent with the medium-term inflation target. It is possible that inflation expectations will be lower for longer than is currently anticipated. On the other hand, wage growth may pick up more quickly than anticipated in response to an improvement in labour market conditions, particularly if employees demand wage increases to compensate for the period of low wage growth over the past few years.

The uncertain outlook for wage growth also has implications for household income and therefore consumption growth. The forecasts assume that households will respond to current near-term weakness in income growth by reducing their rate of saving to maintain their consumption growth. This is likely to be a reasonable assumption if households expect income growth to be weak only temporarily, especially given relatively high rates of saving and gains to household wealth over recent years. It is also consistent with recent data on household savings and consumption decisions. However, if households were to lower their expectations for income growth over the longer term, household consumption growth may be lower than currently forecast.

Dwelling investment

Recent strength in dwelling investment, particularly the construction of high-density dwellings, has played an important role in supporting the rebalancing of economic activity away from the resources sector. Low interest rates and increases in housing prices have encouraged a substantial increase in the supply of apartments and the pipeline of work yet to be done has increased to very high levels. While this pipeline should support economic activity over the next couple of years, the outlook for dwelling investment beyond this is uncertain.

There is concern about the risk of oversupply in specific geographical areas, such as some parts of inner-city Melbourne and Brisbane. So far, outside Western Australia, the increased supply of housing has largely been absorbed by population growth. However, if growth in housing demand does not continue to keep pace with the further large increases in supply already in the pipeline, it could place downward pressure on prices and rents and increase the risk that off-the-plan purchases fail to settle.

If the housing market were to weaken substantially, consumption could be lower than currently expected due to lower growth in household wealth. Consumer price inflation could also be affected, as housing costs comprise a significant share of the CPI basket.

Statement on Monetary Policy

NOVEMBER 2016

Contents

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Statement on Monetary Policy enquiries

Secretary's Department
Tel: +61 2 9551 9830
Fax: +61 2 9551 8033
Email: rbainfo@rba.gov.au

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Overview

Growth in Australia's major trading partners remains a bit below average and is expected to decline a little over the forecast period, reflecting a further moderate easing in growth in China. While longer-term risks associated with high and rising debt in China remain, the downside risks to Chinese growth in the near term appear to have diminished, in large part due to strong growth of government-funded infrastructure projects and buoyant conditions in the property market. These developments have led to an increase in the demand for bulk commodities at the same time as the Chinese authorities have restricted domestic production of commodities to reduce overcapacity. This has contributed to a pick-up in bulk commodity prices and has been associated with a broad-based increase in producer prices in China.

The rise in commodity prices this year has resulted in an increase in Australia's terms of trade. This represents a marked change from the pattern of recent years, whereby the terms of trade had fallen significantly and by more than expected. Although the recent increase in the terms of trade has been associated with an appreciation of the Australian dollar, it is expected to provide some support to income growth, in contrast to the period since the peak in the terms of trade in 2011. The forecasts assume that the terms of trade will remain above the low point reached earlier this year. In part, this reflects the expectation that Chinese demand for steel will remain resilient in the near term and that Chinese production of bulk commodities will not increase substantially. However, the Chinese authorities may relax efforts to reduce overcapacity in their mining industry, in response to recent sharp increases in bulk commodity prices, and there is uncertainty about the extent to which the recovery in the Chinese property market will be sustained. Either of these factors, among other things, could affect the outlook for Australia's terms of trade.

In the major advanced economies, growth in economic activity continues to be supported by accommodative monetary policy and further improvements in labour market conditions. Output is forecast to grow at above-trend rates and a further reduction in spare capacity is expected over the forecast period. That, combined with the rise in the prices of oil and other commodities, is expected to put upward pressure on global inflation over the forecast period. While there is still a risk that low inflation expectations could become entrenched, the risks to global inflation appear to be more balanced than they have been for some time. In the United States, inflation has increased a bit since last year and is only a little below the Federal Reserve's target. Financial market pricing implies that an increase in the federal funds rate by the end of 2016 is more likely than it was at the time of the August *Statement on Monetary Policy*. While inflation remains below the European Central Bank's target, long-run inflation expectations appear to be relatively well anchored at close to 2 per cent. In contrast, inflation and inflation expectations in Japan have declined over the past year.

Any changes to the current stance of monetary policy or in the expected path of policy rates in the major advanced economies are likely to affect a range of financial market prices, including exchange rates. The depreciation of the Australian dollar since 2013 has contributed to the ongoing adjustment of the economy to the end of the resources boom; an appreciating currency could complicate that process.

As expected, the pace of growth in the Australian economy appears to have moderated around the middle of the year following strong growth in the March quarter. There has been little change to the aggregate growth forecasts. GDP growth is expected to be around potential in 2016/17 and gradually pick up thereafter to be between 3 and 4 per cent by the end of the forecast period. Resource exports are likely to make a further significant contribution to GDP growth, as exports of liquefied natural gas (LNG) continue to ramp up. Mining investment is still expected to subtract from growth for a time, albeit by less than was the case over the past year. Non-mining activity is projected to continue to grow at around its average pace over the forecast period. Low interest rates and the depreciation of the exchange rate over the past couple of years will help support household consumption, dwelling investment and exports. Ongoing growth in these areas of the economy is expected to underpin a further increase in non-mining business investment in the period ahead.

Consumption growth was below average in the June quarter, but has been above the growth in household disposable income in year-ended terms for some time – supported by low interest rates and rising household wealth, and consistent with measures of consumer sentiment remaining above average. Consumption growth has been accommodated by a gradual decline in the household saving ratio, which is expected to continue over the forecast period. Households' expectations about the likely growth in their incomes will have an important bearing on their consumption, saving and borrowing decisions. These factors, as well as future developments in the housing market, are all risks to future consumption growth.

As expected, private dwelling investment was strong over the year to the June quarter. The value of residential building approvals has reached record levels as a share of GDP and the amount of work in the pipeline has edged higher. Accordingly, dwelling investment is likely to contribute to growth for some time yet. However, the large amount of work in the pipeline raises concerns that some locations could become oversupplied, particularly in inner-city areas where a lot of high-density housing is planned. This could lead to settlement failures by off-the-plan purchasers and a general reduction in rents and prices.

Conditions in the established housing market have eased relative to a year ago, although some indicators suggest that conditions may have strengthened over recent months. In particular, housing price growth has picked up noticeably in Sydney and Melbourne, where auction clearance rates have also increased to high levels. However, the number of auctions and housing market turnover more generally are lower than they were last year and properties are, on average, taking longer to sell. While housing credit growth has also declined over the past year, loan approvals data suggest that lending to investors has increased a little over recent months. Housing market conditions remain weak in Perth, where prices of both apartments and detached dwellings have declined further over the past year.

The unemployment rate has declined over the course of this year, but so too has employment growth. Moreover, the growth in employment has been accounted for by part-time employment. Forward-looking indicators are consistent with moderate employment growth in the months ahead. The unemployment rate is expected to edge just a little lower over the next couple of years. This forecast is largely unchanged from that presented in the August *Statement* and implies that a degree of spare capacity remains in the labour market. However, there is uncertainty about how much spare capacity there is and the extent to which it will ultimately feed into inflation. One aspect of this uncertainty is that the underemployment rate remains elevated and implies more spare capacity than indicated by the unemployment rate alone. At the same time, however, there is evidence that wage growth has stabilised, in part because it appears that the drag on aggregate wage growth from the movement of workers from mining-related activities to lower-paying jobs in the non-mining sector has diminished. The growth in labour costs is expected to rise over the forecast period as labour market conditions improve and the effects of the large decline in the terms of trade and mining investment on demand wane. Even so, growth in labour costs is likely to remain low.

The September quarter inflation data were in line with expectations. Underlying inflation has been around 1½ per cent in year-ended terms over recent quarters, while headline inflation was around 1¼ per cent. Petrol prices have subtracted from year-ended headline inflation over recent years.

Domestic cost pressures remain subdued as the economy continues to rebalance following the end of the resources boom. Low growth of labour costs is clearly evident in very low inflation in prices of market services. Also, rent inflation remains very low, while growth in the cost of constructing a house has declined, which is somewhat at odds with the strength in dwelling investment across much of the country. The prices of tradable items (excluding volatile items and tobacco) fell slightly in the September quarter and were unchanged over the year. Inflation in those parts of the retail sector subject to heightened competitive pressures over recent years also remains low, but stabilised in the September quarter.

There has been no material change to the forecast for underlying inflation, which is expected to remain around current rates in the near term, before gradually picking up to around 2 per cent by the end of the forecast period. The disinflationary effects from heightened retail competition are expected to dissipate over time and gradually rising labour cost growth is forecast to add to inflation over the forecast period. Higher prices for oil over recent months and increases in the tobacco excise tax are also expected to add to headline inflation. On the other hand, low rent inflation is expected to persist, while the boost to the prices of tradable items from the earlier depreciation of the exchange rate appears to have largely run its course.

The Reserve Bank Board reduced the cash rate by 25 basis points in May, following weaker-than-expected inflationary pressures, and by the same amount again in August, when the data confirmed that inflationary pressures remained low. Those reductions in the cash rate will provide some additional support to demand and enhance the prospects of inflation returning to target over time. In August, the Board also noted that, compared with 2015, conditions in the housing market had eased and housing credit growth was lower, partly as a result of earlier actions to tighten lending standards.

The flow of data over the past few months has been consistent with the earlier forecasts. Inflation is expected to remain low for some time, before gradually returning to more normal levels. While there is uncertainty about the outlook for employment growth, it is likely that there will still be some spare capacity in the labour market over the forecast period. At the same time, housing prices are rising at a brisk rate in some locations, although overall housing credit growth and housing turnover remain lower than they were last year.

Taking all these considerations into account, at its recent meetings the Board judged that there were reasonable prospects for achieving sustainable growth in the economy with inflation returning to the medium-term target over time and, hence, it was appropriate to leave the cash rate at 1.50 per cent.

1. International Economic Developments

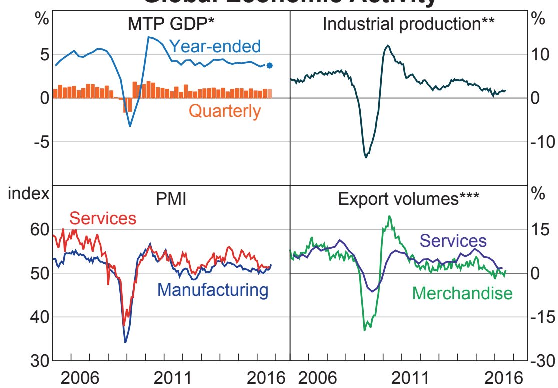
Global economic growth is lower than average but appears to have stabilised over recent months (Graph 1.1). Economic conditions in China have steadied over the past six months. Growth in a number of the higher-income economies of east Asia remains below average, having been adversely affected by the slowdown in global trade in recent years and, in particular, slowing demand from China. Growth in New Zealand and India has been relatively strong over the past year.

Growth in the major advanced economies has eased over the past year but is expected to pick up over the second half of 2016. The economic recovery in these economies is expected to continue, supported by accommodative monetary policy. Growth is likely to exceed potential in the coming quarters, leading to a further reduction in excess capacity. However, potential growth appears to have declined over the course of the past decade or so as a result of lower growth in investment and productivity and the effect of population ageing.

Growth in global industrial production, manufacturing activity and trade remains subdued. Growth in these indicators has been below average for much of the period since the global financial crisis, reflecting heightened uncertainty and weak investment. It is possible that industrial activity and trade will continue to lag behind aggregate global growth, given the relative resilience of consumption and service-industry growth globally.

Inflation has remained below most central bank targets since 2010, despite substantial reductions in unemployment rates in a number of economies (Graph 1.2). Low wage growth, particularly in the

Graph 1.1
Global Economic Activity



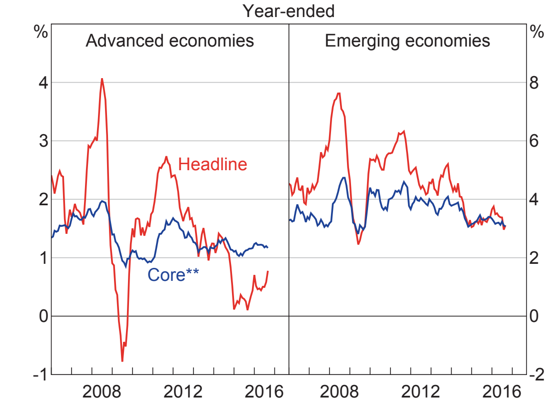
* Major trading partners' (MTP) GDP, weighted using Australia's export shares; RBA estimate for September quarter 2016

** Industrial production is weighted by world industrial production shares at market exchange rates; year-ended growth

*** Services exports are for select MTPs and Australia; year-ended growth

Sources: ABS; Bloomberg; CEIC Data; CPB; IMF; Markit Economics; OECD; RBA; Thomson Reuters

Graph 1.2
Global Inflation*
Year-ended



* PPP-weighted; sum of emerging and advanced economies accounts for around 80 per cent of world GDP

** Excludes food and fuel

Sources: CEIC Data; IMF; RBA; Thomson Reuters major advanced economies, suggests that there remains some spare capacity in labour markets. However, in the United States and Japan, unit labour cost growth is noticeably higher than it has been for some time and this has put pressure on business margins. Further gradual reductions in spare capacity are expected to place upward pressure on inflation in advanced economies, while the recent increases in oil prices, and commodity prices more generally, are also likely to contribute to global inflation. The recent turnaround in oil prices has already been evident in headline inflation measures picking up in advanced economies over the past year. In contrast, headline measures in emerging economies have fallen in response to easing food price inflation.

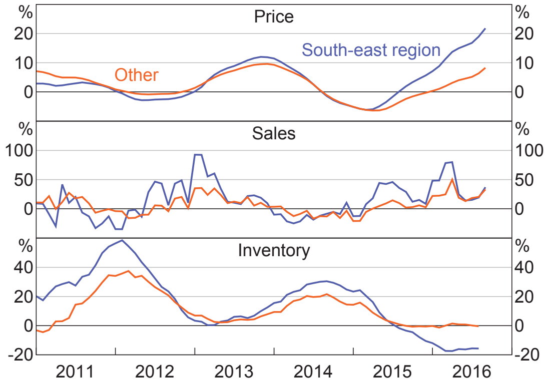
China and East Asia

Chinese economic growth has steadied over the course of the past six months or so. Growth has been supported by a pick-up in the property sector and continued strong infrastructure investment, underpinned by ongoing financial accommodation and fiscal expansion. While these developments have had positive flow-on effects to upstream industries, excess capacity problems in the industrial sector have persisted and private sector investment has slowed noticeably over the past year or more.

Residential property prices have increased sharply over the course of this year, partly reflecting speculative buying in larger cities (Graph 1.3). Buoyant conditions have supported overall growth of housing investment. Sales have grown strongly over the year to date and inventories of unsold housing have fallen. The fall in inventories has been concentrated in larger cities on the eastern seaboard, while a large overhang of housing inventory has persisted in smaller cities.

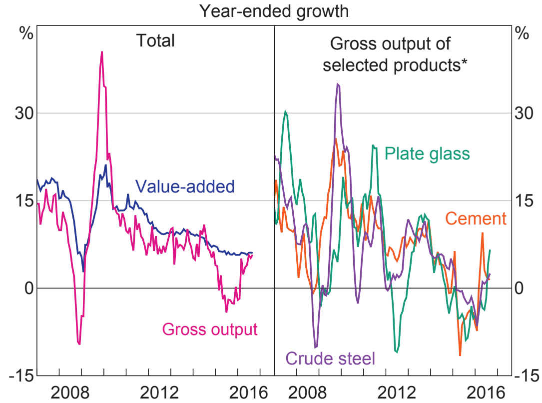
The pick-up in growth of residential and non-residential property construction has been associated with a recovery of manufacturing production in related industries, such as cement, plate glass and steel (Graph 1.4). In recent months,

Graph 1.3
China – Residential Property Market Indicators
Year-ended growth



Sources: CEIC Data; CRIC; RBA

Graph 1.4
China – Industrial Production
Year-ended growth

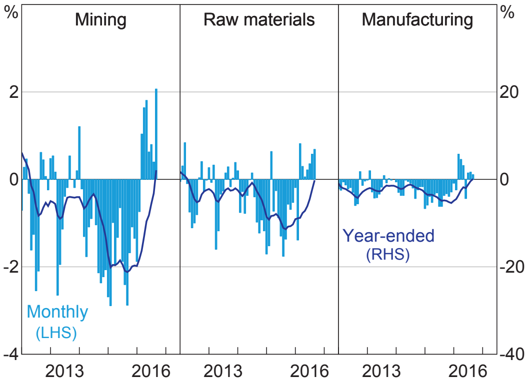


* Three-month moving average
Sources: CEIC Data; RBA

the authorities have increased public spending on infrastructure, including transport-related projects. This has also helped to support the demand for steel.

The rise in the demand for steel, combined with some reductions in the domestic supply of coal and iron ore in China, has contributed to higher bulk commodity prices globally (see 'Box A: Production of Iron Ore and Coal in China'). In part driven by stronger commodity prices, Chinese producer prices have been rising recently, a marked turnaround from the earlier deflationary trend (Graph 1.5). These upstream price pressures are yet to translate into higher consumer price inflation, which remains subdued in China and across east Asia.

Graph 1.5
China – Growth of Producer Prices

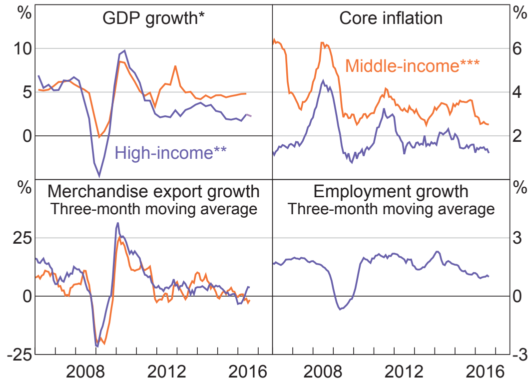


Sources: CEIC Data; RBA

It is uncertain how long the current strength in the Chinese property sector and associated demand for upstream manufactured items will be sustained. Local government authorities have responded to rising property prices by introducing a range of measures, including increases in minimum downpayments in numerous cities and direct restrictions on house purchases in some locations. To date these initiatives have not been enough to stop prices from rising further; instead, price rises have become more widely dispersed across the country. But it is likely that continued efforts to restrict price growth will eventually result in slower residential investment and dampen demand for related industrial products and commodities.

Developments in China will continue to influence outcomes in other Asian economies, which as a group account for a significant share of Australia's trade. Weakness in global trade, including weaker trade with China, has contributed to lower growth in the high-income economies in east Asia, which are all quite reliant on trade (Graph 1.6). Business investment growth in these economies has declined over the past two years and, more recently, consumption and employment growth has also slowed. Fiscal stimulus has supported domestic demand since 2015 but the prospect of further fiscal support is diminishing as the authorities adjust to self-imposed fiscal discipline rules. The middle-income east Asian economies are also

Graph 1.6
East Asia – Economic Indicators
Year-ended



* Estimate for September quarter 2016
** Hong Kong, Singapore, South Korea and Taiwan
*** Indonesia, Malaysia, Philippines and Thailand
Sources: CEIC Data; IMF; RBA; Thomson Reuters

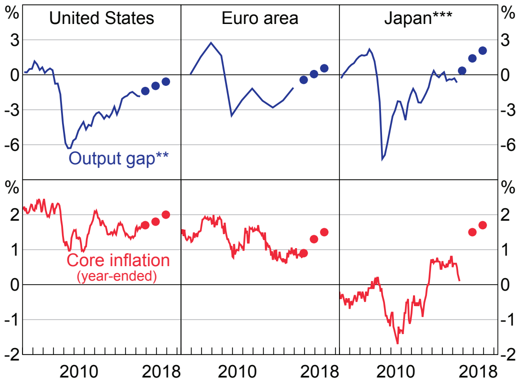
facing subdued external demand but, because they are less reliant on trade, the impact on their growth has been more limited. A number of central banks in the east Asian region have eased monetary policy in the past year.

Major Advanced Economies

The economic recovery in the major advanced economies has continued. Over the past year, growth in demand has been driven by consumption, while business investment has remained weak. GDP growth is now around, or a little above, estimates of potential. Growth is expected to be supported over the period ahead by accommodative monetary policies and further improvements in labour market conditions. At the same time, the effect of population ageing has weighed on potential growth, especially in Japan. The weak investment and productivity growth of recent years, if maintained, will also exert a drag on potential growth.

Growth in output is expected to lead to further reductions in spare capacity over the next two to three years, leading to an increase in inflation. Policymakers in the United States expect to reach the Federal Reserve's inflation goal by 2018 (Graph 1.7). Inflation in the euro area and Japan is

Graph 1.7
Major Advanced Economies – Output Gaps and Inflation
Central bank forecasts*



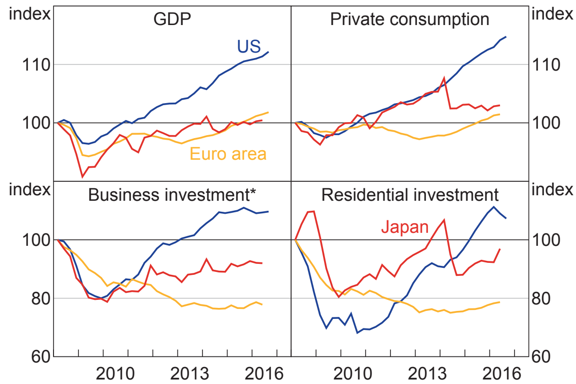
* ECB and FOMC forecasts as at September 2016; BoJ forecasts as at November 2016

** Output gap projections based on central banks' forecasts for GDP growth and potential GDP growth estimates from the BoJ, Congressional Budget Office and European Commission

*** BoJ forecasts are for fiscal years; inflation forecasts are for CPI excluding fresh food in 2017 and 2018; inflation data exclude the effects of the consumption tax increase in April 2014

Sources: Bank of Japan; ECB; FOMC; RBA; Thomson Reuters

Graph 1.8
Major Advanced Economies – GDP and Components
March 2008 = 100



* Non-residential public and private investment shown for euro area

Sources: RBA; Thomson Reuters

likely to remain below the respective central banks' targets until at least 2018.

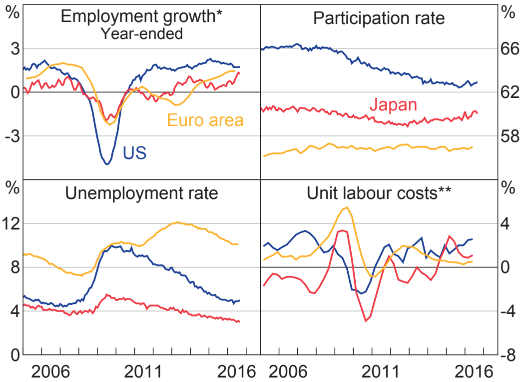
Growth in the United States picked up in the September quarter and continued at the modest pace of recent quarters in the euro area, while GDP in Japan has been little changed over the past year or so (Graph 1.8). Private consumption has been a key driver of growth in the United States and the euro area over the past two years. In contrast, consumption in Japan has remained subdued following the consumption tax increase in early 2014. Conditions in the major advanced economies remain supportive of household consumption, with low borrowing costs, a recovery in housing prices, relatively strong employment growth and above-average consumer confidence.

However, investment growth in advanced economies has been weak in recent years. The United States has experienced a broad-based slowing in business investment for over a year. The weakness has been most acute in the oil & gas and manufacturing sectors. Residential investment eased recently, but residential construction activity is at a high level. In the euro area and Japan, residential and business investment remain well below pre-crisis levels, although, in the euro area, machinery and equipment investment has grown at an above-average pace since early 2015. The large appreciation of the yen since late 2015 has weighed on Japanese corporate profits and business investment.

Labour markets have improved considerably in recent years across the major advanced economies (Graph 1.9). Employment growth has been robust, encouraging an increase in workforce participation that has offset, at least temporarily, some of the effects of population ageing on labour supply. Unemployment rates in the United States and Japan have declined to be at or below their long-run average levels. The unemployment rate in the euro area has also declined and is now only a little above levels seen in the mid 2000s.

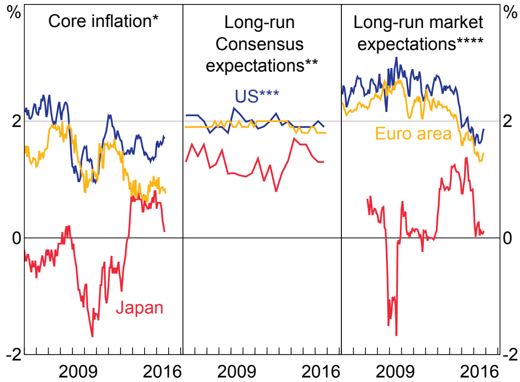
Tightening labour markets have been accompanied by stronger growth in some measures of labour compensation in the United States and Japan over the past 2½ years. Of particular note, given its relevance to inflation pressures, unit labour costs in the US and Japanese economies have been growing at above-average rates, putting pressure on business margins.

Graph 1.9
Major Advanced Economies – Labour Market



* Three-month moving average for Japan
** Three-month moving average year-ended growth
Sources: Eurostat; RBA; Thomson Reuters

Graph 1.10
Major Advanced Economies – Inflation
Year-ended



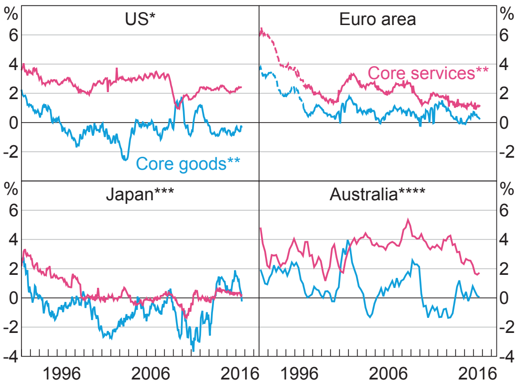
* PCE inflation for the US; CPI for the euro area and Japan; Japan data exclude the effects of the consumption tax increase in April 2014
** Euro area series is from the Survey of Professional Forecasters
*** US expectations adjusted for the average difference between CPI and PCE
**** Inflation expectations from 5 and 10-year inflation swaps; latest month is an average in the month-to-date
Sources: Bloomberg; Consensus Economics; ECB; RBA; Thomson Reuters

Headline inflation in the major advanced economies remains below central banks' targets. In the United States and the euro area, core inflation is above its recent trough and, in the United States, core inflation is not far below the Federal Reserve's inflation objective (Graph 1.10). Short-term measures of inflation expectations have declined in recent years to historically low levels, coinciding with the fall in oil prices and lower headline inflation. Economists' longer-term expectations have declined only marginally and remain close to these central banks' inflation targets, suggesting that expectations remain relatively well anchored. Longer-term market-based measures of inflation expectations have moderated since early 2016, but are likely to have been influenced by other financial market developments, such as declining risk premia, and there are signs that these measures may have picked up recently.

In contrast, in Japan, core inflation has fallen in recent months. Longer-term market and consumer inflation expectations have fallen sharply since late 2015, returning to where they were before the Bank of Japan (BoJ) adopted its inflation target and started its quantitative easing program in early 2013. The BoJ recently committed itself to 'overshooting' its 2 per cent inflation target, with the intention of raising inflation expectations; however, measures of inflation expectations have been little changed since this announcement.

In the advanced economies, lower inflation in the prices of services has been an important driver of subdued core inflation in the post-crisis period (Graph 1.11). As services are more likely to be non-tradable, this is likely to reflect the weak domestic price pressures arising from spare capacity – in labour and product markets – that followed the global financial crisis. In Australia's case, the increase in spare capacity in the labour market followed the end of the resources boom. On the other hand, goods inflation across advanced economies, which on the whole contains more tradable items, has remained low but has not generally contributed to inflation being lower in the post-crisis period. In Australia, the depreciation in the exchange rate since 2013 has supported inflation of tradable items, although heightened competition recently in the retail sector means that inflation of these items has been lower than otherwise.

Graph 1.11
Advanced Economies – Core Inflation
Year-ended



* Personal Consumption Expenditures (PCE) inflation

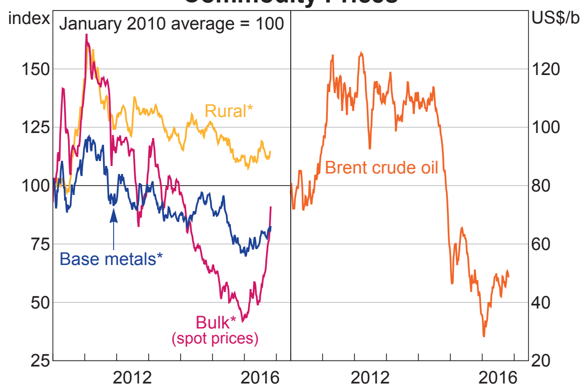
** Core measures exclude volatile items: food, energy and for some economies alcohol and tobacco; euro area dashed lines are estimates

*** Excludes the effects of the 1997 and 2014 consumption tax increases

**** For Australia, non-tradables and tradables inflation (excluding volatile items) are shown instead of core services and core goods, respectively; adjusted for the tax changes of 1999–2000 and excludes interest charges and deposit & loan facilities, where relevant

Sources: ABS; ECB; RBA; Statistics Japan; Thomson Reuters

Graph 1.12
Commodity Prices



* RBA Index of Commodity Prices (ICP) sub-indices

Sources: Bloomberg; RBA

Commodity Prices

Commodity prices have been driven higher, since early 2016, by the sharp rise in bulk commodity prices (Graph 1.12; Table 1.1). This rise in commodity prices has been reflected in the first increase in Australia's terms of trade in 2½ years. As discussed in the 'Outlook' chapter, the outlook for the terms of trade is now more positive than previously thought, and it is expected that the trough is now past.

The spot price of iron ore remains well above its recent low of December 2015, reflecting both higher Chinese demand and lower iron ore production in China. However, the global supply of low cost iron ore is expected to increase further, as capacity expansions come on line in Australia and Brazil. This is likely to exert some downward pressure on prices in the period ahead.

The spot prices of both hard-coking and thermal coal have increased sharply since the previous *Statement*, to levels not reached in several years (Graph 1.13). Coal prices have been supported by cuts to Chinese production and temporary

Table 1.1: Commodity Price Growth[(a)]
SDR, three-month-average prices, per cent

	Since previous *Statement*	Over the past year
Bulk commodities	37	42
– Iron ore	7	9
– Coking coal	95	120
– Thermal coal	40	41
Rural	–1	1
Base metals	5	5
Gold	2	16
Brent crude oil[(b)]	2	0
RBA ICP	9	7
– using spot prices for bulk commodities	20	21

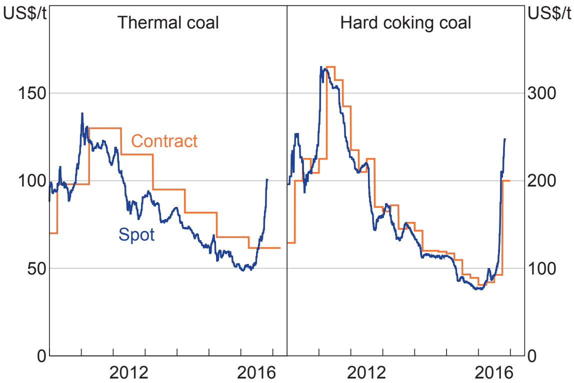
(a) Prices from the RBA Index of Commodity Prices (ICP); bulk commodity prices are spot prices

(b) In US dollars

Sources: Bloomberg; IHS; RBA

Graph 1.13
Coal Prices

Free on board basis



Sources: Department of Industry, Innovation and Science; IHS; RBA

disruptions to global supply. However, most of Australia's coal exports are still sold under contract, at prices that are currently lower than those in the spot markets. Contracts for the December quarter have settled at US$200 per tonne, representing an increase of 116 per cent from the September quarter benchmark price of US$92.5 per tonne. So while the profitability of Australian coal miners has improved, the immediate gains are a bit less than implied by the very sharp rise in spot prices. The Bank's liaison suggests that prices would need to remain elevated for some time to induce any noticeable increase in Australian production. Recent price increases are expected to partly unwind as temporary disruptions to supply ease.

Oil prices have risen since early 2016, although they have been relatively stable over the past few months (Graph 1.12). In late September, OPEC members agreed in principle to cap production at between 32.5 and 33 million barrels per day, which is below current production levels. Government officials in Russia have indicated that they might join OPEC in capping oil production. The oil price increases since the beginning of the year have started to be reflected in higher regional liquefied natural gas (LNG) prices.

Box A

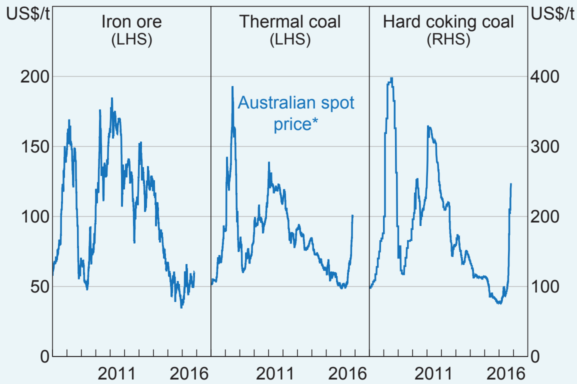
Production of Iron Ore and Coal in China

The global prices of bulk commodities (iron ore and coal) have risen noticeably since early 2016 following significant declines over the previous few years. In China, a recovery in the demand for these commodities over the course of this year, including for use in the production of steel, has been accompanied by a decline in their domestic production. In addition, there have been some temporary disruptions affecting the distribution of coal both within China and elsewhere that have contributed to sharp increases in prices, particularly for coking coal.

Bulk commodities account for around one-quarter of the value of Australia's total exports. Since late 2015, iron ore prices have increased by 77 per cent (Graph A1). The rise in coal prices from around that time has been even more pronounced. Thermal coal prices have risen by 111 per cent since the low point in early 2016 and coking coal prices by more than 200 per cent over a similar period.

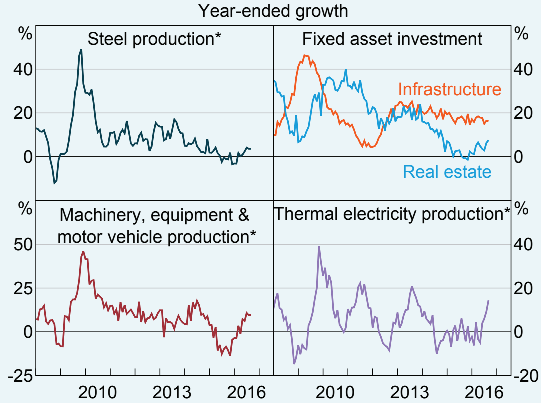
In China, demand for both steel (which uses iron ore and coking coal) and electricity generated by thermal coal has picked up recently (Graph A2). For steel, this improvement reflects a rebound in Chinese property investment in the first half of 2016 combined with strong growth in infrastructure investment, which have underpinned demand for construction- and transport-related steel products. There has also been a pick-up in the production of machinery & equipment and motor vehicles, which all use steel intensively. The noticeable pick-up in coal-fired power generation in recent months is consistent with a rise in demand for electricity from the range of manufacturing industries experiencing stronger conditions of late.

Graph A1
Bulk Commodity Prices
Free on board



* Iron ore fines; Newcastle thermal coal; prime hard coking coal
Sources: Bloomberg; IHS; RBA

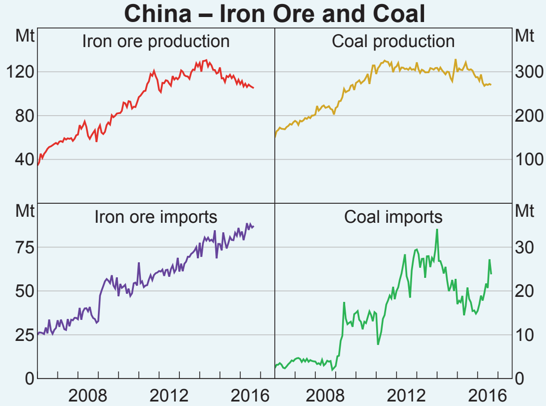
Graph A2
China – Demand for Iron Ore and Coal
Year-ended growth



* Gross output indicators
Sources: CEIC Data; RBA

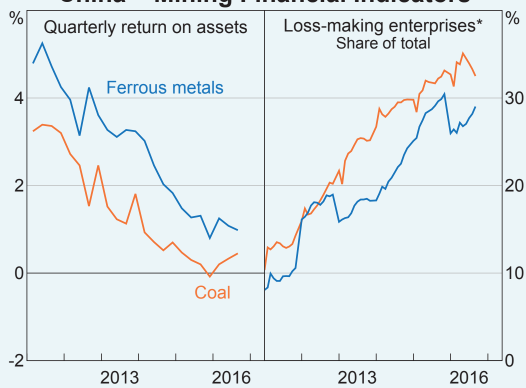
At the same time, there has been a further noticeable decline in Chinese production of iron ore and coal (Graph A3). The decline in part reflects a response to earlier large falls in their prices and the high cost of much of China's production

Graph A3
China – Iron Ore and Coal



Sources: CEIC Data; RBA

Graph A4
China – Mining Financial Indicators



* December observations removed

Sources: CEIC Data; RBA

(compared with production in other parts of the world, including Australia). The net result of lower domestic supply of bulk commodities and stronger demand has been an increase in imports.

Despite these reductions in domestic supply, some mines in China have operated longer than would have been expected given their falling profitability (Graph A4). The proportion of firms producing iron ore and coal that are loss-making has risen noticeably.

Government policy changes have also affected the domestic output of bulk commodities in 2016, particularly with respect to coal production. The Chinese Government has long sought to close down inefficient, unsafe and polluting mining facilities. In February, the State Council (China's premier legislative body) issued plans to reduce coal production capacity by around 1 billion tonnes over the next 3–5 years.[1] Government officials have indicated that most of the capacity reductions targeted for 2016 have already been completed. The State Council also issued a direction that the number of working days for coal mines be reduced from 330 days to 276 days per year. However, following the sharp rise in coal prices, the National Development and Reform Commission signalled that the 276 working day policy would be amended for selected coal producers to allow them to increase their days of operation temporarily as a means of relieving supply shortages.

Although Chinese domestic demand and supply trends have had a significant effect on bulk commodity prices, reductions in supply from coal-exporting countries have also played a role. In August and September, the Australian coal industry experienced a number of temporary disruptions related to a train derailment in Queensland, roof collapses at some mines and industrial action at a Queensland mine. However, the overall effect on global supply is likely to have been minor. Weather-related disruptions and production cuts in Indonesia (the world's largest supplier of seaborne thermal coal) have also delayed deliveries in recent months, and coking coal exports from the United States have continued their trend decline. A consequence of disrupted supply and resilient demand is that inventories of both thermal and coking coal at ports (and inventories of coking coal at steel mills) fell to relatively low levels in August. Major buyers of thermal coal have started to rebuild stocks, but coking coal inventories remain low.

1 Consistent with this, the National Development and Reform Commission is targeting capacity reductions of 250 million tonnes of coal by the end of 2016 alone.

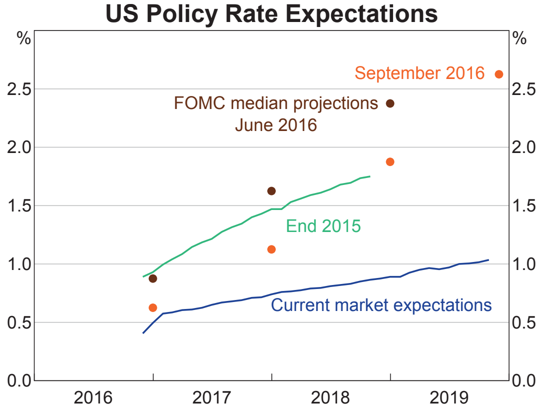
2. International and Foreign Exchange Markets

Global financial markets continue to be influenced by evolving expectations for monetary policy in the major economies. In recent months, sovereign yields have risen following a scaling back of expectations for further monetary stimulus in most of the larger developed economies; market-based measures of expected inflation have also increased, which may reflect a more balanced outlook for the risks around global inflation. Yields in the United Kingdom have increased particularly sharply, and the UK pound has depreciated, as concerns have risen that the United Kingdom may lose access to the European Single Market as a consequence of its exit from the European Union. Movements in other major currencies have been modest. Major market equity prices have generally traded in narrow ranges following a relatively quick recovery from the declines recorded in the wake of the UK referendum. Emerging market share prices have seen strong increases over recent months.

Central Bank Policy

The US Federal Open Market Committee's (FOMC's) target range for the federal funds rate remains at 0.25–0.50 per cent. However, the FOMC has indicated that the case for a rate increase has continued to strengthen in recent months and minutes from the September meeting noted that the decision not to increase the target range at that meeting was a close call. Recent FOMC discussions have centred on the degree of unutilised capacity in the labour market and the risk that delaying tightening might lead to a need for a faster rate of increases in the future. FOMC members now anticipate a 25 basis point increase in the policy range in December 2016, broadly in line with market pricing, which currently implies around a four-in-five chance of such an increase. Forecasts for increases in the policy rate in 2017 have been scaled back by FOMC members. However, members still expect 50 basis points of increases during 2017, in contrast to market expectations for at most 25 basis points of tightening (Graph 2.1).

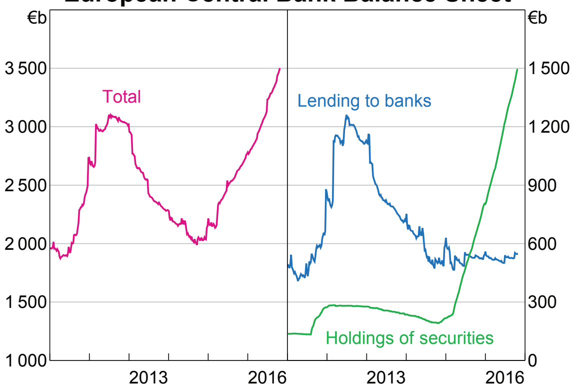
Graph 2.1
US Policy Rate Expectations



Sources: Bloomberg; Board of Governors of the Federal Reserve System

The European Central Bank (ECB) has left policy unchanged since it announced additional stimulus measures at its March meeting, though in September it tasked committees with evaluating options to ensure the continued smooth implementation of its asset purchase program. The evaluation could result in the modification of some of the existing constraints to asset purchases (such as minimum yield requirements, holding limits and the requirement for purchases to be proportional to members' contributions to the ECB's capital), which seem likely to become increasingly binding in the months ahead. The ECB's current asset purchase program is scheduled to run until at least March 2017; market observers expect an extension, either at the current pace of €80 billion per month or with a gradual tapering of purchases. At the same time, the take-up of ECB term funding by euro area banks continues to be modest; allotments at the second targeted long-term refinancing operation in September were €34 billion (net of repayments), similar to the €31 billion of net borrowing at the June quarter allotment, compared with a total capacity of €1.6 trillion (Graph 2.2).

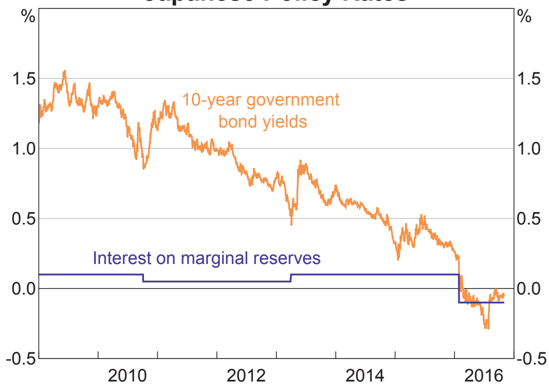
Graph 2.2
European Central Bank Balance Sheet



Sources: European Central Bank; Thomson Reuters

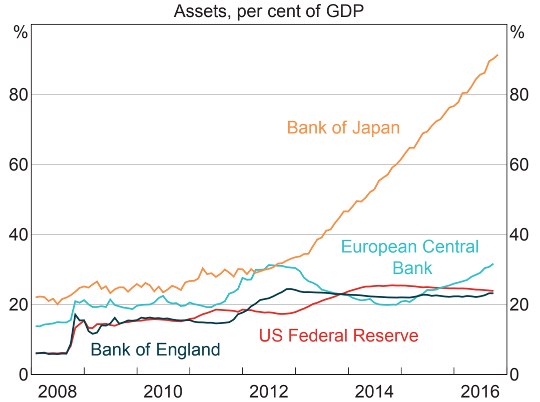
The Bank of Japan (BoJ) announced the results of its comprehensive review of monetary policy and changes to its monetary policy framework at its September meeting. The BoJ committed itself to exceeding the 2 per cent inflation target for some period of time to increase inflation expectations. To achieve this, the BoJ announced that the targeted expansion of the monetary base has been replaced with a new framework: Quantitative and Qualitative Monetary Easing with Yield Curve Control. To exert control over the yield curve, the BoJ will use the interest rate on marginal reserves held at the central bank (which it left unchanged at –0.1 per cent) to control short-term interest rates and the purchase of Japanese government bonds (JGBs) to control long-term interest rates. In particular, it will target a 10-year JGB yield of around zero per cent, which is consistent with its current level (Graph 2.3). The BoJ has announced that it expects purchases of JGBs to continue at around the current rate of ¥80 trillion per year (Graph 2.4).

Graph 2.3
Japanese Policy Rates



Sources: Bank of Japan; Bloomberg

Graph 2.4
Central Bank Balance Sheets
Assets, per cent of GDP



Sources: Central banks; Thomson Reuters

The Bank of England (BoE) lowered its policy rate by 25 basis points to 0.25 per cent at its August meeting, noting downside risks to economic activity owing to uncertainty generated by the result of the UK referendum, and suggested that this is close to the effective lower bound, which it believes is slightly above zero. It also announced several additional monetary stimulus programs. It will purchase £60 billion of UK government bonds over the 6 months beginning August 2016 and £10 billion of sterling-denominated corporate bonds over the 18 months beginning September 2016. Eligible corporate bonds are those issued by companies the BoE considers to be making a 'material contribution' to the UK economy and include a number of foreign companies with a UK presence. The BoE also announced a Term Funding Scheme, which provides funding to banks at the BoE's policy rate to help reinforce the transmission of monetary policy to the real economy; banks have borrowed £1.3 billion under this scheme so far. The BoE anticipates that the total take-up of the scheme will be around £100 billion.

In China, the volatility and level of interbank interest rates increased a little in recent months in part because of unexpected changes to the maturity of the People's Bank of China's (PBC's) open market operations. The PBC has left system-wide reserve requirement ratios unchanged since a 50 basis point reduction in February and has held benchmark interest rates steady so far this year.

A number of other central banks have also eased policy in recent months, largely in response to ongoing low inflation (Table 2.1). The Reserve Bank of New Zealand reduced its policy rate by 25 basis points to 2.0 per cent, noting a persistently high exchange rate. The Central Bank of Russia, the Reserve Bank of India and the Central Bank of Brazil all lowered policy rates in response to declines in inflation. Bank Indonesia also lowered its target rate by 25 basis points, noting weaker-than-expected growth and low inflation. In contrast, the Bank of Mexico raised its policy rate by 50 basis points, its fourth increase this year, to counter inflationary pressures stemming from a depreciation of the exchange rate.

Table 2.1: Monetary Policy

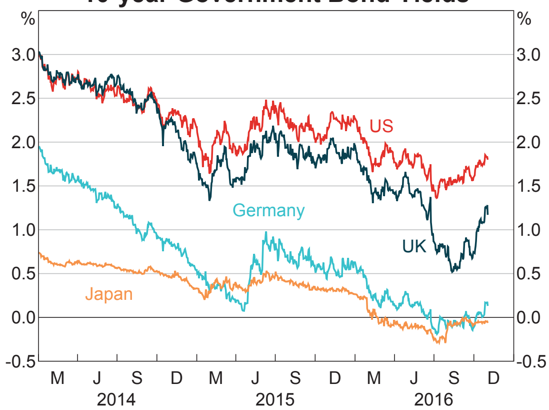
	Policy rate Per cent		Most recent change
Euro area[(a)]	–0.40	↓	Mar 16
Japan[(a)]	–0.10	↓	Jan 16
United States[(b)]	0.375	↑	Dec 15
Australia	1.50	↓	Aug 16
Brazil	14.00	↓	Oct 16
Canada	0.50	↓	Jul 15
Chile	3.50	↑	Dec 15
India	6.25	↓	Oct 16
Indonesia	4.75	↓	Oct 16
Israel	0.10	↓	Feb 15
Malaysia	3.00	↓	Jul 16
Mexico	4.75	↑	Sep 16
New Zealand	2.00	↓	Aug 16
Norway	0.50	↓	Mar 16
Russia	10.00	↓	Sep 16
South Africa	7.00	↑	Mar 16
South Korea	1.25	↓	Jun 16
Sweden	–0.50	↓	Feb 16
Switzerland[(b)]	–0.75	↓	Jan 15
Thailand	1.50	↓	Apr 15
Turkey	7.50	↓	Feb 15
United Kingdom	0.25	↓	Aug 16

(a) Marginal rate paid on deposits at the central bank
(b) Midpoint of target range
Sources: Central Banks; RBA; Thomson Reuters

Sovereign Debt Markets

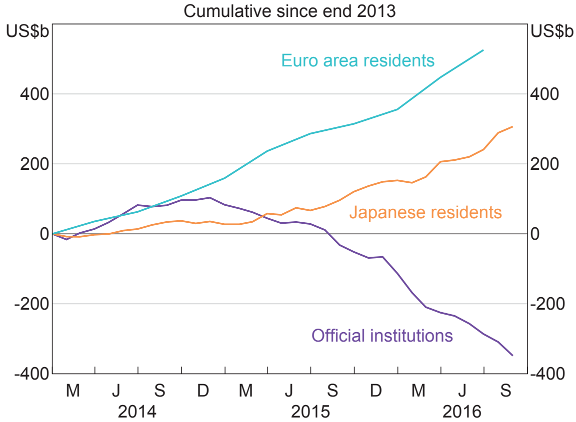
After declining sharply over the first six months of the year, yields on 10-year sovereign bonds in major developed markets have increased over the past few months (Graph 2.5). The recent rises partly reflect an unwinding of the risk aversion that affected markets in the wake of the UK referendum result in late June, as well as a scaling back of expectations for further monetary stimulus in the euro area, Japan and the United Kingdom. Better economic data, higher commodity prices and, relatedly, rising market-based measures of inflation expectations have also contributed. The rise in major market yields has seen the share of government bonds trading with a negative yield decline from around 30 per cent in early July to around 20 per cent currently.

Graph 2.5
10-year Government Bond Yields



Source: Bloomberg

Graph 2.6
Foreign Purchases of US Bonds
Cumulative since end 2013



Sources: Bloomberg; European Central Bank; Ministry of Finance Japan; RBA; Thomson Reuters

Yields in the United Kingdom have seen the largest moves among the major government bond markets this year. After falling sharply in the wake of the UK referendum result, yields rose as market-based inflation expectations increased following a significant depreciation of the UK pound and comments by Prime Minister May that suggested that fiscal policy will be eased.

In the United States, better economic data and rising expectations of an increase in interest rates by the US Federal Reserve in December have been reflected in higher US Treasury yields.

Following the BoJ's announcement of its yield curve control policy in September, yields on 10-year JGBs have remained close to the BoJ's new target of around zero per cent for these yields.

Japanese and euro area residents have continued to make sizeable purchases of foreign bonds over 2016, particularly of US securities, although purchases by Japanese residents have slowed of late (Graph 2.6). These purchases have occurred in response to the ongoing influence of BoJ and ECB purchases in their domestic sovereign bond markets. However, total foreign resident holdings of US bonds have been broadly unchanged, reflecting an offsetting reduction in foreign official institution holdings over that period, consistent with a reduction in reserves held by several oil-exporting nations and China.

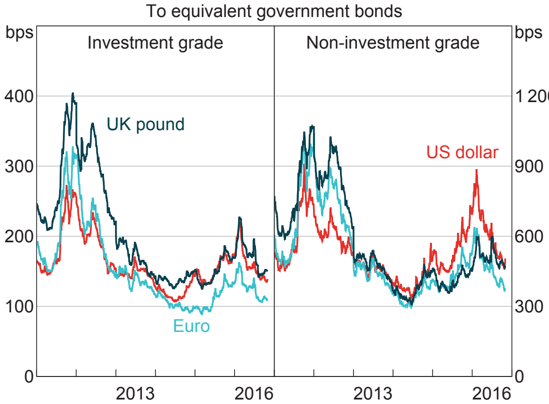
Spreads on bonds issued by governments in the European periphery over German Bunds were generally little changed in recent months. Spreads on Italian government bonds have widened relative to those on Spanish government bonds over 2016, reflecting the possibility of a 'no' vote at the December constitutional referendum in Italy, which could lead to a repudiation of the reform agenda of Prime Minister Renzi. Spreads on Portuguese government bonds have widened over the year, reflecting concerns surrounding the country's fiscal position and weak growth prospects.

Movements in yields on local currency-denominated emerging market sovereign bonds have been mixed in recent months, but yields are generally lower over 2016. Brazilian government bond yields have declined by around 45 basis points since the previous *Statement*, reflecting the official appointment of a new president in late August, a lower inflation outlook, the announcement of economic reforms and a reduction in the Central Bank of Brazil's policy rate. In contrast, local currency-denominated Philippine government bond yields have risen by around 85 basis points over the period, largely reversing the sharp decline in yields that followed the country's presidential election in May.

Credit Markets

Borrowing costs for investment grade corporations in major bond markets have generally risen over the past few months, but by less than the increase in sovereign bond yields, and spreads remain around historically low levels (Graph 2.7). Borrowing costs for non-investment grade corporations in these markets have fallen, partly reflecting the prevalence of resource-related issuers that benefit from higher commodity prices. In the United States, forecasts of higher earnings have supported debt serviceability expectations and contributed to flows into corporate bond funds. In the euro area, continued corporate bond purchases by the ECB have supported the market; having purchased around €8 billion per month since June, the ECB now holds €38 billion of corporate bonds, which is a small share of the investment grade market.

Graph 2.7
Corporate Bond Spreads
To equivalent government bonds

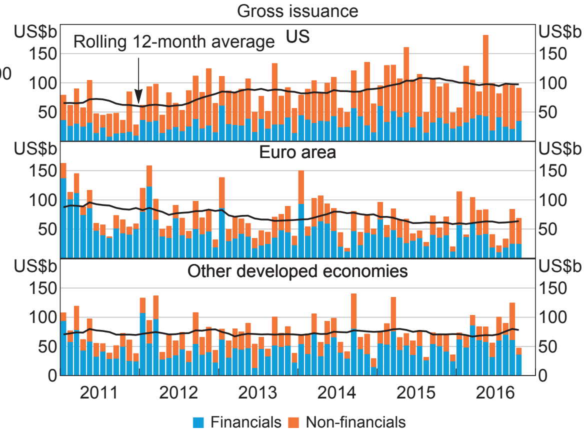


Sources: Bank of America Merrill Lynch; RBA; Thomson Reuters

In the United Kingdom, the sharp rise in sovereign yields has resulted in overall borrowing costs rising for UK firms, despite spreads on UK corporate bonds narrowing following the BoE's announcement of its Corporate Bond Purchase Scheme. The program started on 27 September and to date the BoE has purchased around £2 billion of corporate bonds. The pace of these purchases has so far been faster than implied by the BoE's policy of buying £10 billion over 18 months.

Gross corporate bond issuance has remained strong, particularly in the US, with firms borrowing in part to roll over existing debt at lower interest rates, and to finance share buybacks and acquisitions (Graph 2.8). Corporate bond issuance in the euro area and the United Kingdom picked up following the announcement of corporate bond purchase programs by the respective central banks. The first two euro-denominated non-financial sector corporate bonds with negative yields to maturity were issued in August. Issuance by corporations in other developed economies has also been robust. Issuance by financial firms in US dollars has been particularly strong, partly due to the lower cost of issuing in US dollars and swapping the proceeds into local currencies. Yen-denominated issuance by Japanese firms, though a small segment of the global corporate bond market, has also increased over the past few months.

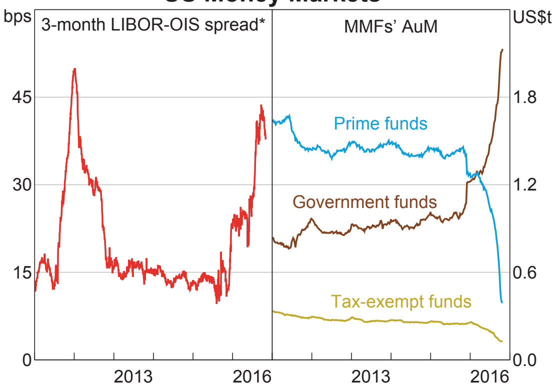
Graph 2.8
Corporate Bond Issuance
Gross issuance



Sources: Dealogic; RBA

In recent months, short-term bank funding rates in US dollar markets rose to their highest levels since 2012 due to the implementation of US money market fund (MMF) reforms (Graph 2.9). As a result of these reforms, the value of assets under management (AuM) of prime MMFs (those that lend to banks) has declined by more than US$1 trillion, or around 70 per cent, over the past year as some prime funds have switched their classification

Graph 2.9
US Money Markets

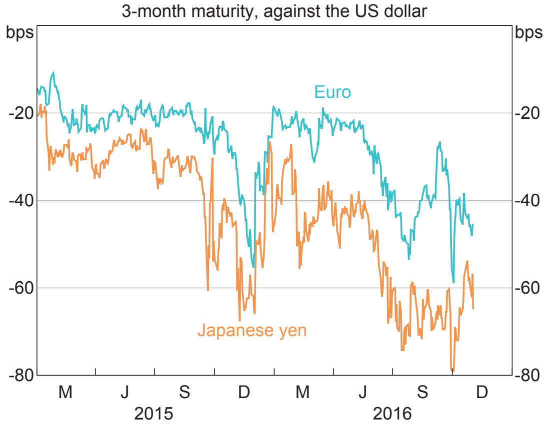


* Difference between the London Interbank Offered Rate and the Overnight Index Swap rate

Sources: Bloomberg; Investment Company Institute

Graph 2.10
Cross-currency Basis

3-month maturity, against the US dollar



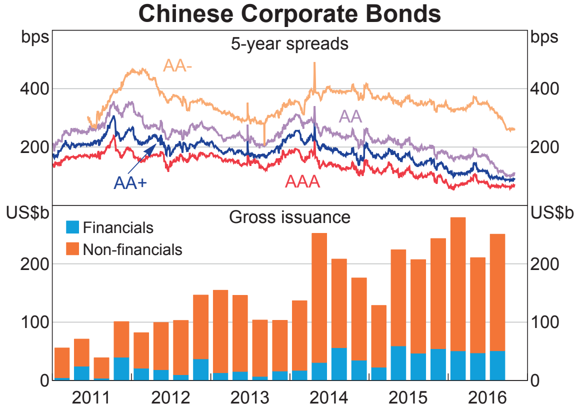
Source: Bloomberg

to government-only funds and investors have reallocated away from prime funds. Since the reforms came into effect, spreads on short-term bank funding have narrowed slightly and the weighted-average maturity of prime funds' assets has increased modestly.

The premium for borrowing US dollars in exchange for yen in short-term foreign exchange swap markets fell to its lowest level since June alongside the slowing in the pace of foreign bond purchases by Japanese residents in recent weeks (Graph 2.10). The cost of borrowing in exchange for euros has increased and rose sharply around the end of the September quarter, in part as concerns rose about the capital position of European banks.

Gross and net bond issuance by Chinese corporations increased in the September quarter, following slower issuance in the June quarter (Graph 2.11). Investor sentiment towards the corporate bond market in China has improved, despite the first liquidation of a company that had issued bonds in the interbank market. A number of factors have contributed to the improved sentiment, including: a lower frequency of missed bond payments over recent months; reports of increased government support for a number of state-owned companies; the release of draft regulations that would restrict the ability of banks' wealth management products to invest funds in

Graph 2.11
Chinese Corporate Bonds



Sources: Bloomberg; CEIC Data; Dealogic; RBA

asset classes considered riskier than corporate bonds; and a recovery in commodity prices, which has supported firms in a number of industries. Correspondingly, spreads on lower-rated corporate bonds over Chinese government bonds have narrowed significantly over recent months and spreads on highly rated bonds have been stable around historical lows, although corporate leverage in China remains at a high level.

In late September, Chinese authorities approved the first deal (for Sinosteel, a central government-owned enterprise) under a new debt-for-equity swap program, which aims to reduce the debt burden of companies in overcapacity industries. In

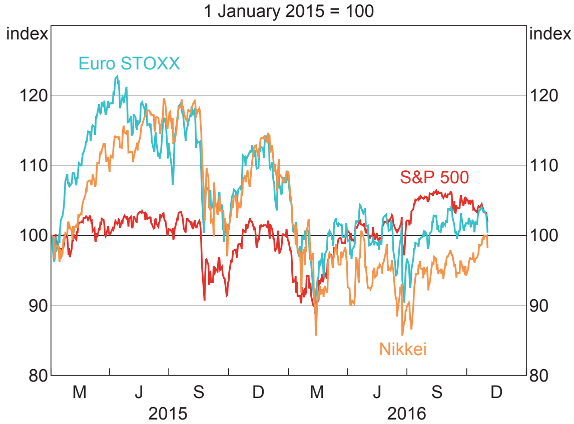
October, the State Council released guidelines for reducing corporate leverage, including encouraging the use of a number of measures that have been implemented recently, such as debt-for-equity swaps, mergers and acquisitions, bankruptcies and the securitisation of non-performing loans. The guidelines for debt-for-equity swaps specify that companies that have little prospect of returning to profitability are prohibited from participating and that the process is to be market oriented.

Spreads on US dollar-denominated bonds issued by other emerging market corporations over US Treasuries have mostly continued to narrow in recent months, in line with changes in sovereign bond spreads. Bond issuance by emerging market corporations has increased recently, but remains low over the year.

Equities

Global equity prices recovered quickly from the declines recorded in the wake of the UK referendum and have subsequently mostly traded in narrow ranges (Graph 2.12). Periods of volatility stemming from changes in the outlook for monetary policy have been brief. In the United States, share prices have been supported by expectations that aggregate corporate earnings in the September quarter will increase for the first time since mid 2015, although uncertainty around the outcome of the US presidential election has weighed on share prices more recently. European and Japanese share prices have benefited from the continued highly accommodative monetary policy of their respective central banks. Purchases of exchange-traded funds by the BoJ have provided additional support in Japan. However, equity prices in both markets remain below their levels at the start of the year (Table 2.2). In the United Kingdom, share prices have more than recovered from their sharp falls following the UK referendum result, despite concerns around the ramifications of a possible exit by the United Kingdom from the European Single Market, and have outperformed most other developed markets over the year. Internationally focused firms in particular have outperformed, reflecting the sharp depreciation of the UK pound.

Graph 2.12
Major Share Price Indices
1 January 2015 = 100



Source: Bloomberg

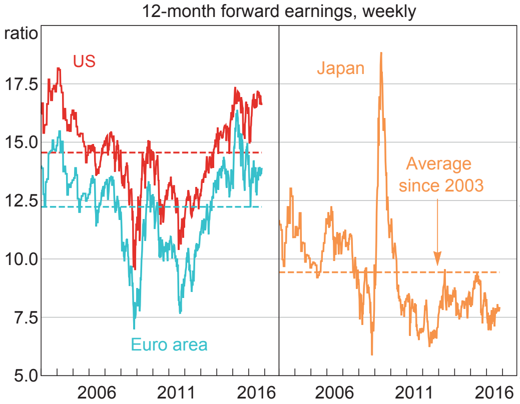
Table 2.2: Changes in International Share Prices
Per cent

	2016 to date
United States – S&P 500	3
Euro area – STOXX	–7
United Kingdom – FTSE	10
Japan – Nikkei	–10
Canada – TSE 300	12
Australia – ASX 200	–1
China – MSCI All China	–7
MSCI indices	
– Emerging Asia	8
– Latin America	27
– Emerging Europe	7
– World	**2**

Source: Bloomberg

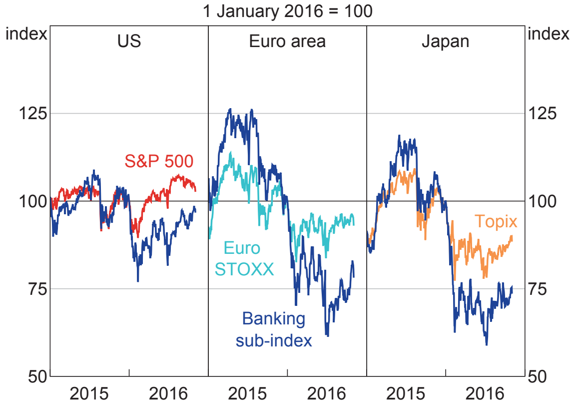
In the United States, and to a lesser extent in the euro area, valuation measures such as forward price-to-earnings ratios remain relatively high, though levels are within historical ranges (Graph 2.13). The elevated valuations in part reflect historically low interest rates, as well as expectations of an extended recovery in corporate earnings.

Graph 2.13
Forward P/E Ratios
12-month forward earnings, weekly



Sources: RBA; Thomson Reuters

Graph 2.14
Major Market Bank Share Prices
1 January 2016 = 100



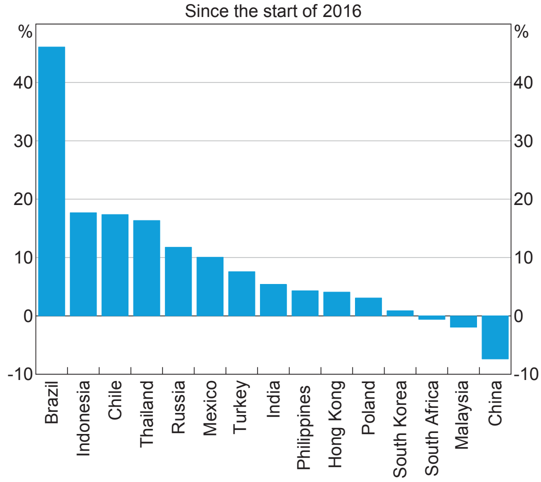
Source: Bloomberg

Japanese valuation measures remain below their long-run average.

Bank share prices in the United States and euro area have outperformed their respective broader indices since recovering from their lows that followed the UK referendum result, but remain below their levels at the start of the year (Graph 2.14). This outperformance occurred despite a period of concern around the size of potential fines that may be imposed on Deutsche Bank by the US Department of Justice. September quarter profits for the major US and European banks were generally higher than in the same period last year and were higher than analysts' forecasts, because of an increase in client fixed income and currency trading activity, which rose due to volatility following the UK referendum and ahead of the implementation of US money market fund reforms.

Share prices in emerging markets have risen slightly over recent months and have outperformed most developed markets since the beginning of the year (Graph 2.15). Chinese equity prices have risen recently, but are still below their levels at the beginning of the year following sharp declines in early 2016. Hong Kong share prices have benefited from a significant increase in southbound investment via the Shanghai-Hong Kong Stock Connect scheme; differences between share prices

Graph 2.15
Change in Emerging Market Share Price Indices
Since the start of 2016



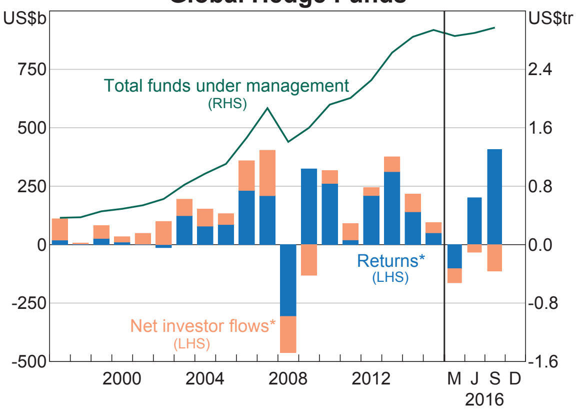
Source: Bloomberg

in Hong Kong and on the mainland A-share market of Chinese companies with a dual listing (the AH Premium) have narrowed to their lowest level since December 2014. Share prices in Brazil have risen by around 45 per cent since the beginning of the year, outperforming other developed and emerging equity markets owing to a rise in commodity prices, reduced political uncertainty and a more favourable economic outlook. Over 2016, emerging market equity indices have increased by about 10 per cent, driven by Latin America and, to a lesser extent, emerging Asia.

Hedge Funds

Global hedge funds recorded an asset-weighted return on investment of 2.1 per cent over the September quarter, underperforming a balanced portfolio of global bonds and equities (Graph 2.16). Equity-focused funds posted the strongest returns, particularly those that invest in the technology, healthcare and energy sectors. Funds focused on emerging markets also experienced strong returns, led by funds targeting emerging Asia. Investors made net withdrawals from hedge funds for the fourth consecutive quarter, but positive investment returns resulted in funds under management increasing by more than US$70 billion over the September quarter to US$3 trillion.

Graph 2.16
Global Hedge Funds



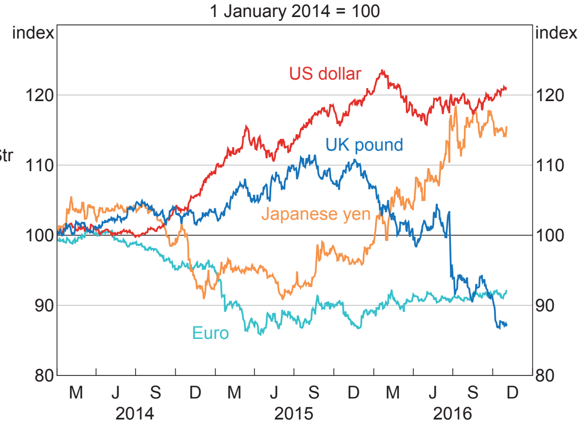
* Annualised for 2016 data
Sources: Hedge Fund Research, Inc.; RBA

Foreign Exchange

The current and expected policies of the major central banks continue to be an important driver of foreign exchange markets. In addition, the UK pound, which depreciated significantly after the June referendum result to leave the European Union, has depreciated further over the past month in response to developments around the timing and nature of the United Kingdom's exit. Despite a pick-up in volatility in the UK pound, observed and forward-looking measures of volatility in other developed market currency pairs remain around their long-run averages.

The US dollar is little changed on a trade-weighted basis (TWI) since the start of the year, but in the intervening period has moved in line with changing expectations about the timing and extent of policy rate increases by the FOMC (Graph 2.17). The euro has appreciated against the US dollar and on a trade-weighted basis since the beginning of 2016, alongside a scaling back of expectations for further monetary stimulus by the ECB (Table 2.3).

Graph 2.17
Nominal Trade-weighted Indices
1 January 2014 = 100



Sources: BIS; Bloomberg; Board of Governors of the Federal Reserve System

The UK pound has continued to depreciate over the past few months despite economic data releases having been stronger than expected. In particular, the currency has depreciated since early October, prompted by a speech by Prime Minister May that set out a broad timetable for the exit and intimated that it was likely to involve the United Kingdom leaving the European Single Market. The UK pound has depreciated by 16 per cent against the US dollar and by 15 per cent on a trade-weighted basis from its level immediately prior to the UK referendum in late June, and is now around its lowest level on a trade-weighted basis in over 100 years (Graph 2.18). Realised volatility also increased very notably on 7 October when the UK pound depreciated sharply early in the Asian trading session; the currency

Table 2.3: Changes in the US Dollar against Selected Currencies
Per cent

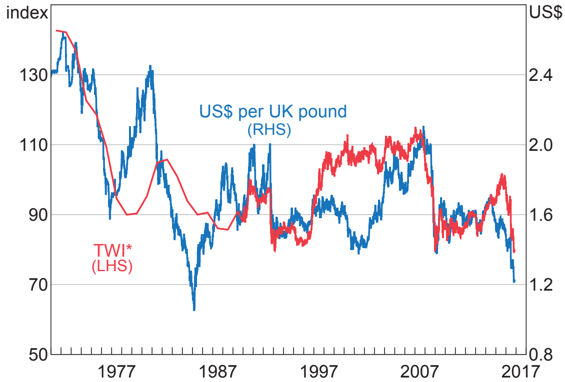
	Over 2015	2016 to date
UK pound sterling	6	20
Mexican peso	17	13
Swedish krona	8	6
Chinese renminbi	5	4
Philippine peso	5	3
Indian rupee	5	1
European euro	11	–2
South Korean won	8	–2
Singapore dollar	7	–2
Malaysian ringgit	22	–3
Swiss franc	1	–3
Thai baht	10	–3
Canadian dollar	19	–3
New Taiwan dollar	4	–4
Australian dollar	12	–5
Indonesian rupiah	11	–5
New Zealand dollar	14	–6
Russian rouble	24	–12
Japanese yen	0	–14
Brazilian real	50	–18
Trade-weighted index	**10**	**0**

Sources: Bloomberg; Board of Governors of the Federal Reserve System

quickly retraced some of the decline to finish the day only around 1 per cent lower against the US dollar. While the trigger for the initial decline remains unclear, the depreciation occurred when liquidity was low.

The Japanese yen rose significantly over the first half of 2016, and in July reached its highest level in almost three years against the US dollar and on a trade-weighted basis. Thereafter, the yen has tended to move sideways, with the appreciation being arrested by expectations that a further easing of monetary policy would be announced following the BoJ's comprehensive review of monetary policy in late September. In the event, the easing was less than expected but the yen has continued to move broadly sideways, in part because of the widening in the differential between yields on Japanese bonds and those of other major sovereigns.

Graph 2.18
UK Pound

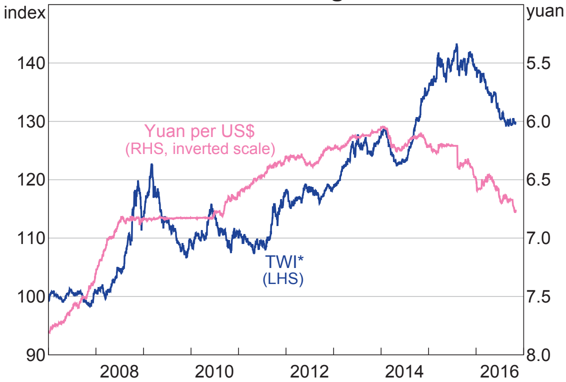


* 1971–2016 average = 100, data prior to 1990 are annual averages
Sources: Bank of England; Bloomberg; RBA

The Chinese renminbi (RMB) has been little changed on a trade-weighted basis over recent months. This partly reflects some easing of concerns about the near-term economic outlook in China, which had weighed on the RMB over much of the previous year; the RMB remains 7 per cent lower on a trade-weighted basis since the start of the year and 10 per cent lower since its August 2015 peak (Graph 2.19). Against the US dollar, the RMB has depreciated by 4 per cent since the start of the year, to trade at its lowest level since 2010. Realised volatility in the RMB against the US dollar has declined since March, reflecting the gradual nature of the RMB's recent depreciation.

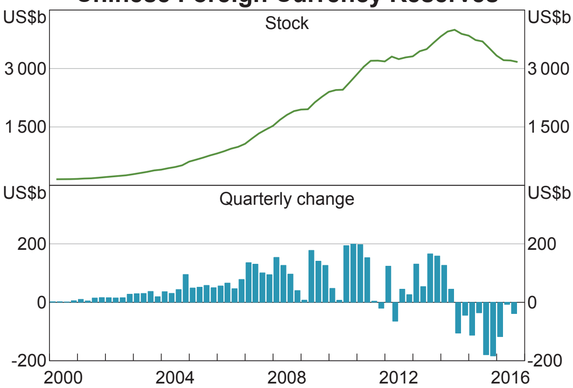
The value of the PBC's foreign currency reserves has been broadly stable since February, at around US$3.2 trillion (29 per cent of GDP) following sharp declines in the year to the March quarter 2016 (Graph 2.20). On 1 October the RMB entered the basket of currencies that determine the value of the IMF's Special Drawing Right (SDR) following the IMF Executive Board's decision in November 2015. The RMB has a weight of around 11 per cent in the basket, the third largest weight after the US dollar and the euro. In September, the World Bank issued the first tranche of bonds denominated in SDRs (but

Graph 2.19
Chinese Exchange Rates



* 2007 average = 100
Sources: BIS; Bloomberg; RBA

Graph 2.20
Chinese Foreign Currency Reserves

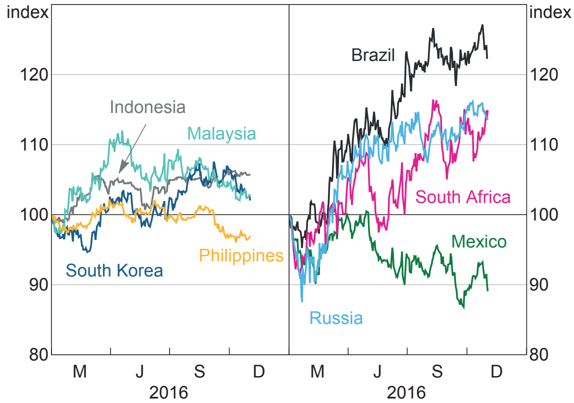


Source: CEIC Data

settled in RMB) in the onshore Chinese market, after becoming the first entity to receive approval from the PBC to issue such bonds.

Over the past few months, most emerging market currencies have been little changed or have depreciated against the US dollar (Graph 2.21). Increased expectations of further monetary policy tightening in the United States have weighed on emerging market currencies, and depreciations have generally been more pronounced in countries experiencing domestic political uncertainty. One exception has been the Russian rouble, which has appreciated by 5 per cent against the US dollar alongside stronger oil prices, to be around 30 per cent higher than its trough in

Graph 2.21
Asian and Emerging Market Currencies
Against the US dollar, 1 January 2016 = 100



Source: Bloomberg

mid January. Over the past few months, volatility in emerging market currencies declined to be around its average level since 2010.

The Mexican peso has depreciated a little against the US dollar since the previous *Statement* but has experienced large swings in its value over the period, reflecting developments in the US presidential election campaigns (Graph 2.22). From a longer-run perspective, the peso has depreciated by around 25 per cent against the US dollar since the end of 2014, consistent with the currency's use as a hedging and speculative instrument for risk in emerging market economies, uncertainty around US monetary policy and lower oil prices over this period.

The gross foreign currency reserves of most emerging market economies have been little changed or have increased slightly since the end of June (Table 2.4). The increase in Indonesia's gross foreign currency reserves since the end of June has partly reflected Bank Indonesia intervening to stem appreciation pressure in the rupiah following increased capital inflows, including as a result of the implementation of a tax amnesty program.

Australian Dollar

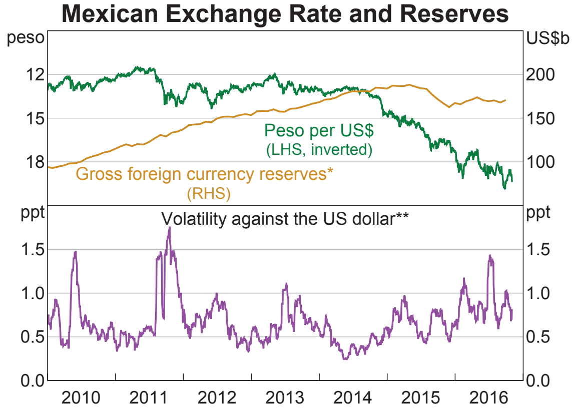
Since its most recent trough in late May, the Australian dollar has gradually appreciated and is now 7 per cent higher against the US dollar and on

Table 2.4: Gross Foreign Currency Reserves[(a)]

	Percentage change since:		Level
	End September 2015	End June 2016	US$ equivalent (billions)
China	–10	–1	3 166
Saudi Arabia	–15	–3	545
Taiwan[(b)]	2	1	437
South Korea	2	2	368
Brazil	1	1	354
Hong Kong	7	1	354
India	5	1	342
Russia	2	0	316
Singapore	1	2	251
Thailand	16	1	171
Mexico	–1	1	171
Indonesia	14	6	109
Turkey	0	0	100
Malaysia	5	1	90

(a) Data to end August for Mexico and Saudi Arabia; to end September for China, Hong Kong, Indonesia, Singapore, South Korea, Taiwan and Thailand; to 14 October for India, Malaysia, Russia and Turkey; and to 21 October for Brazil
(b) Foreign exchange reserves (includes foreign currency and other reserve assets)
Sources: Bloomberg; CEIC Data; Central Banks; IMF; RBA

Graph 2.22
Mexican Exchange Rate and Reserves



* Data to end September 2016
** Rolling 22-day standard deviation of daily percentage changes
Sources: Bank of Mexico; Bloomberg; IMF; RBA

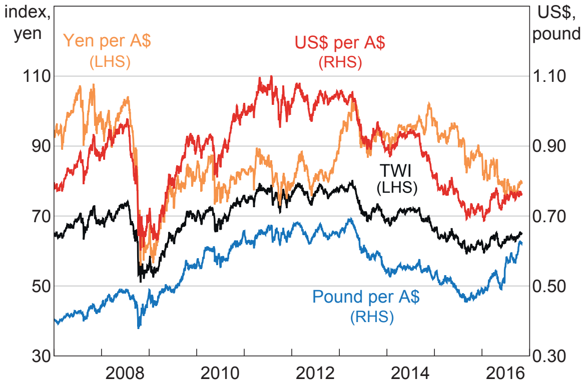
a trade-weighted basis (Table 2.5; Graph 2.23). The appreciation over this period has occurred alongside a rise in the terms of trade, and largely reflects appreciations against the RMB and, to a lesser extent, the UK pound. However, the Australian dollar remains around 30 per cent lower against the

Table 2.5: Changes in the Australian Dollar against Selected Currencies
Per cent

	Over 2015	2016 to date
UK pound sterling	–6	26
Chinese renminbi	–7	9
Indian rupee	–7	6
US dollar	–11	5
European euro	–1	3
South Korean won	–4	3
Singapore dollar	–5	3
Malaysian ringgit	9	2
Swiss franc	–10	2
Thai baht	–2	2
Canadian dollar	6	2
Indonesian rupiah	–1	–1
New Zealand dollar	2	–1
South African rand	19	–9
Japanese yen	–11	–9
Trade-weighted index	**–6**	**4**

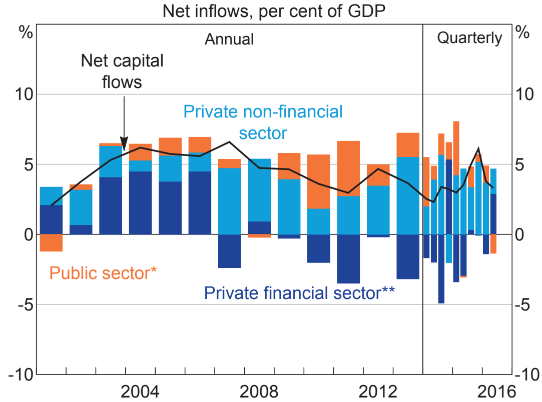
Sources: Bloomberg; RBA

Graph 2.23
Australian Dollar



Sources: Bloomberg; RBA

Graph 2.24
Australian Capital Flows
Net inflows, per cent of GDP



* Excludes official reserves and other RBA flows
** Adjusted for US dollar swap facility in 2008 and 2009
Sources: ABS; RBA

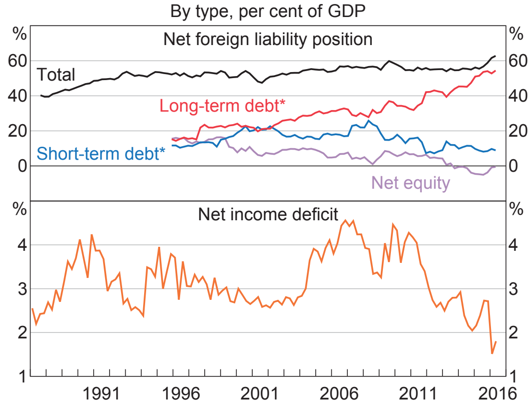
US dollar and around 20 per cent lower on a trade-weighted basis than its peak in the first half of 2013.

Capital Flows

Net capital inflows to the Australian economy were equivalent to 3½ per cent of GDP in the June quarter, around 1 percentage point lower than the average of net capital inflows over the past 15 years (Graph 2.24). Consistent with the pattern of capital flows observed since 2007, recent net capital inflows have largely reflected flows to the private non-financial sector. Most of these net inflows were directed to the mining sector (which is majority foreign owned). Net inflows to the general government sector have continued at a moderate pace over recent years. Notwithstanding this, the foreign ownership share of Australian Government Securities declined by around 4½ percentage points (to around 60 per cent) over the first half of 2016, as net issuance was larger than foreign purchases; the foreign ownership share of state government debt increased slightly.

Australia's lower-than-average current account deficit, corresponding to the below-average capital inflows, has partly reflected a longer-term decline in the net income deficit. The net income deficit, which largely comprises payments made on Australia's net foreign liabilities, has fallen to historically low levels. In the past few years, the decline has reflected higher receipts from foreign equity assets owned by Australian entities. Australia's net foreign liability position increased to a little over 60 per cent of GDP at the end of the June quarter, with recent increases mostly reflecting valuation effects (Graph 2.25).

Graph 2.25
Net Foreign Liabilities
By type, per cent of GDP



* Short-term includes debt with an original maturity of one year or less; long-term includes all other debt
Sources: ABS; RBA

3. Domestic Economic Conditions

In 2015/16, output in Australia grew at around central estimates of the economy's potential rate of growth (Table 3.1; Graph 3.1).[1] Growth was supported by a significant increase in resource exports, consistent with new capacity coming online. At the same time, there were further large falls in mining investment. The transition of economic activity towards the non-mining sector has continued, as reflected in strong growth in dwelling investment and public demand and further growth in household consumption. Nominal income rose at a modest pace in 2015/16, mainly owing to the decline in commodity prices and low wage growth. However, commodity prices have risen over the course of 2016 and the terms of trade have increased of late following four years of significant declines.

The unemployment rate has declined a little further over recent months. While this suggests that labour market conditions have continued to improve,

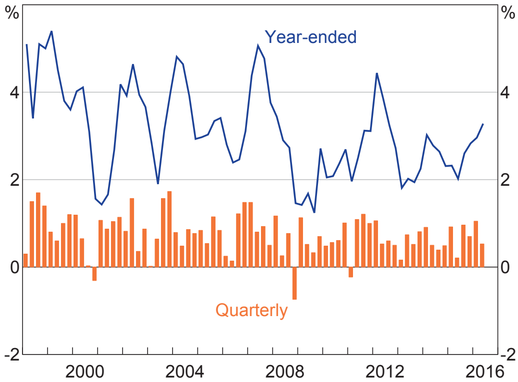
Table 3.1: Demand and Output Growth
Year average, per cent

	2015/16	2014/15
GDP	2.8	2.4
Domestic final demand	1.2	1.1
– Private demand[(a)]	0.6	1.2
– Consumption	2.9	2.6
– Dwelling investment	9.8	7.8
– Mining investment	–27.5	–20.1
– Non-mining investment[(a)]	1.0	6.9
– Public demand[(a)]	3.5	0.6
Change in inventories[(b)]	–0.1	0.3
Exports	6.7	6.7
Imports	–0.3	1.2
Mining activity	–2.0	–3.4
Non-mining activity	3.5	3.4
Nominal GDP	2.3	1.7
Real gross domestic income	0.6	0.1

(a) RBA estimates
(b) Contribution to GDP growth
Sources: ABS; RBA

1 Although the 2015/16 annual national accounts (shown in Table 3.1) contain the most recent data on GDP, the June quarter 2016 national accounts, which were released prior to the annual national accounts, contain the most recent data on quarterly movements in GDP.

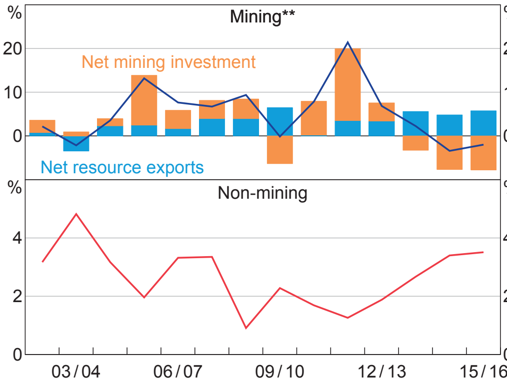
Graph 3.1
GDP Growth



Source: ABS

Graph 3.2
Mining and Non-mining Activity*

Year-average growth



* Mining and non-mining activity estimated by the RBA

** Components are contributions to year-average mining activity growth; contribution from mining inventories omitted

Sources: ABS; RBA

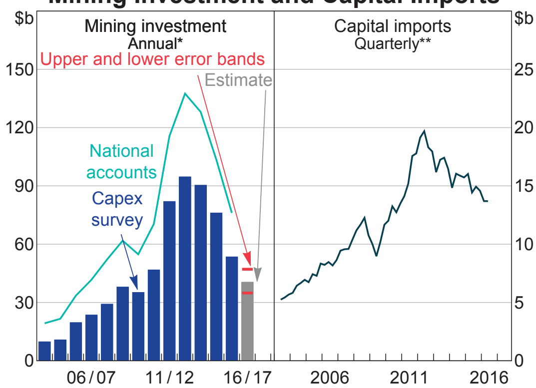
some other labour market indicators have been less positive. Employment growth has moderated from its strong pace last year and full-time employment has declined over the course of this year. In line with that, the underemployment rate has remained elevated over the past year or so. Together with low wage growth, this suggests that there is more spare capacity in the labour market than implied by the unemployment rate.

Mining Activity

Activity in the mining sector declined in 2015/16, as the fall in mining investment was only partly offset by strong increases in resource exports (Graph 3.2). Mining activity is expected to expand as the drag from mining investment wanes over the next year or so and exports of liquefied natural gas (LNG) continue to ramp up. Further growth in iron ore export volumes is also likely, supported by increased production from Australia's large low-cost producers.

Mining investment has fallen significantly since its peak in 2012/13, from 9 per cent of GDP to about 4½ per cent in 2015/16 (Graph 3.3). Further declines are expected as work on LNG facilities continues to decline and few new projects are expected to commence. However, the largest subtraction of mining investment (net of imports) from GDP growth looks to have already occurred; the ABS

Graph 3.3
Mining Investment and Capital Imports



* Current prices

** Chain volume; reference year 2013/14

Sources: ABS; RBA

capital expenditure (Capex) survey of investment intentions and Bank liaison point to a smaller subtraction in 2016/17.

Overall economic conditions remain relatively weak in Western Australia and, to a lesser extent, Queensland. The earlier large falls in commodity prices from their peak in 2011 exerted a significant drag on growth in output and income in those states. The increase in commodity prices over 2016 to date represents a marked change from previous years. If sustained, higher commodity prices will provide some support to growth in nominal income, but are not expected to lead to much additional mining investment over the next couple of years.

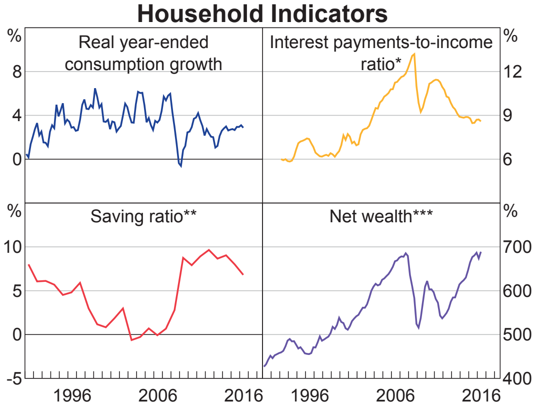
Non-mining Activity

Growth in non-mining activity has picked up over recent years, supported by low interest rates and the depreciation of the exchange rate since early 2013 (Graph 3.2). In 2015/16, non-mining activity increased by a little more than its average rate.

Household sector

Consumption growth has continued to be supported by low interest rates, rising household wealth and further increases in employment, although wage growth has been subdued. The household saving ratio has declined gradually, but remains at a relatively high level compared with outcomes over recent decades (Graph 3.4).

Graph 3.4
Household Indicators



* Excludes unincorporated enterprises
** Net of depreciation
*** Per cent of annual household disposable income before the deduction of interest payments
Sources: ABS; RBA

In 2015/16, growth in household consumption was close to its decade-average rate. However, growth was more moderate in the June quarter, owing to a decline in the consumption of goods; consumption of services grew at a similar pace to recent quarters. The weakness in goods consumption was consistent with subdued growth of retail sales in the June quarter. Growth in the value of retail sales remained modest early in the September quarter, potentially signalling further weakness in goods consumption. On the other hand, households' perceptions of their own finances have been above average for some time and increased in the September quarter.

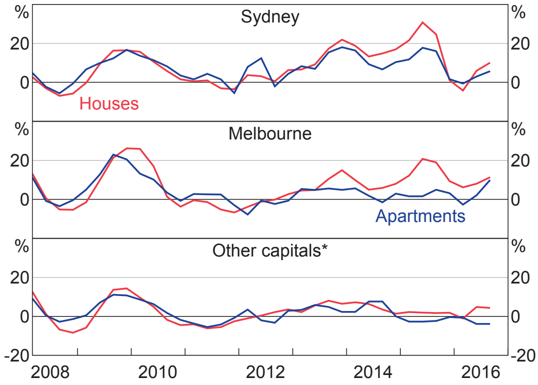
There is some uncertainty about the likely strength of consumption growth over the period ahead. If weak growth in household income persists, households may restrain growth in future consumption, which would imply a more modest decline in the household saving ratio than has been observed in the past few years.

Housing price growth and auction clearance rates have risen in Sydney and Melbourne recently, although the number of auctions held remains lower than a year ago (Graph 3.5; Graph 3.6). In the private treaty market, the average discount on vendor asking prices has decreased slightly, but the average number of days that a property is on the market has increased from the lows of last year, mainly reflecting developments outside Sydney and Melbourne. Housing loan approvals have edged higher over recent months, driven by investor lending, and growth in lending to investors for housing has picked up to be close to that for owner-occupiers (see 'Domestic Financial Markets' chapter for further details on housing finance).

Notwithstanding the recent strengthening in housing market conditions in Sydney and Melbourne, overall conditions in the established housing market have eased relative to mid last year. Housing price inflation remains below the peaks in 2015. Housing credit growth is lower than a year ago, consistent with the tightening in lending standards since then and lower turnover. Tighter lending standards have been reflected in the declining share of interest-only loans over the past year and a decrease in new lending with loan-to-valuation ratios greater than 90 per cent.[2] Moreover, much of the increase in credit is being used to finance new housing construction rather

2 See RBA (2016), *Financial Stability Review*, October, pp 18–19.

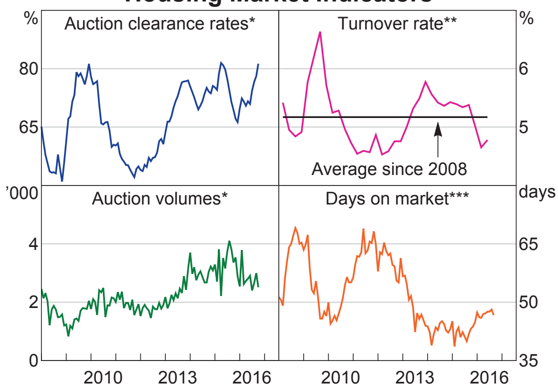
Graph 3.5
Housing Price Growth by Dwelling Type
Six-month-ended annualised, seasonally adjusted



* Dwelling stock weighted average of Adelaide, Brisbane and Perth

Sources: APM; RBA

Graph 3.6
Housing Market Indicators



* Average of Melbourne and Sydney

** Share of dwelling stock; annualised

*** Capital city dwelling stock weighted median for private treaty sales only

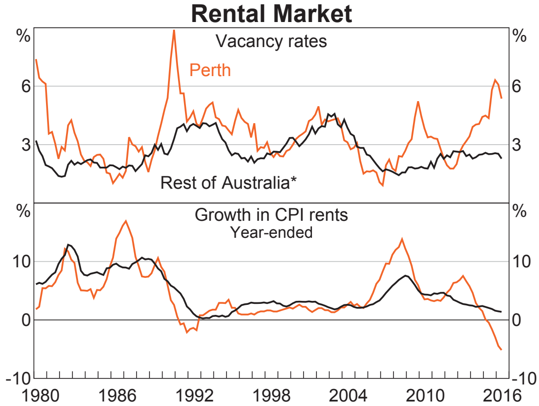
Sources: ABS; APM; CoreLogic; RBA; Real Estate Institute of Victoria

than consumption (in contrast to the experience of the early 2000s).

Private dwelling investment continued to grow at an above-average rate in 2015/16. Residential building approvals remain well above their long-run average, driven by higher-density approvals, and there is a significant amount of work in the pipeline. That work is expected to support a high level of dwelling investment for some time, although the rate of growth in dwelling investment is expected to decline over the forecast period.

In some residential markets, such as apartment markets in inner-city areas of Melbourne and Brisbane, there are concerns that the significant new supply of dwellings in the pipeline will outpace growth in demand for housing and place downward pressure on rents and prices. This in turn could increase the risk of off-the-plan purchases failing to settle.[3] While there are reports of some settlement delays and settlement failures, liaison suggests that so far the incidence of these is not higher than usual (although there looks to have been a slight rise in settlement delays for some foreign buyers). In Western Australia, over recent years population growth has declined, the unemployment rate has increased, household income growth has moderated and yet dwelling completions have been high. This has led to a sharp rise in rental vacancy rates and a noticeable decline in rents and prices in Perth (Graph 3.7). Rent growth in the rest of the country has declined to low levels, but vacancy rates have been generally steady and relatively low.

Graph 3.7
Rental Market



* Capital cities only; excludes Adelaide from March quarter 2015

Sources: ABS; RBA; REIA

3 If the buyer is unwilling or unable to settle the purchase of the property, the deposit is forfeited and the property developer can resell the property. See RBA (2016), 'Box B: The Housing Market', *Statement on Monetary Policy*, August, pp 42–44; RBA (2016), *Financial Stability Review*, October p 17.

Non-mining business sector

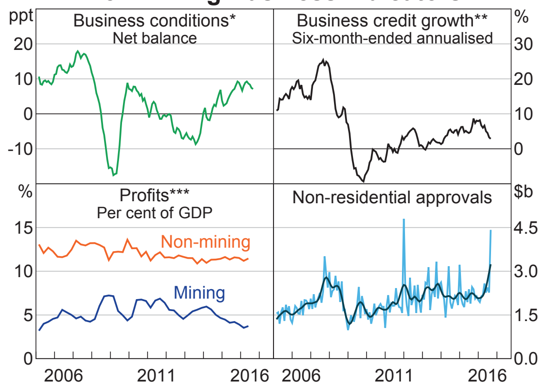
Revised data in the annual national accounts suggest that non-mining business investment has been on an upward trend for the past few years, after declining in 2012/13, although growth was modest in 2015/16. The rise in non-mining investment is consistent with the pick-up in non-mining activity over recent years, which has been supported by low interest rates and the earlier depreciation of the exchange rate.

Indicators such as the ABS Capex survey suggest that non-mining business investment is likely to be subdued in 2016/17. However, the Capex survey only covers about half of the non-mining business investment captured by the more comprehensive national accounts measure; it does not cover certain industries, such as some service industries that have had relatively strong investment outcomes over recent years, nor does it measure investment in intangible capital such as software, which has also grown relatively strongly. Private non-residential building approvals have picked up of late, reflecting increases in New South Wales and Victoria, although work yet to be done (as a share of GDP) has been on a downward trend for the past two years or so.

By state, the Capex survey suggests that the weakness in non-mining investment has been most evident in Western Australia and Queensland, where the downturn in the terms of trade and mining investment have had a large, direct effect on demand. In contrast, non-mining business investment appears to have increased somewhat in New South Wales and Victoria, which are less exposed to the mining sector and where economic conditions have improved over the past couple of years.

Survey measures of business conditions in the non-mining sectors have been above average for some time (Graph 3.8). Survey measures of profitability are at above-average levels, although the ABS measure of non-mining company profits has been little changed as a share of nominal GDP. Business credit growth has moderated recently, although this partly reflects a reduction in the growth of credit extended to mining-related firms.

Graph 3.8
Non-mining Business Indicators



* Deviation from long-run average; gross value added weighted; three-month moving average

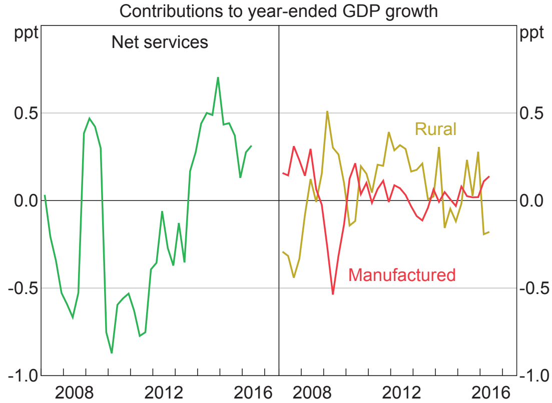
** Business credit includes mining and non-mining industries

*** Inventory valuation adjusted gross operating profits

Sources: ABS; APRA; NAB; RBA

The depreciation of the exchange rate since early 2013 has supported growth in non-mining exports. Net service exports have made a significant contribution to GDP growth over this period, with tourism, education and business services exports all expanding (Graph 3.9). Manufactured exports have picked up since the beginning of 2016, following several years of little change. Rural exports, most notably wheat and beef, have declined in the year

Graph 3.9
Non-mining Exports
Contributions to year-ended GDP growth



Sources: ABS; RBA

to date. The global stock of wheat is at a historically high level resulting in low wheat prices, while Australian beef supply has been tightening as farmers rebuild their herds.

Government sector

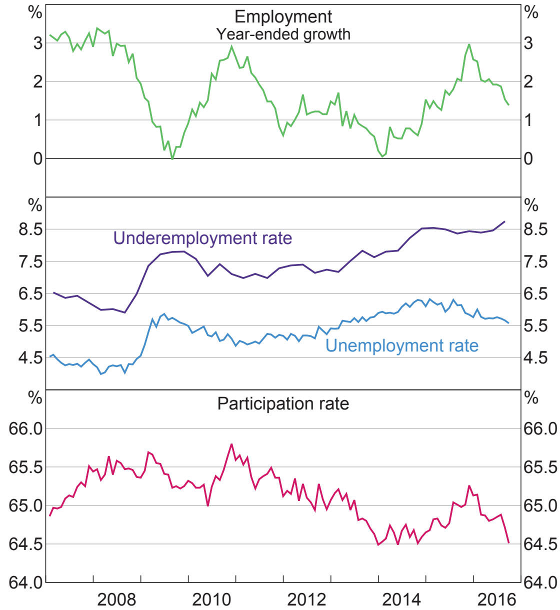
Public demand has contributed strongly to growth over the past year, in part reflecting an increase in infrastructure investment in New South Wales and Victoria. Federal and state budgets suggest that the consolidated deficit will widen a little in 2016/17 to around 3 per cent of GDP. Deficits are expected to be progressively lower over subsequent years and the consolidated deficit is forecast to return to a balanced position by around 2019/20.

Labour market

The unemployment rate continued to decline in the September quarter and is a bit more than half a percentage point below its peak in mid 2015 (Graph 3.10). While the unemployment rate has declined more quickly than had been expected a year ago, other indicators paint a more mixed picture and are consistent with some moderation in labour market conditions over the course of this year.

In particular, following strong growth in late 2015, employment growth has slowed to a more modest pace and the increase in employment since then has been in part-time jobs (See 'Box B: Trends in Part-time and Full-time Employment'). Also, the underemployment rate – which captures employees who are available and would like to work more hours – has picked up a little over the past year and remains elevated. The pick-up in underemployment has been driven by males, while underemployment has been little changed for females. This difference may reflect the loss of full-time jobs in industries that tend to hire a larger share of males, such as mining, manufacturing and utilities. Moreover, the participation rate has declined a little of late, mostly because of a decline in male participation.

Graph 3.10
Labour Market

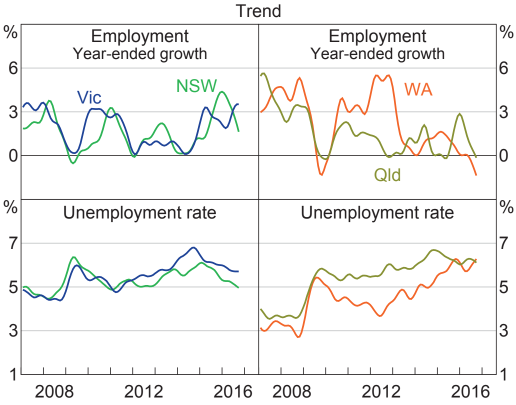


Source: ABS

Differences in the labour market across states are consistent with the rebalancing of economic activity from mining to the non-mining sectors. Although most new jobs created this year have been part-time, total employment has grown in New South Wales and Victoria, been subdued in Queensland and declined in Western Australia (Graph 3.11). Over the past two years, the unemployment rate has declined in all states except Western Australia, where it has increased noticeably. A sharp slowing in net interstate and overseas immigration to the resource-rich states has assisted adjustment to slowing growth in labour demand and helped to limit the rise in unemployment rates in Queensland and Western Australia.

By sector, household services has been the most important contributor to employment growth over the past couple of years. Within that sector, there have been further increases in employment in the health and education industries and, more recently, employment growth in the accommodation & food industry has increased, possibly reflecting a

Graph 3.11
Labour Market by State

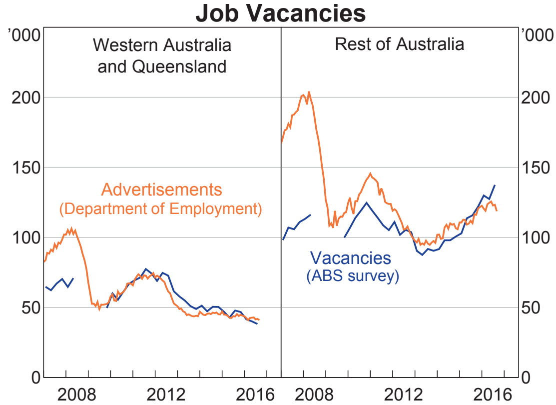


Sources: ABS; RBA

boost in demand owing to the earlier depreciation of the exchange rate. Within the goods sector, construction employment has grown strongly for several years, owing to the pick-up in residential construction activity, which has offset the decrease in employment associated with the decline in mining-related construction work. Mining employment is now back to around 2011 levels.

Overall, forward-looking indicators of labour demand point to continued moderate growth in total employment in the near term. Job vacancies have increased steadily in the non-resource states, but remain subdued in the resource-rich states, indicating that the divergence in employment outcomes between the states is likely to continue for a time (Graph 3.12). Although reductions in mining-related employment associated with falls in mining investment appear to be largely complete, there are likely to be some further job losses over the next couple of years associated with the completion of LNG projects. The degree of excess capacity in the construction industry in Western Australia is unlikely to abate over the next year or so.

Graph 3.12
Job Vacancies

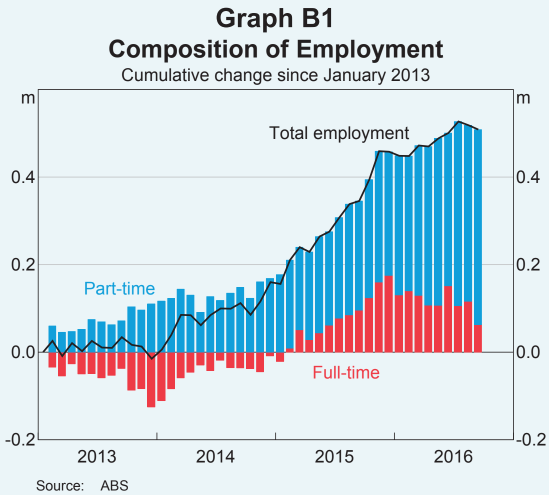


Sources: ABS; Department of Employment; RBA

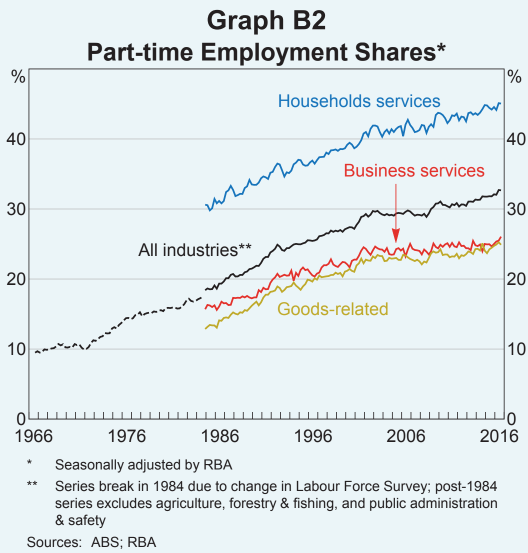
Box B

Trends in Part-time and Full-time Employment

Part-time work has accounted for all of the increase in employment since the beginning of the year and more than two-thirds of the increase since 2013 (Graph B1).[1] Over the longer run, the share of part-time employment has increased steadily to be around one-third of total employment, compared with 10 per cent in the mid 1960s (Graph B2).



The secular rise in the share of part-time employment reflects developments in both labour supply and demand.[2] On the supply side, more flexible employment arrangements have made it easier for people to combine employment with other activities such as education and caring for family members (although factors such as greater access to childcare have also contributed). On the labour demand side,



firms have used part-time employment to respond to fluctuations in demand for their output and to increase organisational flexibility.

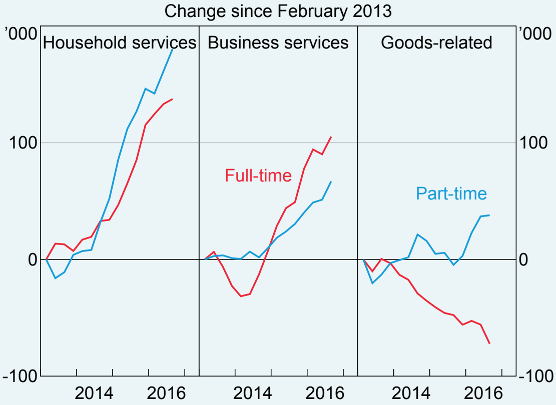
Over recent years, the relative strength in part-time employment has also reflected changes in the sectoral composition of employment growth. Since 2013, employment growth has been strongest in the household services sector, where the share of part-time employment is relatively high at about 45 per cent (Graph B3).[3] The strength in household services employment is consistent with the pick-up in the growth of non-mining activity as the economy rebalances away from mining investment. Over this period, the share of

1 The Labour Force Survey classifies people as full-time if they worked more than 35 hours across all jobs in the survey reference week or if they worked less than 35 hours but usually work more than 35 hours. Part-time employment consists of those who usually, and in the survey reference week, work less than 35 hours.

2 For further information on longer-run trends in part-time employment see Abhayaratna J, L Andrews, H Nuch and T Podbury (2008) 'Part Time Employment: the Australian Experience', Productivity Commission Staff Working Paper, June.

3 The household services sector includes the accommodation & food, arts & recreation, education and health & social assistance industries. The business services sector includes the administration & support, financial & insurance, media & telecommunications, professional, scientific & technical, and rental, hiring & real-estate industries. The goods-related sector includes the construction, manufacturing, mining, retail trade, transport, postal & warehousing, utilities, and wholesale trade industries.

Graph B3
Employment by Sector*



* Seasonally adjusted by RBA; does not remove the effects of changes in the timing of ABS supplementary surveys; four-quarter moving average

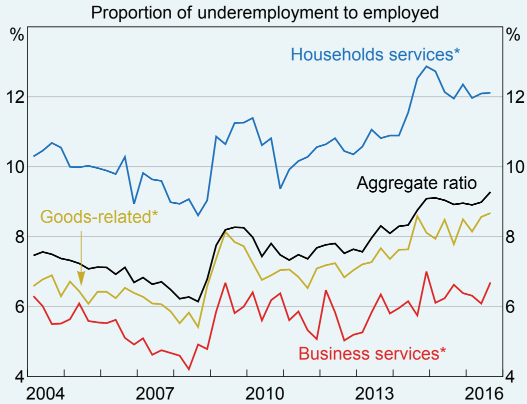
Sources: ABS; RBA

part-time employment in the business services and goods-related sectors has also increased, but remains much lower than for household services at around 25 per cent. Employment growth has been weakest in the goods-related sector, in part reflecting the fall in employment related to mining activity since 2013 and the ongoing decline in manufacturing employment.

Since 2013, the shift towards part-time employment *within* each sector has also become more pronounced. This is most obvious in the household services and goods-related sectors, where part-time employment has risen by more than full-time. The shift towards part-time employment within sectors is consistent with liaison reports that firms have been hesitant to employ full-time workers until they see evidence that increased demand for their output is likely to be sustained. Firms can more easily adjust the hours of part-time workers than those of full-time workers. As such, part-time employees provide firms with greater flexibility than full-time employees to adjust hours of work in response to fluctuations in demand for their output.[4] Adjusting hours for full-time employees (including via changes to overtime) typically provides a more limited margin of adjustment. Casual employees provide firms with greater flexibility than permanent part-time employees (although they are typically compensated for this flexibility with a higher wage). However, there has been relatively little change to the share of part-time employees who are casual over the past few years.

While the unemployment rate has declined over the past year, the underemployment rate – which captures the share of employed people who want and are available to work additional hours – has remained elevated (Graph B4).[5] This suggests that the recent strength in part-time employment is more likely to have been driven by weakness in labour demand than changes in employee preferences. The underemployment rate has risen noticeably for males, in part because of the relatively

Graph B4
Underemployment Ratio by Sector



* Seasonally adjusted by RBA

Sources: ABS; RBA

4 More generally, there is evidence that a larger share of cyclical labour market adjustment since the late 1990s has come about via changes in average hours worked per employee, as opposed to changes in employment. See Bishop J, L Gustafsson and M Plumb (2016), 'Jobs or Hours? Cyclical Labour Market Adjustment in Australia', RBA Research Discussion Paper, No 2016-06.

5 It is not uncommon for the underemployment rate to remain elevated for a period of time following a peak in the unemployment rate.

high proportion of male employment in goods-related industries where full-time employment has declined. In contrast, employment growth has been strong in the household services sector and the underemployment ratio in this sector has stabilised. The elevated level of underemployment implies that there is more spare capacity in the labour market than indicated by the unemployment rate alone.

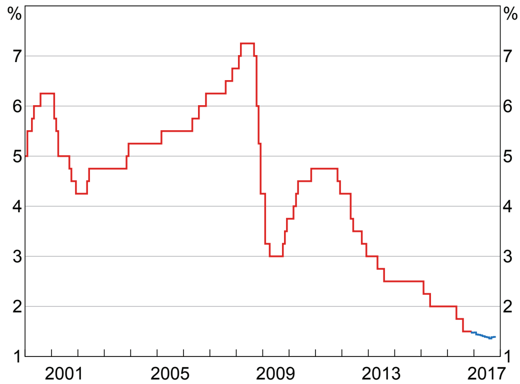
4. Domestic Financial Markets

Australian financial markets have been relatively quiet over recent months. Housing and business lending rates are at historic lows following the cash rate reduction in August. Bond yields are also at very low levels. The Australian Government and the major banks have been able to issue significant volumes of bonds at longer-than-usual maturities. Notwithstanding historically low interest rates, credit growth has continued to ease. Credit extended to businesses has slowed since earlier in the year and non-financial corporate bond issuance has remained low, particularly in the resources sector. Housing credit growth has also slowed a little, consistent with a reduction in turnover in the housing market. Equity prices have declined in recent months after having risen earlier in the year.

Money Markets and Bond Yields

After lowering the cash rate target in two 25 basis point steps in May and August, the Reserve Bank has maintained the cash rate target at 1.5 per cent. Rates on overnight indexed swaps (OIS) imply some chance of a further reduction in the cash rate over the year ahead (Graph 4.1).

Graph 4.1
Cash Rate*



* Data from December 2016 onwards are expectations derived from interbank cash rate futures

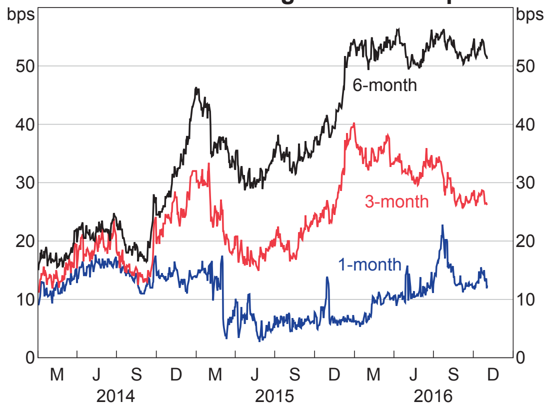
Sources: ASX; Bloomberg

Short-term secured interest rates in the repurchase agreement (repo) market have risen relative to OIS rates, though these spreads have retreated from their highs in recent weeks. The wider repo spreads reflect heightened demand for secured funding from market participants, particularly non-residents, and appears to be related to developments in the foreign exchange swap market and the bond futures market.[1] In the foreign exchange swap market, Australian dollars can be lent against yen at a relatively high implied Australian dollar interest rate; as a result, some investors have been borrowing Australian dollars under repo to do this. Bond futures have also been trading at higher implied prices than the basket of bonds that underlie the futures and, in response, some investors have sold the futures and bought the bonds using repo funding.

Short-term interest rates more closely related to bank funding costs have remained low. The unsecured interbank overnight interest rate – the cash rate – has continued to trade at the Reserve Bank's target. Since the start of the year, 3-month bank bill rates (BBSW) have declined relative to OIS rates, while spreads for 6-month bank bill rates have remained broadly steady (Graph 4.2).

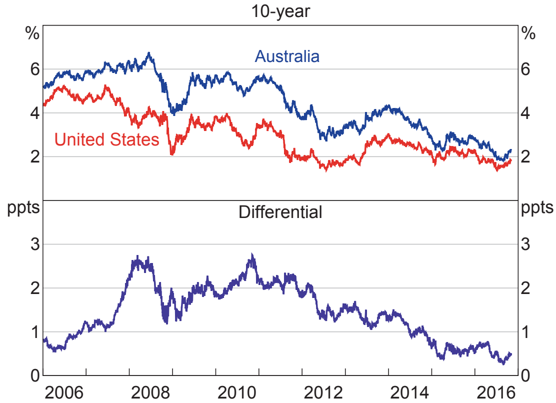
1 For more information, see Becker C, A Fang and J C Wang (2016), 'Developments in the Australian Repo Market', RBA *Bulletin*, September, pp 41–46.

Graph 4.2
BBSW to Overnight Index Swap



Sources: AFMA; Tullett Prebon (Australia)

Graph 4.3
Government Bond Yields



Sources: Bloomberg; RBA

After reaching an historic low of 1.8 per cent in August, yields on 10-year Australian Government Securities (AGS) have subsequently increased by around 50 basis points, primarily reflecting global developments (Graph 4.3). The spread between AGS and US Treasury yields, after narrowing earlier this year, is currently around 50 basis points. Of note, the Australian Office of Financial Management (AOFM) issued a 30-year bond for the first time in October, raising $7.6 billion via syndication at a yield to maturity of 3.27 per cent. The bond had greater international participation than seen at prior syndications, particularly from fund managers in Europe and North America.

State and territory governments have raised $33 billion in bonds ('semis') in the year to date. After taking into account maturities, the total stock of bonds outstanding has been little changed at around $242 billion. Funding requirements for the 2016/17 financial year are expected to be modest compared to recent years, reflecting asset sales such as the Port of Melbourne and Ausgrid.

Bond issuance by non-residents in the domestic market ('Kangaroo' issuance) over the past year has been below the average of recent years. Several US corporations issued large volumes of bonds earlier in the year, but issuance by supranational institutions, foreign sovereigns and agencies has been slightly below average in recent months.

Secondary market spreads to AGS for AAA rated issuers have tightened in recent months and are back around levels seen in late 2015.

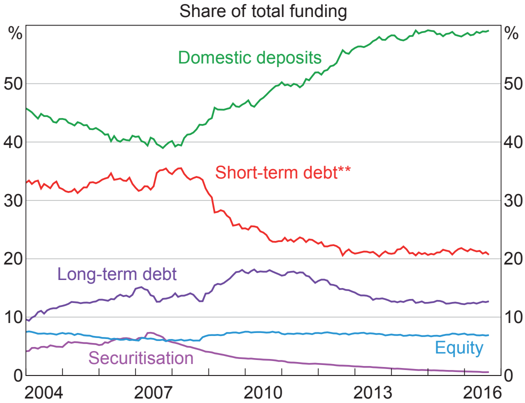
Financial Intermediaries

Growth in banks' balance sheets has continued to be a little slower than in 2015. The composition of banks' funding has remained fairly steady (Graph 4.4). Recent growth in liabilities has been driven by term deposits and long-term wholesale debt.

The introduction of the Net Stable Funding Ratio (NSFR) in January 2018 is influencing the composition of banks' balance sheets. The NSFR forms part of the Basel III liquidity reforms and provides an incentive for banks to fund their assets and off-balance sheet activities with more stable sources of funding such as retail deposits, term deposits, long-term debt and equity, while encouraging less reliance on short-term wholesale liabilities.

Following the May and August cash rate reductions, estimates of the major banks' debt funding costs have come down. Since the beginning of the year, these costs have declined by a little less than the cash rate, mainly reflecting less than complete pass-through of the cash rate reductions to term deposit rates (see below). Estimated funding costs are expected to fall further as the cost of new wholesale debt remains below the cost of outstanding debt (Graph 4.5).

Graph 4.4
Funding Composition of Banks in Australia*
Share of total funding

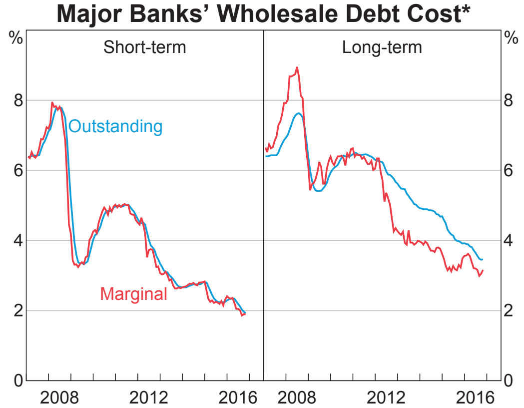


* Adjusted for movements in foreign exchange rates; tenor of debt is estimated on a residual maturity basis

** Includes deposits and intragroup funding from non-residents

Sources: APRA; RBA; Standard & Poor's

Graph 4.5
Major Banks' Wholesale Debt Cost*

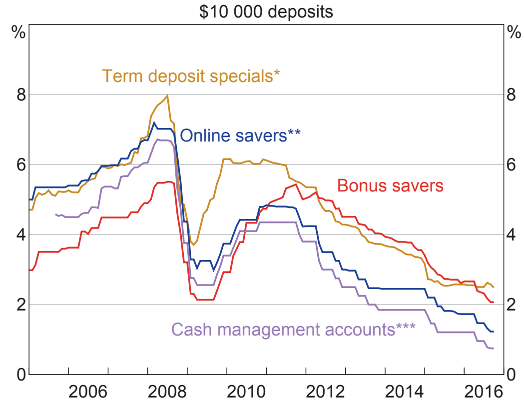


* RBA estimates; rates do not include interest rate hedges

Sources: Bloomberg; RBA

Competition for retail deposits, particularly term deposits, has increased over 2016 and banks expect this to continue over the next year, ahead of the introduction of the NSFR. The May and August cash rate reductions have been largely reflected in lower advertised rates for at-call deposits, while the major banks have only partially reduced term-deposit rates (Graph 4.6). In fact, following the August cash rate reduction the major banks increased rates on longer-dated term deposits, which comprise less than 2 per cent of total funding, although some of these increases have subsequently been reversed.

Graph 4.6
Major Banks' Deposit Rates
$10 000 deposits



* Average of 1–12, 24-, 36- and 60-month terms

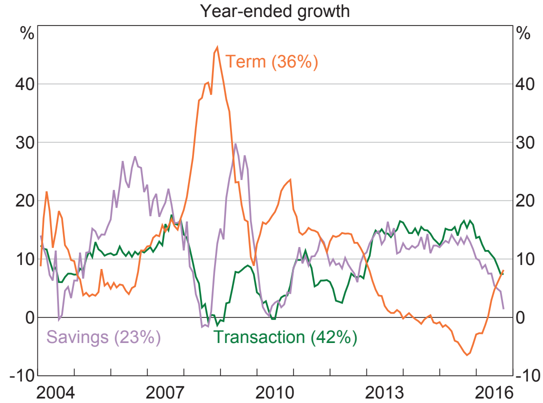
** Excludes temporary bonus rates

*** Deposits over $250 000

Sources: Canstar Cannex; RBA

The recent widening in the spread between term deposit rates and the cash rate follows a period of several years when term deposit rates were relatively low compared to interest rates on other funding sources, such as short-term wholesale funding and bonus saver accounts. Consistent with interest rates on term deposits becoming more attractive than other deposit types, stronger growth in term deposits has been observed more recently (Graph 4.7).

Graph 4.7
Deposits by Product Type*
Year-ended growth

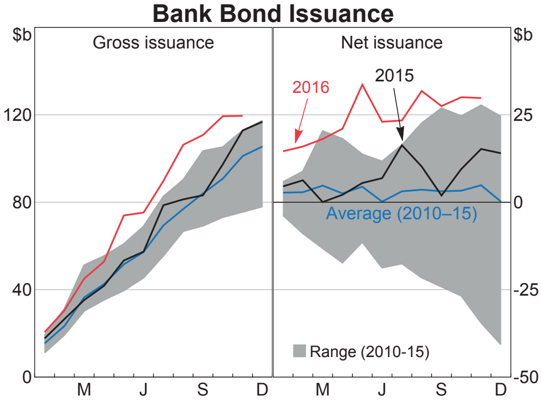


* Break-adjusted; not seasonally adjusted; excludes foreign currency, intra-group deposits and certificates of deposit; values in brackets represent share of AUD deposits

Sources: APRA; RBA

Australian banks have issued a large volume of bonds this year, with net bond issuance well above the average over the past few years (Graph 4.8). Some of this issuance is in advance of some large maturities over coming quarters. Banks are also responding to strong demand for longer-term paper by issuing more bonds at the 10-year tenor. This continues the trend seen over the past couple of years, and the average tenor of new bank bond issuance has increased from four years in 2014 to around five years now. Secondary market yields on major banks' bonds remain very low, while spreads to benchmark rates have narrowed since earlier in the year.

Graph 4.8
Bank Bond Issuance

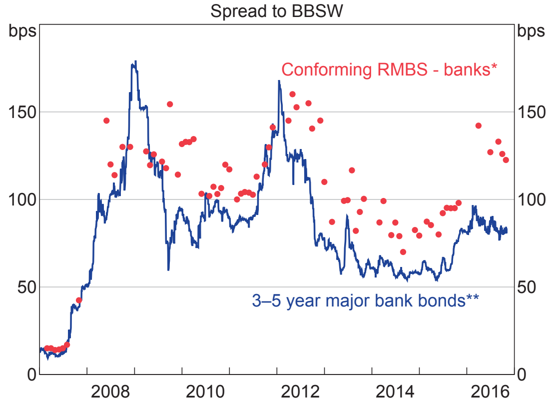


Source: RBA

Activity in the asset-backed securities (ABS) market has been below average in the year to October, owing mainly to a reduction in residential mortgage-backed securities (RMBS) issuance by the major banks. Other issuers, including non-bank originators and issuers of securities backed by automotive loans and leases, recorded low issuance early in the year, although their issuance has picked up in recent months. Primary market spreads to bank bills remain elevated, particularly relative to spreads on unsecured bank debt, although they have narrowed since their peak earlier in the year (Graph 4.9).

Hybrid issuance by Australian financial institutions has continued at a pace above that of recent years, with $17 billion issued so far this year. Recent deals

Graph 4.9
Bond Spreads
Spread to BBSW



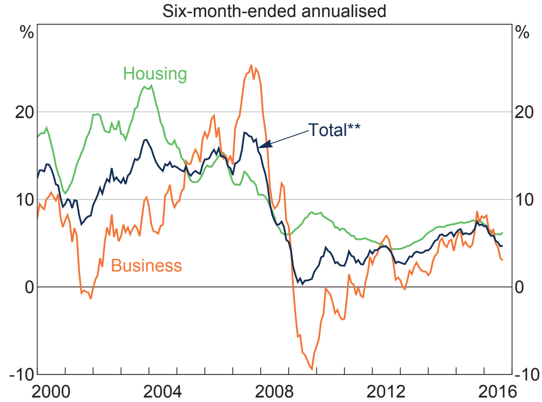
* Primary market pricing of AAA rated tranches
** Secondary market prices
Source: RBA

have included a Basel III-compliant Additional Tier 1 (AT1) hybrid by a major bank and Tier 2 issuance by a range of banks and insurance companies.

Financial Aggregates

Total credit growth has continued to slow in recent months (Graph 4.10). Growth in housing credit has eased relative to the pace seen in 2015, while business credit growth has softened further. Total credit has been growing at around the same pace as broad money (Table 4.1).

Graph 4.10
Credit Growth by Sector*
Six-month-ended annualised



* Seasonally adjusted and break-adjusted; including securitisation
** Includes housing, personal and business credit
Sources: ABS; APRA; RBA

Table 4.1: Financial Aggregates
Percentage change[(a)]

	Three-month ended		Year-ended
	June 2016	Sep 2016	Sep 2016
Total credit	1.1	1.2	5.4
– Housing	1.5	1.6	6.4
– Owner-occupier	1.6	1.6	7.3
– Investor	1.1	1.6	4.8
– Personal	–0.3	–0.5	–1.3
– Business	0.8	0.6	4.7
Broad money	1.1	1.3	5.8

(a) Growth rates are break adjusted and seasonally adjusted
Sources: APRA; RBA

Household Financing

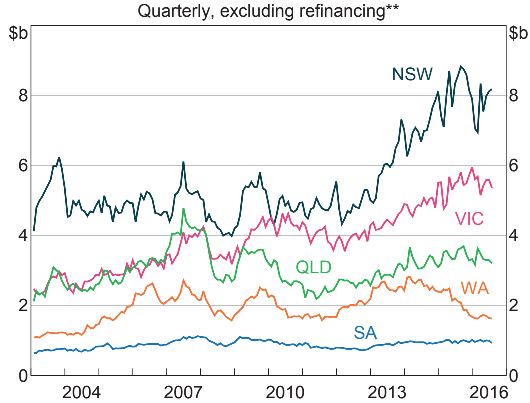
Housing credit growth has eased to an annualised pace of around 6 per cent. Growth in net housing debt is about 1 percentage point below growth in housing credit due to ongoing strong growth in deposits in mortgage offset accounts.

While the slowing in housing credit growth and loan approvals has been reasonably broad based, there remains some divergence in the pace of growth across states (Graph 4.11). The slowing in loan approvals has been particularly pronounced in Western Australia; while loan approvals in NSW have also eased over the past year, they continue at a pace noticeably above the national average.

Growth in credit advanced to investors has increased a little in recent months, consistent with a pick-up in investor housing loan approvals. In contrast, growth in credit advanced to owner-occupiers has eased a little recently. The current level of approvals is consistent with housing credit growth continuing at around its current pace (Graph 4.12).

The slowing in housing loan approvals over the past year is consistent with the decline in turnover in the housing market. It also reflects slower growth in average dwelling prices and a decrease in the average loan-to-valuation ratio. The latter follows the introduction of measures by the Australian Prudential Regulation Authority (APRA) to strengthen lending standards. Another factor that

Graph 4.11
Housing Loan Approvals by State*
Quarterly, excluding refinancing**

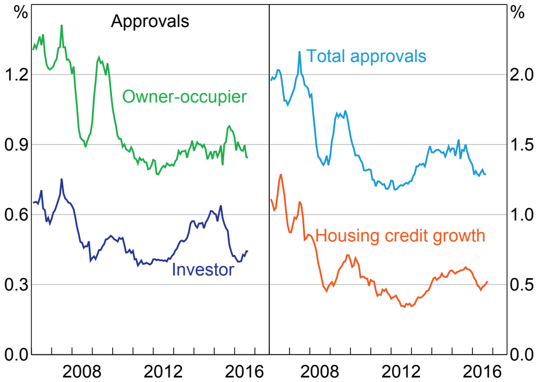


* Seasonally adjusted
** Investor refinancing is RBA estimate
Sources: ABS; APRA; RBA

may be contributing to the easing in housing credit growth over the past year is an increase in the share of off-the-plan purchases, which are yet to flow through to the demand for credit. These transactions do not involve a mortgage at the time the dwelling is purchased off the plan, but add to the stock of housing credit when a mortgage is provided to the purchaser upon completion of the dwelling.

Around half of the August cash rate reduction was passed through to most advertised housing lending rates. The average outstanding housing interest rate has fallen by around 35 basis points this year and is likely to decline a little further as maturing loans are replaced with loans on lower

Graph 4.12
Housing Loans*
Monthly; per cent of housing credit outstanding

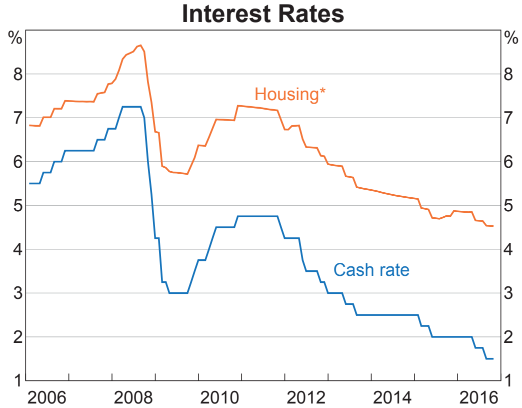


* Seasonally and break-adjusted; as share of housing credit; net of refinancing (investor refinancing is RBA estimate)

Sources: ABS; APRA; RBA

interest rates (Table 4.2; Graph 4.13). The lowest available variable interest rates are more than 50 basis points below the average outstanding interest rate and, reflecting the lower rates on offer, the level of refinancing activity remains relatively high. One bank has recently introduced a loan product with the interest rate margin fixed at 249 basis points above the cash rate.

Graph 4.13
Interest Rates



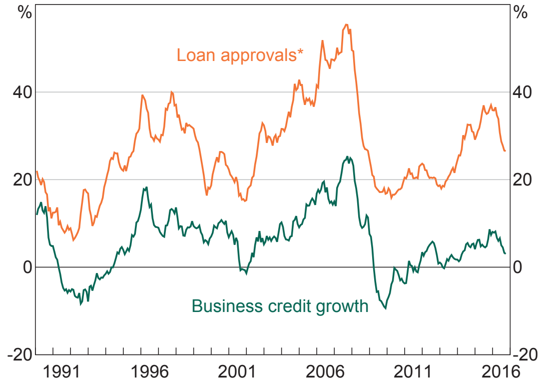
* Estimated outstanding rate

Sources: ABS; APRA; Perpetual; RBA

Business Financing

Business credit growth has slowed over the past six months, consistent with the fall in business loan approvals (Graph 4.14). The decline in credit growth

Graph 4.14
Business Loan Approvals and Credit
Six-month annualised



* Net of refinancing and reductions; as a share of business credit

Sources: ABS; APRA; RBA

has been largely driven by a slowdown in lending to larger businesses. Some banks have been reducing exposures to businesses in selected industries, such as mining and resources, and to sectors with higher non-performing loans. Business credit continues to grow at a stronger pace than a broader measure of business debt, reflecting very modest wholesale debt issuance and slow growth in cross-border syndicated lending.

The slowdown in business loan approvals has been reasonably broad based outside the residential property sector. This reflects some easing in loan approvals to sectors such as finance and insurance, manufacturing, mining and property, business and other services (Table 4.3). Business loan approvals for residential property development have remained at a high level, while loan approvals for commercial property have declined.

Business lending rates have declined by less than the cash rate this year. Major banks passed through a little over half of the August cash rate reduction to their business lending rates. Banks have tightened underwriting standards and increased their margins on some lending to large businesses over the past year (Graph 4.15).

Bond and hybrid issuance by Australian corporations remains relatively low this year (Graph 4.16). This

Table 4.2: Intermediaries' Lending Rates

	Interest rate	Change since July 2016	Change since December 2015
	Per cent	Basis points	Basis points
Housing loans			
– Standard variable rate[a][d]			
– Owner-occupier	5.26	–13	–36
– Investor	5.50	–13	–39
– Package variable rate[b][d]			
– Owner-occupier	4.51	–8	–31
– Investor	4.75	–8	–36
– Fixed rate[c][d]			
– Owner-occupier	4.02	–26	–41
– Investor	4.13	–35	–57
– Average outstanding rate[d]	4.53	–12	–33
Personal loans			
– Variable rate[e]	11.27	–10	1
Small business			
– Term loans variable rate[f]	6.39	–11	–21
– Overdraft variable rate[f]	7.27	–11	–21
– Fixed rate[c][f]	5.22	–4	–21
– Average outstanding rate[d]	5.34	–15	–29
Large business			
Average outstanding rate[d]	3.51	–20	–40

(a) Average of the major banks' standard variable rates
(b) Average of the major banks' discounted package rates on new, $250 000 full-doc loans
(c) Average of the major banks' 3-year fixed rates
(d) RBA estimates
(e) Weighted average of variable rate products
(f) Residentially secured, average of the major banks' advertised rates
Sources: ABS; APRA; Canstar Cannex; RBA

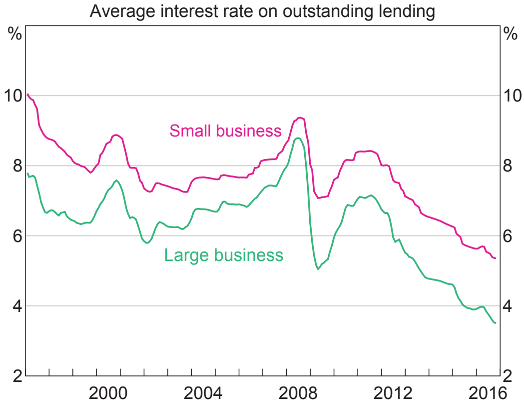
Table 4.3: Business Loan Approvals by Industry[a]

Percentage change

	Year-ended	Industry share of credit
	September quarter 2016	June 2016
Property, business and other services	–10	48
Finance and Insurance	–6	19
Wholesale and retail trade and transport	8	13
Agriculture, forestry and fishing	1	7
Manufacturing	–27	5
Mining	–60	4
Construction	10	4
Total	**–8**	**100**

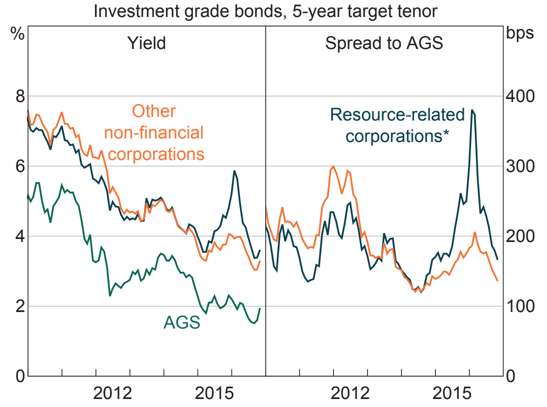
(a) Loan approvals by industry are gross of refinancing and reductions
Sources: APRA; RBA

Graph 4.15
Business Lending Rates*
Average interest rate on outstanding lending



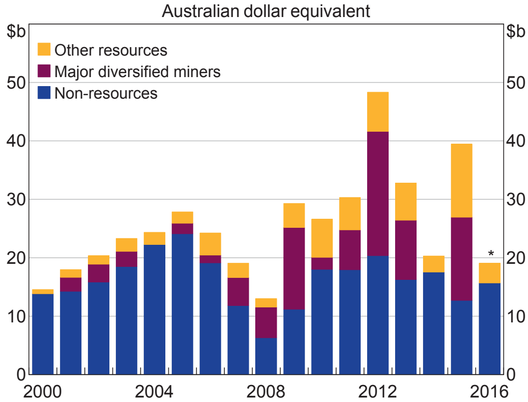
* RBA estimates
Sources: APRA; RBA

Graph 4.17
Australian Corporate Bond Pricing
Investment grade bonds, 5-year target tenor



* Includes Origin Energy
Sources: Bloomberg; RBA; S&P Capital IQ

Graph 4.16
Corporate Bond and Hybrid Issuance
Australian dollar equivalent



* Issuance is year to date
Source: RBA

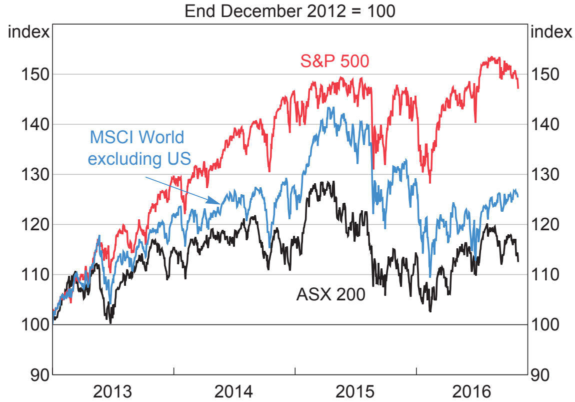
mostly reflects the continued absence of issuance by the major diversified miners. However, in recent months there has been an increase in issuance by other non-financial corporations, with a range of deals issued in the domestic bond market and offshore. Yields for both resource-related and other non-financial corporations' bonds are around historic lows; spreads to AGS have continued to tighten in recent months and have reversed the widening that occurred over the second half of 2015 (Graph 4.17).

Net equity raisings by non-financial corporations totalled around $9 billion in the September quarter. This includes a few large transactions by listed corporations to fund acquisitions, as well as initial public offerings by two real estate investment companies. Merger and acquisition activity by listed companies has totalled $41 billion this year, with activity concentrated in the industrials and consumer discretionary sectors.

Equity Markets

Australian equity prices have declined in recent months, after having risen earlier in the year (Graph 4.18).

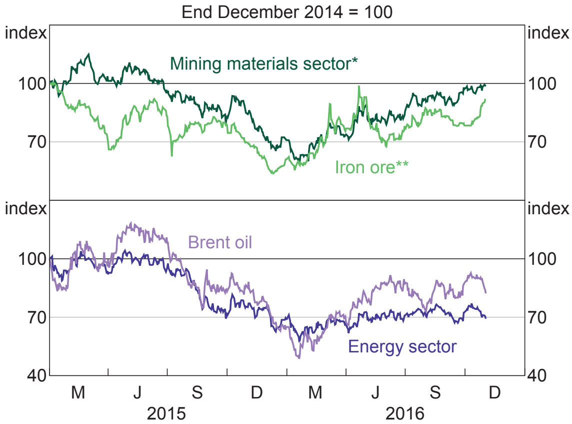
Graph 4.18
Share Price Indices
End December 2012 = 100



Source: Bloomberg

Resources share prices have risen notably since their trough at the beginning of 2016, with a particularly sharp recovery in the mining materials sector, reflecting an increase in a number of commodity prices (Graph 4.19).

Graph 4.19
Resources Share Prices and Commodity Prices



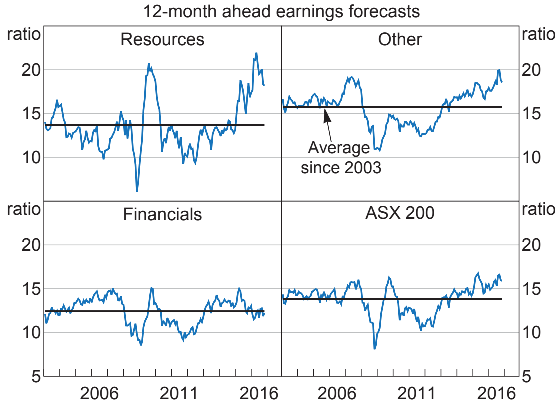
* Derived from resources sector share prices
** Qingdao import iron ore spot price
Sources: Bloomberg; RBA

Financial sector share prices have declined in recent months, and remain lower than at the beginning of the year. Share prices for companies outside the resources and financial sectors have declined more recently, with falls in healthcare, real estate, telecommunication and utilities stocks.

The valuations of Australian equities, as measured by forward price-earnings ratios, remain at or above their long-term averages (Graph 4.20). The high valuations in the resources sector partly reflect low earnings expectations, although analysts have revised up their earnings expectations since the beginning of the year alongside the increase in commodity prices.

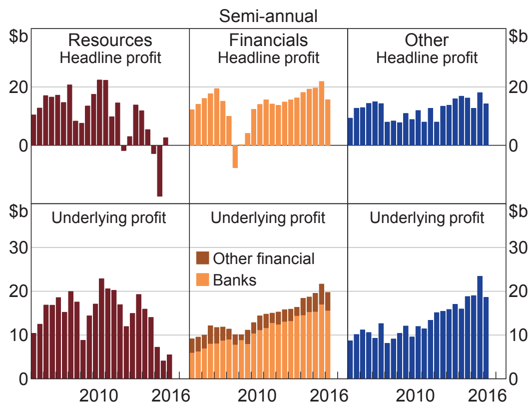
ASX 200 companies reported their results for the first half of 2016 in August. Aggregate headline profits rose by 5 per cent from the same period in 2015 (Graph 4.21). This was driven by the resources sector, as there were fewer sizeable asset write-downs by mining companies.

Graph 4.20
ASX 200 Forward Price-earnings Ratios



Source: Thomson Reuters

Graph 4.21
ASX 200 Profits



Sources: Bloomberg; Morningstar; RBA

Abstracting from the effect of these one-off items, aggregate underlying profits declined by 5 per cent in the first half of 2016 from the same period a year earlier. This decline was primarily due to a 16 per cent fall in resources sector profits over the year. Resources sector revenues declined substantially due to lower commodity prices than in the first half of 2015, and this more than offset the effects of cost cutting and reduced capital expenditure. However, resources sector profits increased relative to the second half of 2015, owing to the recovery in commodity prices.

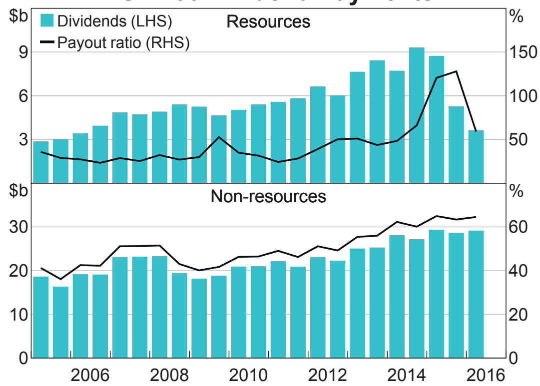
The underlying profits of financial companies were little changed in the first half of 2016 compared with the same period a year earlier. However, headline profits declined reflecting losses incurred by NAB associated with the divestment of its UK subsidiary Clydesdale. The major banks reported slightly higher underlying profits, with a modest increase in net interest income, reflecting continued growth in mortgage lending, only partly offset by higher funding costs. Net interest margins were broadly unchanged, though bad and doubtful debt charges increased for most banks. However, insurers' profits declined, largely reflecting weaker underwriting profits.

Underlying profits for the other sectors declined over the year. Heightened competition and further price deflation resulted in sizeable profit declines for the major supermarket chains. Both major supermarket chains also recognised sizeable asset impairments. In contrast, companies with exposure to residential housing construction, healthcare and tourism generally recorded higher profits.

Alongside a decline in aggregate underlying profits, distributions to shareholders fell over the year. This was largely due to significantly lower dividends paid by resource companies (Graph 4.22). The resources sector's payout ratio, as measured by the ratio of dividends to underlying profit, fell sharply to around 60 per cent, as the major diversified miners ended their 'progressive dividend policies' under which they had committed to maintain or increase dividend payments per share. The payout ratio in the non-resources sector was little changed.

In aggregate, listed corporations' balance sheets were little changed in the first half of 2016 compared to the second half of 2015. The value of resources sector assets fell due to write-downs (albeit fewer than there had been in the second half of 2015) and insufficient capital investment to offset depreciation.

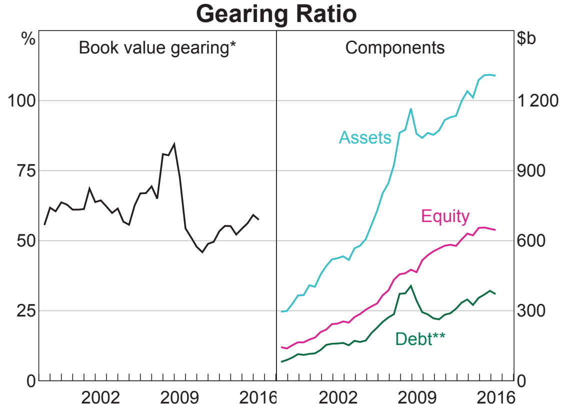
Graph 4.22
ASX 200 Dividend Payments



Sources: ASX; Morningstar; RBA

Working in the other direction, the value of assets grew in the healthcare, telecommunications and real estate sectors because of acquisitions and asset revaluations. The resources sector repaid debt during the first half of 2016, which contributed to a 4 per cent reduction in aggregate debt and a slight decline in the overall gearing ratio (the ratio of debt to equity; Graph 4.23). Nevertheless, the aggregate gearing ratio has been on an upward trend over recent years.

Graph 4.23
Listed Non-financial Corporations' Gearing Ratio



* Ratio of gross debt to equity; excludes foreign-domiciled companies

** Debt only includes short-term and long-term loans and bonds payable; not equivalent to total liabilities

Sources: Morningstar; RBA

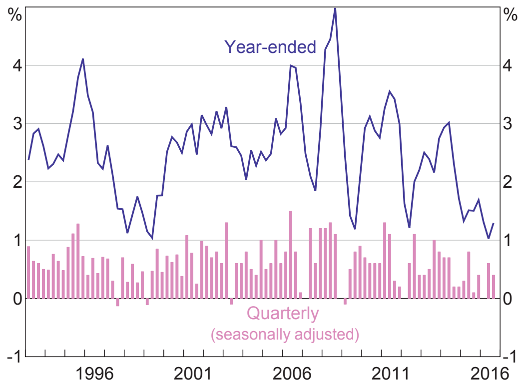
5. Price and Wage Developments

Inflation

A number of factors have contributed to continued low inflation. Spare capacity in the labour market is restraining wage growth. Heightened competition in a number of product markets is also contributing to low inflation outcomes. Furthermore, measures of inflation expectations have declined over the past year, which may be influencing price and wage-setting behaviour. Lower inflation expectations may, in part, reflect the effect of the large fall in oil prices and commodity prices more generally, over recent years. The adjustment to the decline in the terms of trade over recent years has also weighed on nominal growth – including via wages and margins – and the effect of the decline in the terms of trade is evident in the particularly low inflation outcomes in Perth. The depreciation of the exchange rate since 2013 has put upward pressure on tradable prices in recent years.

The September quarter inflation data were broadly in line with forecasts made at the time of the August *Statement*. Headline consumer price inflation increased a little in year-ended terms to 1.3 per cent (Graph 5.1; Table 5.1). Volatile items added to headline inflation in the quarter; higher fruit and vegetable prices caused by supply disruptions more than offset a decline in fuel prices. In year-ended terms, measures of underlying inflation have been around 1½ per cent over the past few quarters (Graph 5.2). Non-tradable inflation was little changed in the September quarter (Graph 5.3). It continues to be weighed down by low price growth of market services and rents.

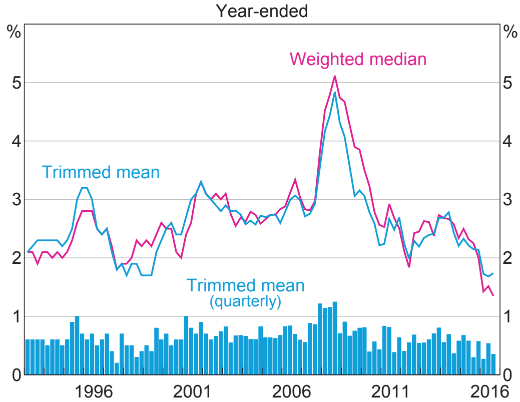
Graph 5.1
Consumer Price Inflation*



* Excludes interest charges prior to the September quarter 1998; adjusted for the tax changes of 1999–2000

Sources: ABS; RBA

Graph 5.2
Measures of Underlying Inflation*
Year-ended



* Excludes interest charges prior to the September quarter 1998; adjusted for the tax changes of 1999–2000

Sources: ABS; RBA

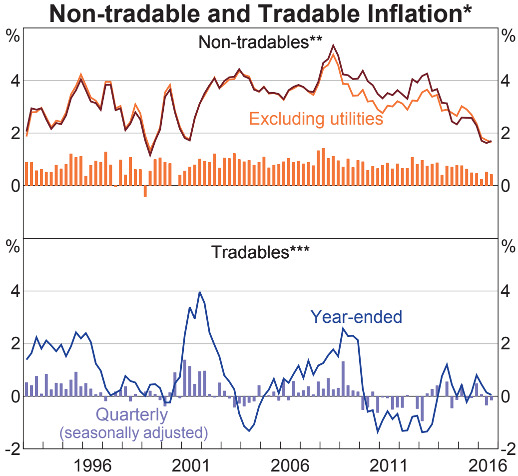
Prices for tradable items (excluding volatile items and tobacco) declined a little in the quarter and were unchanged over the year.

Table 5.1: Measures of Consumer Price Inflation
Per cent

	Quarterly[a]		Year-ended[b]	
	September quarter 2016	June quarter 2016	September quarter 2016	June quarter 2016
Consumer Price Index	0.7	0.4	1.3	1.0
Seasonally adjusted CPI	0.4	0.6	–	–
– Tradables	0.4	0.7	0.7	0.0
– Tradables (excl. volatile items and tobacco)[c]	–0.2	-0.3	0.0	0.1
– Non-tradables	0.4	0.5	1.7	1.6
Selected underlying measures				
Trimmed mean	0.4	0.5	1.7	1.7
Weighted median	0.3	0.5	1.3	1.5
CPI excl. volatile items[c]	0.3	0.4	1.7	1.6

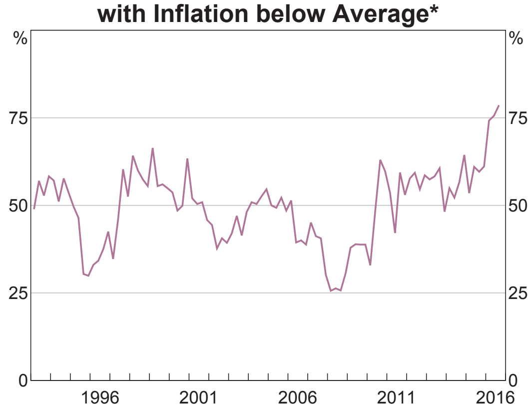
(a) Except for the headline CPI, quarterly changes are based on seasonally adjusted data; those not published by the ABS are calculated by the RBA using seasonal factors published by the ABS
(b) Year-ended changes are based on non-seasonally adjusted data, except for the trimmed mean and weighted median
(c) Volatile items are fruit, vegetables and automotive fuel
Sources: ABS; RBA

Graph 5.3
Non-tradable and Tradable Inflation*



* Adjusted for the tax changes of 1999–2000
** Excludes interest charges prior to the September quarter 1998 and deposit & loan facilities to June quarter 2011
*** Excludes volatile items (fruit, vegetables and automotive fuel) and tobacco
Sources: ABS; RBA

Graph 5.4
Share of CPI Items with Inflation below Average*

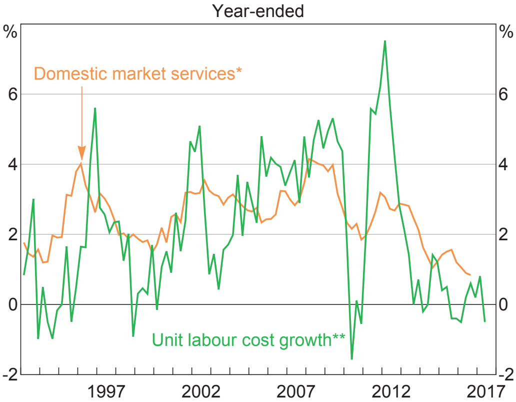


* Share of all CPI expenditure classes (by weight) with year-ended inflation below the item's average inflation rate (in most cases from 1993)
Sources: ABS; RBA

Low inflation has been broad based across the CPI components. Less than one-quarter of the components of the CPI basket have price growth above their long-run average (Graph 5.4). This includes tobacco, childcare and insurance. Tobacco has contributed around ⅓ percentage point to CPI inflation over the past year, largely due to increased excise taxes. Offsetting this, lower automotive fuel prices have subtracted around ⅓ percentage point from CPI inflation over the year. More recently, fuel prices have increased as global oil prices have moved higher, which if sustained will add a little to headline inflation.

Labour costs are an important determinant of inflation and there has been broad-based weakness in measures of labour cost growth (see below). The implications for inflation depend on how labour costs evolve relative to productivity. Unit labour costs have now been little changed for around five years, as low wage growth has been offset by productivity gains (Graph 5.5). Labour costs account for around one-half of final prices for market services; consistent with this, market services inflation is around its lowest level over the inflation-targeting period. In particular, prices for telecommunication equipment & services have fallen sharply over the past two years, reflecting increased competition and technological change in the industry.

Graph 5.5
Market Services Inflation
Year-ended



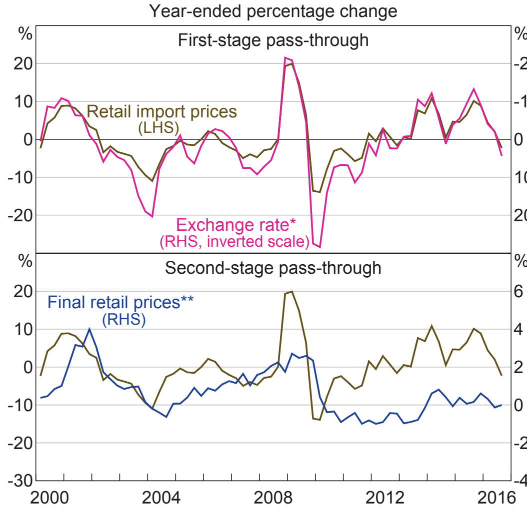
* Excludes interest charges prior to the September quarter 1998, deposit & loan facilities prior to the June quarter 2011, housing services and domestic travel; adjusted for the tax changes of 1999–2000

** Non-farm; moved forward by four quarters

Sources: ABS; RBA

In the retail sector, heightened competition has largely offset the effect of the higher cost of imported goods owing to the earlier depreciation of the exchange rate (Graph 5.6). These competitive pressures largely reflect the entry of overseas retailers.[1] In response to competitive pressures, firms have made efforts to reduce cost pressures along the supply chain, which is reflected in a pick-up over recent years in multifactor productivity growth in the wholesale and retail trade industries. Low wage

Graph 5.6
Retail Prices and the Exchange Rate
Year-ended percentage change



* Import-weighted index; quarter average

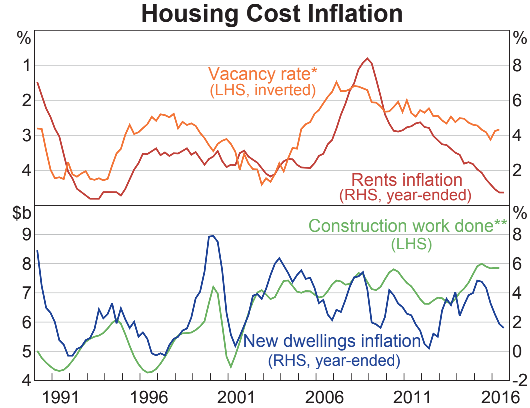
** Adjusted for the tax changes of 1999–2000

Sources: ABS; RBA

growth has also contributed to low retail sector inflation. The effect of heightened competitive pressures on inflation is expected to wane over time, although the point at which this occurs is uncertain.

Rent inflation is well below its inflation-targeting average (Graph 5.7). Rents have continued to fall in Perth, in line with weak economic activity and a marked slowdown in population growth. In other capital cities, an increase in the supply of housing, particularly apartments, has contributed to low rent

Graph 5.7
Housing Cost Inflation



* Excludes Adelaide from March quarter 2015

** Private new detached housing; chain volume reference year is 2013/14; quarterly

Sources: ABS; RBA; REIA

1 For a more detailed discussion, see Ballantyne A and S Langcake (2016), 'Why Has Retail Inflation Been So Low?', RBA *Bulletin*, June, pp 9–17.

inflation. Further increases in housing supply over coming years is expected to result in a protracted period of low rent inflation.

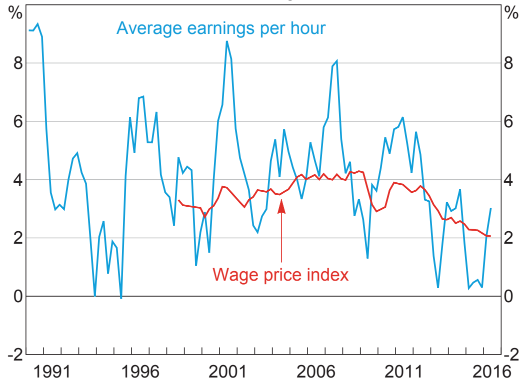
New dwelling price inflation has declined in year-ended terms since mid 2015. This slowing has been fairly broad based across all cities, which appears somewhat at odds with the continued solid level of activity in detached housing construction in Sydney and Melbourne. New dwelling costs are currently measured as the cost of constructing a new detached house and, as such, do not capture the cost of building an apartment where a lot of the activity has been concentrated. Material and labour cost growth remains subdued, although liaison has suggested that there are some pockets of wage pressures, such as for bricklayers, in the eastern states.[2] One potential explanation for subdued price pressures in the detached housing market is that heightened competition has meant builders have been focusing on reducing costs.

Utilities inflation is low relative to its inflation-targeting average. This largely reflects regulatory decisions, which have approved much smaller price rises than those that were granted in the late 2000s. Gas and water & sewerage inflation over the year is low relative to the inflation targeting period, and there were large price falls in the September quarter for a number of cities. In contrast, there were large increases in electricity prices in Sydney and Adelaide in the September quarter, driven in part by higher wholesale electricity costs; these wholesale cost pressures are expected to flow through to Melbourne retail electricity prices in the March quarter. Excluding utilities, administered price inflation is only a little below average levels.

Labour Costs

Wage growth appears to have stabilised, albeit at a low level (Graph 5.8). Growth in the private

Graph 5.8
Labour Costs
Year-ended growth



Source: ABS

sector wage price index (WPI) has been stable for six quarters at an annualised pace of around 2 per cent. Year-ended growth in the public sector WPI also appears to have stabilised around 2½ per cent since early 2015. Wage growth is lower than average across all industries and states and the dispersion in wage growth across industries is at its lowest level since the series began in the late 1990s. Broader measures of labour costs also appear to have stabilised or even picked up. Growth in average earnings per hour from the national accounts (AENA) – which also captures non-wage costs as well as the effect of promotions and changes in the composition of employment – has picked up in recent quarters. There has been little change to unit labour costs over recent years as growth in labour costs have been matched by productivity gains.

The weakness in wage growth over recent years reflects a number of factors, some specific to Australia and others also evident in other countries. First, there has been some spare capacity in the labour market putting downward pressure on wage growth. While it is difficult to be precise, it is estimated that the current unemployment rate is a bit over ½ percentage point higher than full employment. Furthermore, as has been the case in other advanced economies in recent years, it appears that there has been some change in the historical relationship between wage growth and

2 The wage price index (WPI) shows low wage inflation for the construction industry, however this measure also includes wages for workers in non-residential and engineering construction where activity has been weaker. The WPI also does not measure income growth for subcontractors, who make up a high share of workers in the detached housing industry. There is some tentative evidence that the income growth of these subcontractors has picked up.

measures of spare capacity. There are a range of plausible structural and cyclical explanations for this: increased labour market flexibility may have provided firms with greater scope to adjust wages in response to changes in nominal revenue growth; workers may be putting more emphasis on job security than higher wage claims as a result of the global financial crisis or structural change; and/or reduced workers' pricing power as a result of increased competitive pressure from globalisation and technology.[3] The extent to which these factors persist will determine how quickly wage growth picks up as labour market conditions improve.

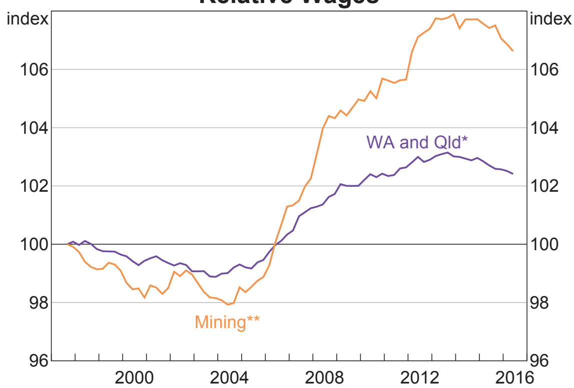
A second influence on wage setting has been low outcomes for headline inflation over the past couple of years and the associated decline in inflation expectations (at least over the short to medium term). Workers may have agreed to smaller wage increases given low actual and expected inflation.

A third factor weighing on wages growth has been increased efforts by firms to contain growth in labour costs. Over recent years, the sharp fall in the terms of trade, heightened competition (such as in the retail market) and spare productive capacity in product markets has weighed on firms' output prices.

Low wage growth in recent years has helped the economy adjust to the lower terms of trade. Combined with the depreciation of the nominal exchange rate since 2013, low growth in labour costs has improved Australia's international competitiveness. This is in contrast to the earlier period of sharply rising commodity prices and mining investment, during which Australia's unit labour cost growth outpaced that in many comparable countries, contributing to a decline in Australia's international competitiveness.

As the economy continues the transition away from mining-led activity, there are likely to be further adjustments to relative wages. Following a period of being above average, wage growth is currently lowest in industries and states that are more exposed to the end of the terms of trade and mining investment boom, and relative wages in these industries and states have started to turn lower (Graph 5.9). Liaison suggests that the movement of workers from higher-paying mining-related jobs to lower-paying jobs elsewhere in the economy is well advanced.

Graph 5.9
Relative Wages



* Wage Price Index in Western Australia and Queensland relative to the rest of Australia
** Wage Price Index in mining relative to all industries
Sources: ABS; RBA

Analysis of micro-level WPI data from the Australian Bureau of Statistics indicates there has been both a decline in the frequency of wage increases and in the average size of the increases in recent years.[4] In particular, the share of jobs that experienced wage growth in excess of 4 per cent has fallen sharply, largely reflecting a decline in large wage rises in mining-related jobs (Graph 5.10). Workers in around half of all jobs have received a wage increase of between 2–3 per cent. Only a small share of jobs has experienced a decline in wages, indicating downward nominal wage rigidity.

Inflation Expectations

Measures of inflation expectations have declined over the past year, consistent with low outcomes for CPI inflation, although consumers' short-term inflation expectations have been little changed

3 See Lowe, P (2016), 'Inflation and Monetary Policy', Address to Citi's 8th Annual Australian & New Zealand Investment Conference, Sydney, 18 October.

4 Further analysis of these data will be available in the September quarter 2016 Wage Price Index release (released 16 November 2016).

Graph 5.10
Wage Changes of Different Sizes
Share of jobs that experience a wage change

* Smoothed using a four-quarter trailing average

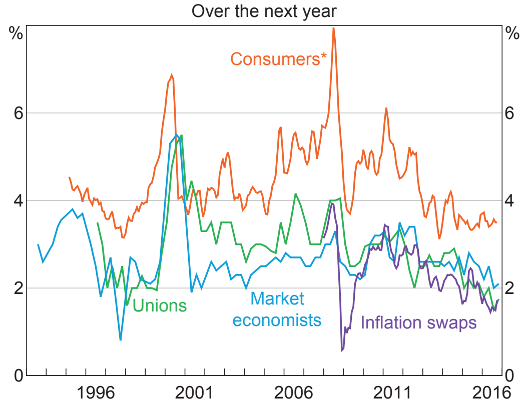
Sources: ABS; RBA

over the past year. More recently, one-year ahead inflation swaps have increased a little (Graph 5.11).

Survey-based measures of long-term inflation expectations remain around the mid-point of the inflation target (Graph 5.12). After falling sharply earlier in the year, financial market measures of inflation expectations have been more stable of late. Five-to-ten year inflation swaps, which capture expected average inflation over the period five-to-ten years ahead, have picked up modestly over the past few months, while inflation expectations based on 10-year bonds have been little changed since June at low levels. The 10-year indexed bond measure has declined over the past year by more than the five-to-ten year inflation swap measure. This is in part because it is an expected average inflation rate over the next 10 years and so is affected by expected low inflation in the near term.

The financial market measures of inflation expectations can be affected by factors other than changes in investors' perceptions of expected future inflation, such as changes in the premium that investors' demand to bear inflation risk. Changes in this premium affect both the inflation swaps and bond-based measure of inflation expectations. The bond-based measure is also affected by changes in the liquidity of inflation-indexed bonds

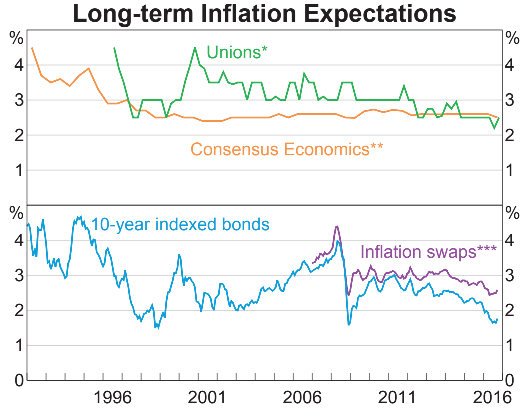
Graph 5.11
Short-term Inflation Expectations
Over the next year



* Three-month moving average of the trimmed mean of survey responses

Sources: Australian Council of Trade Unions; Bloomberg; Melbourne Institute of Applied Economic and Social Research; RBA; Workplace Research Centre

Graph 5.12
Long-term Inflation Expectations



* Average over the next five to ten years

** Average over six to ten years in the future

*** Five-to-ten-year forward

Sources: Australian Council of Trade Unions; Bloomberg; Consensus Economics; RBA; Workplace Research Centre

relative to nominal bonds. Regulatory changes since 2008 may have led to a relative deterioration in liquidity of inflation-indexed bonds; this would tend to raise the yield on indexed bonds and depress the implied inflation rate. Bank estimates suggest that much of the decline in the bond-based measure over the past 12 months is due to changes in the liquidity and inflation risk premia rather than long-term expectations of inflation, which have been relatively little changed.

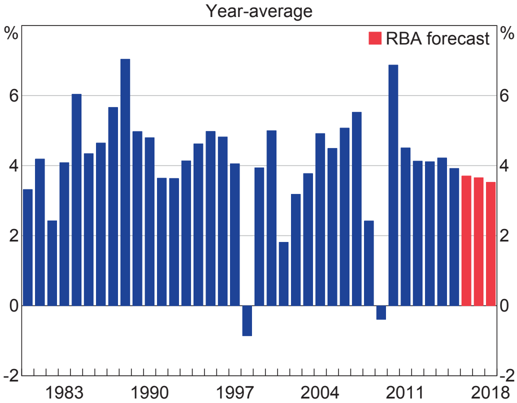
6. Economic Outlook

The International Economy

The assessment of the global economy is largely unchanged from the August *Statement*. GDP in Australia's major trading partners has grown at a little below its decade-average rate over the past year. Growth is expected to decline gradually over the next few years, driven by further easing of growth in China, in part because the strength in the Chinese property market is not expected to be sustained (Graph 6.1). Growth in east Asian economies (other than China and Japan) is expected to remain below average in the near term, before picking up gradually towards potential by mid 2018 as external demand conditions recover and accommodative monetary and fiscal policies continue to provide support.

GDP growth in the major advanced economies is expected to be a little above potential over the next couple of years, partly because monetary policy is expected to remain accommodative. However, potential growth rates in these economies are generally lower than their long-term average growth rates because of slower growth in the working-age population, productivity and investment, and, in some cases, the lingering effects of the global financial crisis.

Graph 6.1
Australia's Trading Partner Growth*
Year-average



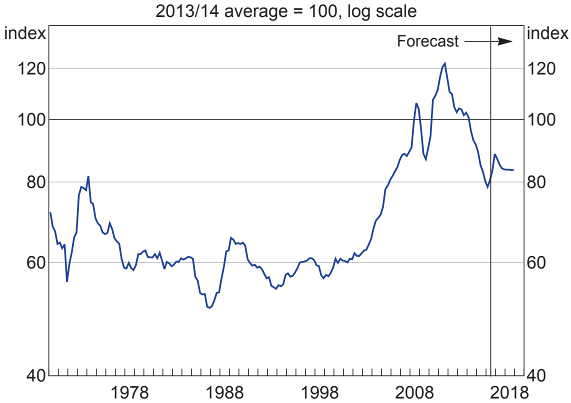
* Aggregated using total export shares
Sources: ABS; CEIC Data; RBA; Thomson Reuters

The United Kingdom's referendum vote to leave the European Union had little immediate impact on economic outcomes. Longer term, however, there are still risks to the UK economy depending on the nature of the UK's exit. The ongoing weakness of the European banking system also continues to pose downside risks. More broadly, political developments could have implications for global economic activity.

Global price and wage pressures have remained largely muted, but are expected to pick up as spare capacity in labour and product markets gradually declines. Labour productivity growth has been weak, which has contributed to above-average growth in unit labour costs in the United States and Japan. If weak productivity growth continues, there may be less spare capacity than indicated by current estimates and potentially a sharper pick-up in inflationary pressures, all else being equal. Furthermore, the increases in the prices of oil and other commodities since around the turn of the year have contributed to global inflation, following a period where commodity prices fell markedly. A sharper pick-up in global inflationary pressures than has been anticipated could lead to tighter-than-expected monetary policy in other economies and a depreciation of the Australian dollar. However, if inflation remains at low rates and below central bank targets for an extended period in some economies, this may lead to lower inflation expectations and therefore lower inflation than would be implied by the degree of spare capacity.

Australia's terms of trade increased in the June quarter for the first time in 2½ years, and look to have risen again in the September quarter, led by higher bulk commodity prices. The terms of trade are forecast to remain above the levels reached in early 2016 (Graph 6.2). The outlook for commodity prices, particularly coal prices, is more positive than previously thought, reflecting an improved outlook for Chinese steel production in the near term and cuts to the production of bulk commodities in China, although current levels of spot prices are not expected to be sustained.

Graph 6.2
Terms of Trade
2013/14 average = 100, log scale



Sources: ABS; RBA

Domestic Activity

The domestic forecasts are conditioned on a number of technical assumptions. The cash rate is assumed to move broadly in line with market pricing as at the time of writing. This assumption does not represent a commitment by the Reserve Bank Board to any particular path for policy. The exchange rate is assumed to remain at its current level over the forecast period (trade-weighted index (TWI) at 65 and A$1=US$0.77). The TWI is a little higher than the assumption underlying the forecasts in the August *Statement*. The forecasts are also based on the price of Brent crude oil being US$50 per barrel over the forecast period, which is 10 per cent higher than the assumption used in August and in line with futures pricing in the near term. The population aged over 15 years is still assumed to grow by 1.5 per cent over 2016 and by 1.6 per cent over 2017 and 2018, drawing on forecasts from the Department of Immigration and Border Protection.

The starting point for the forecasts is that the Australian economy grew at around central estimates of potential growth in 2015/16. Growth in the June quarter was moderate and much as expected, although stronger-than-expected public demand growth offset weaker consumption growth. Recent indicators are consistent with moderate growth in the September quarter.

In 2015/16, non-mining activity grew at a pace that was a little above average, supported by low interest rates and the ongoing effects of the earlier exchange rate depreciation. Growth was reasonably broad based. Growth in dwelling investment and public demand was strong and the contribution from household consumption for the year as a whole was around the decade average. Non-mining business investment grew modestly. Meanwhile, mining activity subtracted from GDP growth in 2015/16, as stronger-than-expected growth in resource exports was more than offset by a substantial decline in mining investment.

Overall, the forecasts for GDP growth are similar to those presented in the August *Statement*. Growth is expected to be around 2½–3½ per cent over the year to June 2017, and then increase to around 3–4 per cent over the year to December 2018 (Table 6.1).

Low interest rates and gains to employment and wealth are expected to continue to support household demand. Consumption growth is projected to increase gradually over the forecast period. Expectations for longer-term growth in household consumption have been lowered slightly relative to the period prior to the global financial

Table 6.1: Output Growth and Inflation Forecasts[(a)]
Per cent

	Year-ended					
	Jun 2016	Dec 2016	Jun 2017	Dec 2017	Jun 2018	Dec 2018
GDP growth	3.3	2½–3½	2½–3½	2½–3½	2½–3½	3–4
CPI inflation	1.0	1½	1½–2½	1½–2½	1½–2½	1½–2½
Underlying inflation	1½	1½	1½–2½	1½–2½	1½–2½	1½–2½
	Year-average					
	2015/16	2016	2016/17	2017	2017/18	2018
GDP growth	2.8	2½–3½	2½–3½	2½–3½	2½–3½	2½–3½

(a) Technical assumptions include A$=US$0.77, TWI at 65 and Brent crude oil price at US$50 per barrel; shaded regions are historical data

Sources: ABS; RBA

crisis, when growth was boosted by strong growth in income, rising labour force participation and rising debt and housing equity withdrawal. The effect on GDP of the downward revision to the forecasts for consumption growth has been offset by a downward revision to import growth. The forecasts for growth in consumption and disposable income now imply a slightly more gradual decline in the household saving ratio than had been projected in the August *Statement*. How households decide to consume and save out of their income in the future remains a key source of uncertainty in the forecasts.

The already substantial amount of residential construction work in the pipeline increased in the June quarter and building approvals in the September quarter are consistent with further increases. Accordingly, the forecast for dwelling investment has been revised up slightly. Dwelling investment is expected to grow for the next year or so, although at a gradually diminishing rate.

The forecasts for growth in public demand are little changed. Solid growth in public demand is expected over the forecast period, consistent with state and federal government budgets, which together imply ongoing growth in public investment.

The outlook for the level of resource exports is lower than previously expected. The liquefied natural gas (LNG) export profile has been revised lower, reflecting more conservative assumptions about the production capacity of the LNG sector, although Australia's LNG exports are expected to continue growing strongly for some time. Coking coal exports are expected to be slightly higher, supported by the improvement in coking coal prices, while thermal coal export volumes are forecast to remain broadly unchanged. The scope for substantial growth in coal exports appears to be limited, as a large number of producers are already operating at close to capacity and are unlikely to undertake new investment given the widely held expectation that prices will decline somewhat in the period ahead.

More generally, the depreciation of the Australian dollar over the past few years is assisting domestic producers of tradable items and service exports are forecast to continue growing at a robust pace for a time.

Mining investment is still expected to continue to fall over the forecast period, as large resource-related projects are completed and few new projects are expected to commence. However, the largest subtraction of mining investment from GDP growth looks to have already occurred. The outlook for non-mining business investment is subdued in the near term, consistent with the ABS capital expenditure survey of firms' investment intentions and the downward trend in non-residential building work yet to be done. However, non-residential building approvals have picked up of late. Non-mining business investment appears to be growing in New South Wales and Victoria, aided by low interest rates and the depreciation of the Australian dollar over the past few years. Moreover, survey measures of capacity utilisation have been increasing over the past couple of years and are currently above their long-term averages.

Labour market outcomes over recent months have prompted a downward revision to the forecasts for employment growth. Leading indicators such as job advertisements and job vacancies also point to more modest growth in employment over the next six months than earlier envisaged. The participation rate is expected to remain around current levels, which is somewhat lower than the profile underlying the forecasts in August.

The combination of these changes means that there has been little change to the forecast for the unemployment rate, which is expected to edge lower over the forecast period. This implies that there is likely to be a degree of spare capacity in the labour market for some time.

Inflation

The September quarter underlying inflation outcome was broadly in line with expectations at the time of the August *Statement*. As a result, there has been little change to the forecast for underlying inflation; it is expected to remain at around 1½ per cent over 2016 and to pick up to around 1½–2½ per cent by the end of the forecast period. There has been some upward revision to the forecast for headline inflation given the legislated rise in the tobacco excise, which is expected to add about 0.4 percentage points to headline inflation in 2017 and 0.3 percentage points in 2018. Headline inflation is expected to pick up to around 1½–2½ per cent by early 2017 and to remain in that range over the rest of the forecast period.

Wage growth appears to have stabilised, although at low levels. Liaison suggests that private sector wage growth is likely to remain broadly stable in the year ahead and that the risks of further declines in growth have diminished somewhat. Growth in the wage price index (WPI) is expected to pick up gradually as labour market conditions improve and the effect of the large decline in the terms of trade on firms' output prices wanes. However, growth in the WPI is expected to remain low as it is anticipated that there will continue to be spare capacity in the labour market over the next few years. Indeed, liaison suggests that there is not strong 'pent-up' demand for larger wage increases, following below-average increases in recent years.

Broader measures of labour costs, such as average earnings per hour from the national accounts (AENA) – which include both non-wage costs (such as allowances) and any effect on labour costs from changes in the composition of employment – are also expected to pick up. Growth in AENA has increased in recent quarters but had been generally weaker than growth in the WPI over recent years, reflecting cyclical weakness in non-wage costs arising from spare capacity in the labour market and workers moving from high-paying mining jobs to similar types of work at lower levels of pay. Both of these factors are expected to wane over the next few years, so AENA is expected to grow at a faster pace than the WPI towards the end of the forecast period.

The effect of these wage developments on firms' costs and, hence, inflation will depend on how labour costs evolve relative to labour productivity. Unit labour costs have been low for a number of years because wage growth has been matched by growth in productivity. Productivity growth has picked up over the past couple of quarters, but it is projected to settle at a bit below its average rate over the inflation-targeting period. Growth in unit labour costs is expected to rise gradually. As labour costs constitute a sizeable share of the inputs to non-tradables components of the CPI, such as market services, the pick-up in unit labour costs is expected to lead to an increase in non-tradables inflation.

The decline in spare capacity in various product markets is also expected to lead to a gradual pick-up in inflationary pressures. For example, the effects of heightened retail competition on food and consumer durable prices are expected to diminish, although only gradually. However, some product markets are likely to experience surplus capacity for some time. In particular, large additions to housing supply are expected to keep rent inflation low over the next few years.

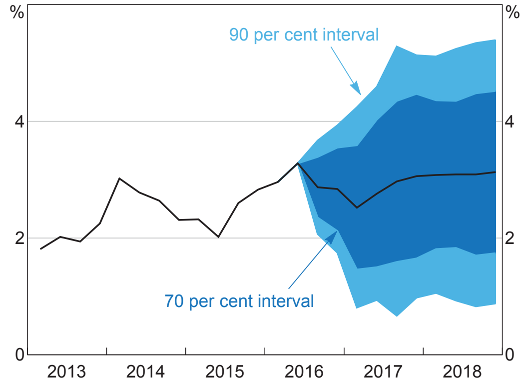
While estimates of the timing and degree of the pass-through of the exchange rate depreciation to final prices are imprecise, it is likely that the boost to the prices of tradables items from the large depreciation since 2013 has largely run its course. The recent increase in prices of commodities, in particular oil, is expected to contribute to inflationary pressures in the period ahead, following a period where fuel prices have subtracted from headline inflation.

Key Uncertainties

The forecasts are based on a range of assumptions about the evolution of some variables, such as the exchange rate and the cash rate, and judgements about how developments in one part of the economy will affect others. One way of demonstrating the uncertainty surrounding the central forecasts is to present confidence intervals based on historical forecast errors (Graph 6.3; Graph 6.4; Graph 6.5).

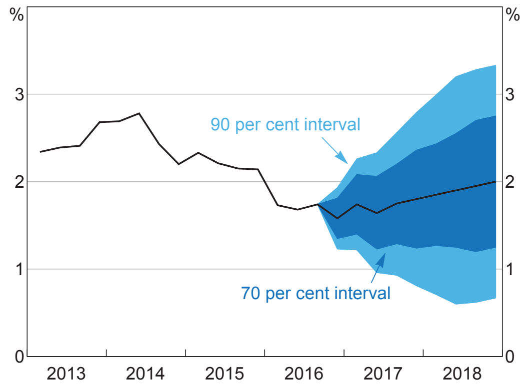
It is also worth considering the consequences that different assumptions and judgements might have on the forecasts and the possibility of events occurring that are not part of the central forecast. A key source of uncertainty for the forecasts continues to be the outlook for growth in the Chinese economy and its implications for commodity prices, Australia's exports and the terms of trade. Higher commodity prices, particularly for oil, are likely to contribute to global inflationary pressures, which could affect the path of monetary policies over the forecast period. This, in turn, could affect financial market prices, particularly exchange rates, which are assumed to be constant in the forecasts. As has been the case for some time, geopolitical risks

Graph 6.3
GDP Growth Forecast*
Year-ended



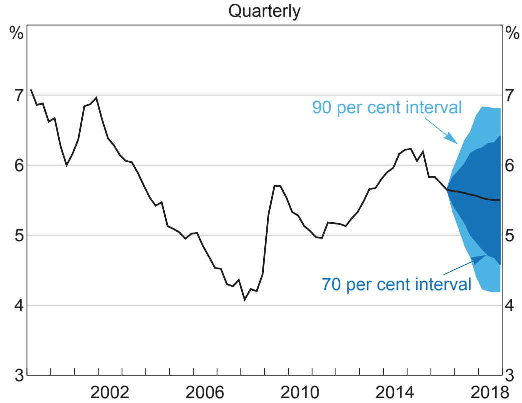
* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

Graph 6.4
Trimmed Mean Inflation Forecast*
Year-ended



* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

Graph 6.5
Unemployment Rate Forecast*
Quarterly



* Confidence intervals reflect RBA forecast errors since 1993
Sources: ABS; RBA

and global financial stability risks could also affect global growth and financial market prices, should they materialise. Domestically, there is considerable uncertainty about the momentum in the labour market, the extent to which household income and consumption growth will pick up over the next few years and the outlook for the housing market. All these sources of domestic uncertainty present risks to the outlook for activity and inflation.

The Chinese economy, commodity prices and Australia's terms of trade

The outlook for the Chinese economy remains a key source of uncertainty for the outlook for commodity prices, Australia's exports and the terms of trade. One aspect of that uncertainty is the high and rising level of debt, particularly within the corporate sector. Also, the longevity of the current strength in the property sector and the associated demand for upstream manufactured items is hard to predict. A number of local government authorities have responded to sharp rises in property prices by introducing a range of measures, including higher minimum downpayments and direct restrictions on house purchases in some locations. Although to date these initiatives have not stopped the upward trend in housing price growth, it is likely that continued efforts will eventually dampen residential investment and, hence, the demand for steel. The forecasts for iron ore and coking coal demand are predicated on a profile for Chinese steel production that increases a little further from current levels before gradually declining. Furthermore, it is not clear whether the Chinese authorities will continue to enforce policies that have contributed to lower Chinese production of iron ore and coal, given the sharp run-up in prices of bulk commodities, particularly for coal.

There is also uncertainty about how the change in the profile for the terms of trade will affect the domestic economy. The increases in commodity prices are not expected to lead to a material change in mining investment over the forecast period, partly because some of the larger price increases are expected to be temporary. However, with the terms of trade no longer falling and expected to be relatively stable over the forecast period, and the drag on GDP growth from falling mining investment likely to wane, it is possible that nominal income growth, domestic demand growth and inflationary pressures will pick up more quickly than currently forecast.

Global inflationary pressures

Overall, the risks to global inflation appear to have become more balanced. The pick-up in oil and other commodity prices from their troughs around the beginning of 2016 is expected to contribute to global inflationary pressures. These effects have already contributed to a pick-up in producer price inflation, including in China and the United States. At the same time, growth in the major advanced economies is expected to reduce the extent of spare capacity in labour and product markets over the forecast period. Indeed, over the past month, at least some of the increase in US, German and UK sovereign 10-year bond yields can be attributed to an increase in longer-term inflation expectations. Financial market measures of long-term inflation expectations in Australia have also stabilised in recent months, after falling earlier in the year. However, there is uncertainty about the extent to which inflationary pressures will build, given the length of time that inflation has been below central banks' targets.

Momentum in the labour market

Indicators of Australian labour market conditions have been mixed. The decline in the unemployment rate over the past year has been larger than expected. However, the participation rate has retraced its earlier increases and the ABS measure of underemployment has remained relatively high, consistent with employment growth having been driven by part-time work. It is possible that the anticipated growth in the demand for labour will be accommodated by providing part-time workers with additional hours. This could see total hours of employment increase without a reduction in the unemployment rate. Furthermore, while the forecasts make some allowance for the fact that a sizeable contribution to GDP growth comes from LNG production over the next few years, it is possible that there will be less employment generated from GDP growth than envisaged. There is also considerable uncertainty around the projection for the participation rate. The expected improvement in demand could encourage people to enter the labour force. However, it is possible that the participation rate could decline further owing to the ageing of the population, in which case the unemployment rate – and the extent of spare labour market capacity – could fall further than forecast.

Household consumption and saving

Household consumption growth has been supported by low interest rates, rising employment and gains to household income and wealth. The household saving ratio has declined, continuing the trend of recent years. The forecasts assume that households will sustain consumption growth in a period of moderate income growth by reducing their rate of saving gradually over the coming year. However, there is uncertainty about households' consumption and savings decisions.

Households' views about the outlook for the growth of their income and wealth are relevant to those decisions, as are any liquidity or credit constraints that households might face and their expectations about interest rates. In the 1990s and early 2000s, household income growth was relatively strong and this was expected to continue. Additionally, households experienced increased access to credit as a result of financial deregulation and the decline in nominal interest rates as a result of disinflation. These factors allowed households to reduce their saving and increase their leverage over a lengthy period of time. Over the second half of the 2000s, the saving ratio increased significantly, partly in response to the uncertainty created by the global financial crisis as well as strong household income growth associated with the mining investment boom, and has declined only gradually over recent years.

If households become more confident about their future employment, income or wealth, then the saving ratio could fall by more than currently forecast and consumption growth would be stronger. However, the saving ratio may not decline if households come to believe that future income growth will be weak, particularly for those households servicing sizeable debts; if that occurs, consumption would be lower than forecast.

The housing market

Recent strength in dwelling investment, particularly the construction of higher-density dwellings, has played a role in supporting the rebalancing of economic activity away from the resources sector. Low interest rates and increases in housing prices have encouraged a substantial increase in the supply of apartments and the pipeline of residential work yet to be done has increased to historically high levels. While this pipeline should support growth in dwelling investment over the next year or so, the outlook for dwelling investment beyond this period is uncertain.

There is concern about the risk of an oversupply of apartments in specific geographical areas, such as inner-city areas of Melbourne and Brisbane. Outside Western Australia, the supply of housing has to date largely been absorbed by population growth. However, if growth in housing demand does not continue to keep pace with the scheduled large increases in supply, it would place downward pressure on housing prices and rents and increase the risk of off-the-plan apartment purchases failing to settle. If the broader housing market was to weaken substantially, consumption growth may be lower than currently expected in response to wealth and income effects. Consumer price inflation would also be affected as housing costs comprise a significant share of household expenditure.

A TIPS Valuation Framework

18 August 2006

Kodjo Apedjinou
212-526-6566
kapedjin@lehman.com

Priya Misra
212-526-6566
prmisra@lehman.com

Anshul Pradhan
212-526-6566
apradhan@lehman.com

EXECUTIVE SUMMARY

- Treasury Inflation Protected Securities (TIPS) offer investors near-complete protection against inflation risk because both their coupon and principal payments are adjusted for realized inflation.
- Investors in nominal Treasury bonds demand compensation not only for expected inflation but also for the uncertainty surrounding inflation expectations. We refer to this compensation as the inflation risk premium.
- We construct a TIPS spline to get constant maturity data series for par, spot, and forward TIPS rates and breakeven spreads.
- We estimate the convexity, the risk premium, and the liquidity premium priced into both TIPS and nominal Treasury bonds.
- Inflation expectations implied by the market can be deduced by comparing the yields of nominal Treasury bonds with the yields of similar-maturity TIPS. However, the difference in yields between nominal bonds and TIPS, known as the breakeven spread, needs to be adjusted for: the inflation risk premium; the difference in convexity value between nominal and TIPS; and the liquidity premium of nominal Treasuries.
- We illustrate new tools on LehmanLive for TIPS valuation.

TABLE OF CONTENTS

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THE U.S. TIPS MARKET

Market Basics

TIPS returns are adjusted for changes in NSA CPI-U

The U.S. Treasury started issuing inflation indexed securities in January 1997. Unlike regular nominal Treasury bonds, these Treasury Inflation Protected Securities (TIPS) offer investors near-complete protection against inflation risk. Indeed, both the semi-annual coupons and the principal payments of TIPS are adjusted for changes in the non-seasonally adjusted Consumer Price Index for All Urban Consumers (NSA CPI-U[1]), a measure of consumer price appreciation. In addition, if the inflation index at maturity is lower than the reference inflation index at issuance (i.e., in a deflationary environment), the investor is still entitled to the original par amount of the TIPS.

TIPS account for more than 12% of total amount outstanding of marketable Treasury coupon debt

The Treasury has issued a total of 22 TIPS since 1997 in various benchmark maturities: 5-year (three issues), 10-year (14 issues), 20-year (two issues), and until 2001, 30-year (three issues). With one TIPS maturing in July 2002, as of July 31, 2006, there are 21 TIPS available with a total amount outstanding of more than $370 billion, which represent more than 8% of the total amount of marketable Treasury debt and 12% of the total amount outstanding of marketable Treasury coupon debt. TIPS are auctioned in regular cycles of January, April, July, and October in the 5-, 10-, and 20-year maturities. Figure 1 shows the characteristics of all the TIPS issued by the Treasury. The time to maturity of the current TIPS ranges from less than six months (TIPS 3.375% of 1/07s) to about 26 years (TIPS 3.375% of 4/32s). For each TIPS, the inflation adjustment for coupon and principal payments is based on its reference CPI index value shown in Figure 1. Given the Treasury commitment to the TIPS program, as well as increased interest from investors, the liquidity of the TIPS market has increased significantly over time. For example, the average daily trading volume[2] for TIPS has increased from about $2 billion in 2002 to more than to $9 billion in 2005. Figure 1 also shows that the issuance size for TIPS has averaged about $17 billion per issue.

TIPS generally appeal to investors who need to hedge their investments against inflation or who have liabilities that grow with inflation. Therefore, insurance companies, pension funds, and endowments are very active in the TIPS market. Along with nominal securities, TIPS also indicate market inflation expectations; hence, leveraged and nominal benchmarked investors also invest in TIPS versus nominal Treasury bonds to take a view on future inflation.

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[1] CPI-U is released by the Bureau of Labor Statistics.
[2] The Bond Market Association.

BOX 1: TIPS Structure

The United States has been a relatively late entrant in the international indexed government bond market. For example, the United Kingdom has been issuing indexed bonds since 1981 and Canada since 1991. For the TIPS cash flow structure, the U.S. Treasury adopted the Canadian design. In the Canadian model (also called the capital or principal indexed structure), the coupon paid out is the fixed rate coupon multiplied by the compounded inflation from the date of issue. The principal paid out is the par amount or the par amount times the compounded inflation from the date of the issue, whichever is greater. Unlike the coupon, the payment of the principal is protected against deflation.

TIPS cash flows are indexed to the non-seasonally adjusted CPI-U, which is typically reported in the second or third week of the following month. For example, the December 2005 CPI-U index level is reported on January 18, 2006. To compute the inflation-adjusted coupon and principal payments, the CPI-U index is used with a two-month lag: The index value on the first of a given month is the CPI-U of the third preceding month. For example, the CPI-U index value for March 1, 2006, is the CPI-U of the month of December 2005 released on January 18, 2006. The index value for any given day in a month is the linear interpolation of the index value at the beginning of the month and the index value at the beginning of the following month. The index value for February 21, 2006, equals the linear interpolation of the index value of 197.6 on February 1, 2006, and of the index value of 196.8 on March 1, 2006. 197.6 is the CPI-U for the month of November 2005 released on December 15, 2005, and 196.8 is CPI-U for the month of December released on January 18, 2006.

$$CPI(Feb\ 21,\ 2006) = CPI(Feb\ 1,\ 2006) + \frac{20}{28}\{CPI(Mar\ 1,\ 2006) - CPI(Feb\ 1,\ 2006)\}$$

where 20 is the number of days between February 21, 2006 and February 1, 2006 and 28 is the number of days between March 1, 2006 and February 1, 2006. $CPI(Feb\ 1,\ 2006)$=197.0286.

At a coupon date, a bond with fixed coupon rate c and face value of 100 pays:

$$100 \times \frac{CPI(coupon\ date)}{CPI(dated\ date)} \times \frac{c}{2} \times \frac{Number\ of\ days\ accrued}{Actual\ number\ of\ days\ in\ coupon\ period}$$

And at maturity, the balloon principal payment is equal to:

$$Max\left\{100, 100 \times \frac{CPI(maturity\ date)}{CPI(dated\ date)}\right\} = 100 \times \frac{CPI(maturity\ date)}{CPI(dated\ date)} + Max\left\{0, 100 - 100 \times \frac{CPI(maturity\ date)}{CPI(dated\ date)}\right\}$$

The right-hand side of the above equation highlights more conspicuously the deflation put option embedded in TIPS.

The above description of the treatment of the cash flows of the TIPS will be clearer with an example. Let's consider the TIPS 3.375% of 1/07s. Suppose the quoted clean real price on February 17, 2006, for settlement on February 21 is $P = 101\text{–}17$. The accrued interest is equal: $AI(Jan\ 15,\ 2006,\ \ Feb\ 21,\ 2006) = \frac{37}{181} \times \frac{3.375\%}{2} \times 100$

Where 37 is the number of days between February 21, 2006, and the last coupon date of January 15, 2006, and 181 is the number of days between the next coupon date of July 15, 2006, and January 15, 2006. The full transaction price is:

$$(P + AI(Jan\ 15,\ 2006,\ \ Feb\ 21,\ 2006)) \times \frac{CPI(Feb\ 21,\ 2006)}{CPI(Jan\ 15,\ 1997)} = 126.6921$$

Where January 15, 1997, is the dated date or the reference date. For each bond, the index ratio $\frac{CPI(settlement\ \ date)}{CPI(dated\ \ date)}$ is published daily on the TIPS relative value report on LehmanLive. At each CPI-U release, the Treasury publishes these index ratios at http://www.publicdebt.treas.gov/of/ofhiscpi.htm.

Figure 1. The TIPS Universe of Securities

Securities	CUSIP	Series	Original Issue Date	Reference CPI Date	Reference CPI Value	Size ($bn)
TIPS 3.625% 15-Jul-02	9128273A8	5-Year	7/15/1997	7/15/1997	160.1548	16.8
TIPS 3.375% 15-Jan-07	9128272M3	10-Year	2/6/1997	1/15/1997	158.4355	15.8
TIPS 3.625% 15-Jan-08	9128273T7	10-Year	1/15/1998	1/15/1998	161.5548	16.8
TIPS 3.875% 15-Jan-09	9128274Y5	10-Year	1/15/1999	1/15/1999	164.0000	15.9
TIPS 4.250% 15-Jan-10	9128275W8	10-Year	1/18/2000	1/15/2000	168.2452	11.3
TIPS 0.875% 15-Apr-10	912828CZ1	5-Year	10/29/2004	10/29/2004	189.4903	28.0
TIPS 3.500% 15-Jan-11	9128276R8	10-Year	1/16/2001	1/15/2001	174.0452	11.0
TIPS 2.375% 15-Apr-11	912828FB1	5-Year	4/28/2006	4/15/2006	198.4867	11.0
TIPS 3.375% 15-Jan-12	9128277J5	10-Year	1/15/2002	1/15/2002	177.5645	6.0
TIPS 3.000% 15-Jul-12	912828AF7	10-Year	7/15/2002	7/15/2002	179.8000	23.0
TIPS 1.875% 15-Jul-13	912828BD1	10-Year	7/15/2003	7/15/2003	183.6645	20.0
TIPS 2.000% 15-Jan-14	912828BW9	10-Year	1/15/2004	1/15/2004	184.7742	21.0
TIPS 2.000% 15-Jul-14	912828CP3	10-Year	7/15/2004	7/15/2004	188.4968	19.0
TIPS 1.625% 15-Jan-15	912828DH0	10-Year	1/18/2005	1/15/2005	190.9452	19.0
TIPS 1.875% 15-Jul-15	912828EA4	10-Year	7/15/2005	7/15/2005	194.5097	17.0
TIPS 2.000% 15-Jan-16	912828ET3	10-Year	1/17/2006	1/15/2006	198.4774	17.0
TIPS 2.500% 15-Jul-16	912828FL9	10-Year	7/17/2006	7/15/2006	201.9516	10.6
TIPS 2.375% 15-Jan-25	912810FR4	20-Year	7/30/2004	7/15/2004	188.4968	28.0
TIPS 2.000% 15-Jan-26	912810FS2	20-Year	1/31/2006	1/15/2006	198.4774	20.0
TIPS 3.625% 15-Apr-28	912810FD5	30-Year	4/15/1998	4/15/1998	161.7400	16.8
TIPS 3.875% 15-Apr-29	912810FH6	30-Year	4/15/1999	4/15/1999	164.3933	19.7
TIPS 3.375% 15-Apr-32	912810FQ6	30-Year	10/15/2001	10/15/2001	177.5000	5.0

Source: The Bureau of Public Debt at http://www.publicdebt.treas.gov/of/ofaicqry.htm.

ANALYSIS OF BREAKEVENS

TIPS versus Nominal Treasuries

As noted above, compared with nominal Treasury bonds, TIPS payments increase with the NSA CPI-U. An investor holding a nominal Treasury bond instead of a TIPS must be compensated for future inflation. Therefore, the yield of a nominal Treasury bond embeds in it expectations of future inflation. To judge the performance of a TIPS versus a nominal Treasury of the same maturity, market participants would judge the expected path of future inflation versus what is priced into nominals and TIPS. Ex-post, an investor would be indifferent between a nominal Treasury and a TIPS if realized inflation turns out to be the same as the expected inflation priced into nominals. If the realized inflation is greater than the expected inflation, then TIPS would outperform nominal Treasuries and vice versa.

Breakeven rate contains market expectations of future inflation

The obvious question is how one infers the expected inflation from the yields of both TIPS and nominal Treasury bonds. To measure the expected inflation embedded in the nominal yield, market participants currently use the crude measure of the breakeven rate, which is defined as the spread between the nominal Treasury yield and the TIPS yield of roughly the same maturity. Figure 2 shows the 1-year nominal and TIPS forward rates and the corresponding breakeven rates for different maturities for the pricing date of August 4, 2006. In this report, we argue that inflation expectations alone cannot account for the difference between TIPS and nominal Treasury yields.

Extracting Inflation Expectations from Breakevens

In addition to inflation expectation, breakeven rate contains convexity difference, liquidity premium difference, and inflation risk premium

Before equating the breakeven rate to the expected inflation priced into the nominal yield, let us first decompose the yields into their different components. Our premise is that the TIPS (real) forward rate is composed of the expected future real rate, the real rate risk premium, and real convexity. Investors demand a real rate risk premium because of the possibility that the realized future real rate might be higher than expected. Convexity, because of the mathematical observation that a bond price is a convex function of bond yield, is valued by investors and thus puts downward pressure on yields, making the forward rate curve flatter and, in fact, downward sloping at some point on the term structure.[3] Similarly, the nominal forward rate contains the expected future real rate and future inflation, the real rate risk premium and inflation risk premium, and convexity adjustment for both the real rate and inflation. Finally, there is a difference in liquidity between TIPS and nominals. Figure 3 illustrates the components of the breakeven rate. To summarize, both the real and nominal interest rates are made of four components:

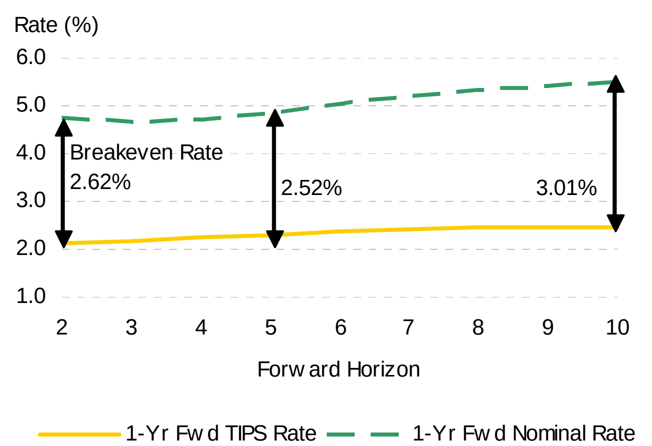
a. Convexity

b. Premium for bearing real and/or inflation risk

c. Liquidity premium

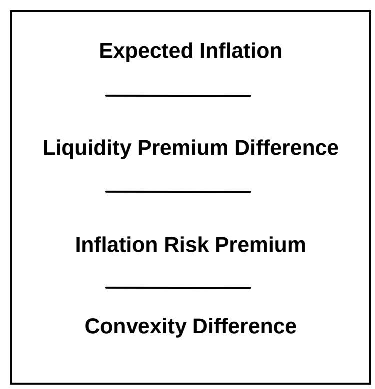
d. Rate expectations

Figure 2. 1-Year Nominal, TIPS, and Breakeven Forward Rates on August 4, 2006



Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

Figure 3. Components of Breakeven Rates



Breakeven rate is defined as the spread between the nominal and TIPS rate of the same maturity and contains inflation risk premium, convexity difference between TIPS and nominal, and liquidity premium difference in addition to the market expectation of inflation.
Source: Kerkhof, 2005, Inflation Derivatives Explained, Lehman Brothers

[3] *See the appendix for a further explanation for the value of convexity priced into bond yields.*

Figure 4. Yield Decomposition by the Four Components of Nominal and Real Rates

Rates	Expectation	Risk Premium	Convexity	Liquidity
Nominal Rate: y^N	E^N	λ^N	$-C^N$	$-L^N$
Real Rate: y^R	E^R	λ^R	$-C^R$	$-L^R$
Breakeven Spread: $y^N - y^R$	$E^N - E^R$	$\lambda^N - \lambda^R$	$-\left(C^N - C^R\right)$	$-\left(L^N - L^R\right)$

More formally, as illustrated in Figure 4, the nominal rate y^N can be decomposed as $y^N = E^N + \lambda^N - C^N - L^N$ where E^N is the expectation of the nominal rate, λ^N is the nominal (both real rate and inflation) risk premium, C^N is the convexity priced into the nominal rate, and L^N is the liquidity premium embedded in the nominal rate. A similar decomposition holds for the real rate y^R. These two decompositions imply that the breakeven rate is $\left(E^N - E^R\right) + \left(\lambda^N - \lambda^R\right) - \left(C^N - C^R\right) - \left(L^N - L^R\right)$. Unless the convexity difference, the liquidity premium difference, and the inflation risk premium demanded by investors are zero or offset each other, the breakeven spread or the simple difference between the TIPS rate and the nominal rate is not a pure measure for market inflation expectations. To get a more precise estimation of the magnitude of the market inflation expectations, we need to estimate and then adjust for the different components of nominal and real rates.

Convexity of TIPS and Nominal Rates

Convexity arises because of the uncertainty surrounding interest rate forecasts

The value of convexity in interest rates, due to the fact that a bond price is a convex function of bond yield, arises because of the uncertainty surrounding interest rate forecasts. The value of convexity is equal to the difference between the value of interest rates in the absence of uncertainty about rate expectations and interest rates when uncertainty is accounted for. Convexity is an increasing function of this uncertainty. To estimate the convexity components in both nominal and TIPS rates, we first need to estimate the volatilities and the parameters of the processes driving interest rates. For each of the set of constant maturity nominal rates and constant maturity TIPS rates gathered through a spline method, we calibrate the levels and the historical volatilities of rates to a two-factor Vasicek model.[4] This exercise determines the parameters and the volatilities of the two factors driving the interest rates. Figure 5 reports the convexity values in basis points for select maturities for some forward rates. Given that the volatility of nominal rates is higher than the volatility of TIPS rates, we observe that the value of convexity in TIPS rates is less than in nominals.

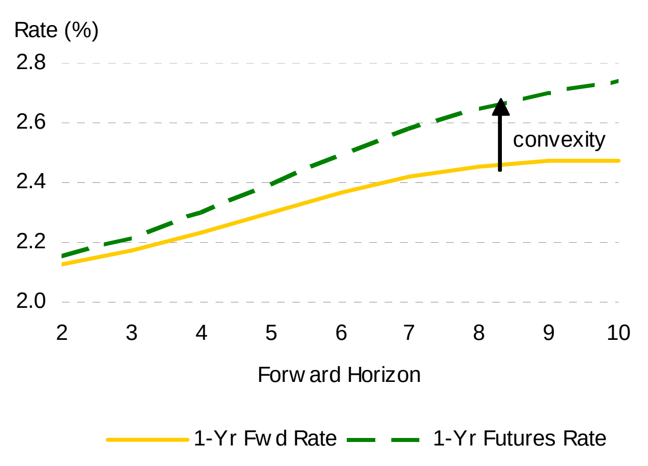
[4] *See the Appendix for the details of the two-factor Vasicek model and the calibration.*

Figure 5. Forward Par Rate Convexity Table (in Basis Points)

Term[5]	TIPS Convexity	Nominal Convexity
2x1	2	4
5x1	9	18
10x1	26	57
5x5	16	31
5x3	12	24
2x3	4	8

The convexity values are the components of rates that are due to the fact that bond prices are convex function of bond yields and increase with the volatilities of rates. Synthetic futures rates are obtained after adjusting forward rates for convexity.
Source: LehmanLive

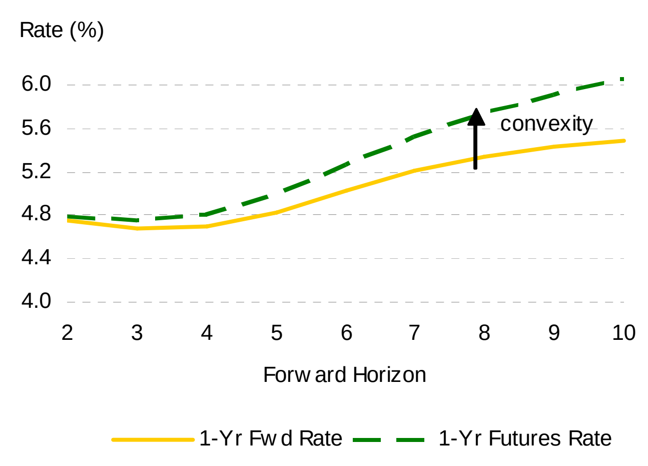
Figure 6a. Convexity Adjusted 1-Year TIPS Forward Par Rates for August 4, 2006



Synthetic TIPS futures par rates are the convexity adjusted TIPS forward rates.

Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

Figure 6b. Convexity Adjusted 1-Year Nominal Forward Par Rates for August 4, 2006



Synthetic nominal futures par rates are the convexity adjusted nominal forward rates

Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

Risk Premium

Ratio of Real Risk Premium to Nominal Risk Premium

Nominal rate risk premium is roughly three times real rate risk premium

To estimate the inflation risk premium, we first estimate the ratio of the total risk premium priced into nominal rates to the risk premium priced into TIPS rates. We assume that the expected 1-year futures rate is constant after a given number of years far enough into the future. For example, we will assume that the expected 1-year rate seven years forward is the same as the expected 1-year rate ten years forward. Therefore, after convexity-adjusting the 1-year forward rates of different maturities (i.e., seven and ten years) to get (synthetic) futures rates and assuming that the liquidity premium is constant across the term structure, the average annualized spread between 1-year futures rates with different maturities (i.e., seven and ten years) is taken as a measure of the risk premium priced into the rates. Effectively, we assume that the slope of the convexity adjusted forward rate curve (far out on the curve) is entirely due to risk premium, as

[5] *5x3 is the 3-year forward rate, 5 years forward.*

opposed to both short rate expectations and risk premium. Using our spline method, we obtained since January 2001 a time series of 1-year TIPS and nominal forward rates with maturity from 0.5 to 30 years. We compute the time series of the annualized spreads between the different forward rates (for example, the spread between the 10x1 and the 7x1 rates) after adjusting them for convexity to get synthetic future rates. Across the different maturity sectors, the median of the ratio of the annualized nominal term spread to TIPS term spread was found to be approximately 3 and relatively stable across time.

Nominal Risk Premium

Nominal rate risk premium estimated using long-dated Eurodollar futures rates

Using our finding in the previous section that the nominal risk premium is roughly three times the real rate risk premium, we can deduce the value of both the TIPS rate and the inflation rate risk premium given the risk premium priced into nominal rates. Following an argument similar to the one in the previous section, the risk premium priced into the nominal rate is approximated by the annualized spread between the back Eurodollar futures rates (contracts 32 to 40). We use Eurodollar futures rates instead of our synthetic futures rates because the former are traded instruments and, hence, are more reliable. Given this measure of risk premium, we can compute the total amount of risk premium priced into any spot, par, and forward rates for both the TIPS and the nominal markets. Figure 7 reports the risk premium values in basis points for select maturities for some forward rates, and Figure 8 reports the rate expectations obtained after adjusting the forward rates for convexity and risk premium.

Figure 7. Forward Par Rate Risk Premium Table (in Basis Points)

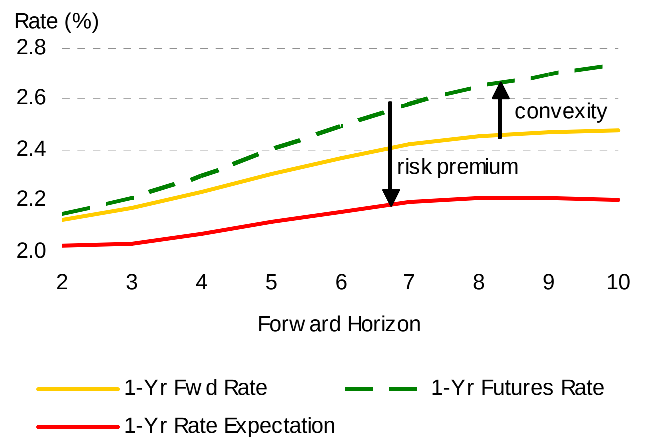
Term	TIPS Risk Premium	Nominal Risk Premium
2x1	13	38
5x1	28	85
10x1	54	162
5x5	38	114
5x3	33	100
2x3	18	53

The risk premium numbers are computed by taking the nominal risk premium to be roughly 15 bp/year and the risk premium priced into TIPS to be about 1/3 the risk premium priced into the nominal rate.
Source: LehmanLive

Liquidity Premium

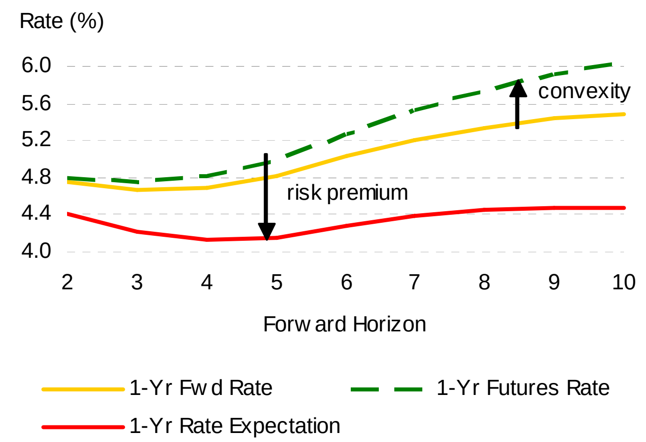
We estimate that nominal rates have some embedded liquidity premium because nominals are used as general collateral and trade special in the repo market. This occurs because of an established short base in nominals. While TIPS also enjoy the “Treasury collateral” premium, they have rarely traded special. We ascribe 15 bp as the average “specialness” of nominals over TIPS. Thus, we need to adjust breakeven spread for this specialness or liquidity premium differential.

Figure 8a. 1-Year TIPS Rate Expectations for August 4, 2006



1-year TIPS synthetic futures rates are the convexity adjusted 1-year TIPS forward rates and 1-year rate expectations are the risk premium adjusted 1-year TIPS synthetic futures rates.
Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

Figure 8b. 1-Year Nominal Rate Expectations for August 4, 2006

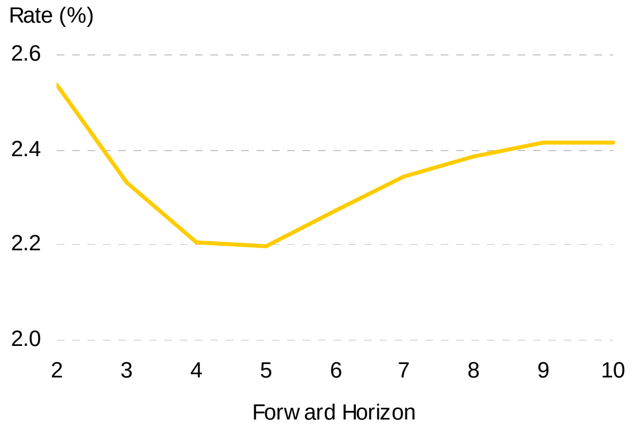


1-year nominal synthetic futures rates are the convexity adjusted 1-year nominal forward rates and 1-year rate expectations are the risk premium adjusted 1-year nominal synthetic futures rates.
Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

Inflation Expectations

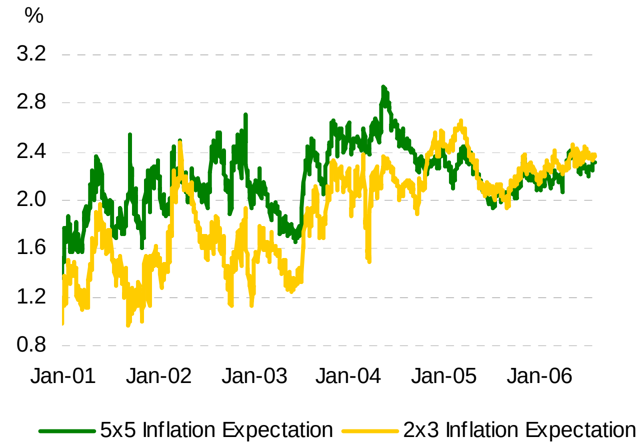
Given the decomposition of the breakeven rate in the previous sections, we reiterate that an adjustment for the convexity and liquidity difference between TIPS and nominal bonds, as well as an inflation risk premium, is required to translate breakeven spreads into inflation expectations. Figure 8 illustrates the yield decomposition (without the liquidity premium) for selected maturities for both TIPS and the nominal market using the constant value of convexity and risk premium reported in Figures 5 and 7, respectively. The expectation of 1-year TIPS rate increases with maturity up to the 7-year point and then flattens. After sloping down up to the 4-year point, the expectation curve of the 1-year nominal rates slopes up until it hits the 7-year point and then flattens. Figure 9 illustrates both the term structure (9a) and time series behavior (9b) of the market inflation expectations, which are the spreads between the expectations of TIPS and nominal rates in Figure 8 net of liquidity premium difference.

Figure 9a. Term Structure of 1-Year Forward Inflation Expectations for August 4, 2006



Inflation expectation is the breakeven rate adjusted for convexity and risk premium differences between TIPS and nominal rates.
Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

Figure 9b. Time Series of Inflation Expectations



Source: Lehman Live. Nominal and TIPS spline constant maturity data series.

CONCLUSION

Long-term inflation expectations are stable, as one would expect

Given the Fed's recent emphasis on inferring market inflation expectations from both the TIPS and the nominal markets, we propose a rigorous method of extracting market inflation expectations. We observe that, according to our new method, inflation expectations are relatively stable in the long end (Figure 9). The stability of long-term inflation expectations should not come as a surprise given the Fed's mandate to ensure long-term price stability. The past few months have seen an increase in the measure of the market's near-term inflation expectations, which is consistent with the recent pickup in realized core and headline inflation. Therefore, we believe the time series properties of market-implied inflation can be useful in addressing the market's changing views about inflation.

TOOLS AND RESOURCES AVAILABLE ON LEHMAN LIVE

In this section, we describe the various analytic tools for TIPS on LehmanLive.

U.S. Treasury Relative Value Report

The U.S. TIPS Relative Value Report can be accessed at *Fixed Income* → *Interest Rates* → *US Treasuries* → *Reports* → *U.S. Relative Value* → *TIPS*. It contains a description of the individual TIPS securities (coupon, maturity, series), standard pricing variables (market yield, price, index ratio, historical yield volatility), sensitivity variables (modified duration, convexity, beta between real and nominal yields), results of model fit using both TIPS and nominal fitted curves, benchmark Treasury security against which the breakeven is quoted, and breakevens (spot and forward). The TIPS Relative Value Report is updated daily based on the closing marks of the Lehman Brothers TIPS trading desk.

Figure 10. TIPS Relative Value Report on August 4, 2006

LEHMAN BROTHERS — U.S. Treasury Relative Value Report -- TIPS

Pricing: 08/04/06
Settle: 08/07/06

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					Index	Fitted Curve			Off-The-Run Breakeven			Quoted Breakeven				Yield Beta		Volatility	Mod	PVBP		
Coupon	Maturity	Series	Yield	Price	Ratio	Spread	Ave	ZScore	Spread	Ave	ZScore	Spot	1d Chg	09/01/06	1d Chg	30 Days	90 Days	Hist	Dur	$/MM	Cvx	Benchmark
3.375	01/15/07	10Y	2.900 (1.8)	100-06+	1.279	25.3	38.6	-1.05	239.6	274.5	1.10	226.1	6.2	228.6	7.2	130.8	100.3	95	0.43	55	0	T 3.125 01/31/07
3.625	01/15/08	10Y	2.380	101-237	1.254	0.7	-1.0	0.65	260.5	280.3	1.17	261.7	-0.4	263.9	-0.7	98.0	83.1	71	1.39	178	3	T 4.375 01/31/08
3.875	01/15/09	10Y	2.260	103-257	1.235	-2.4	-4.0	1.45	265.4	278.5	1.24	262.8	0.2	264.0	0.1	96.5	81.7	64	2.32	298	7	T 3.250 01/15/09
4.250	01/15/10	10Y	2.209	106-230	1.204	-3.5	-3.1	-0.97	264.9	272.8	1.07	263.9	0.3	264.7	0.2	102.9	84.5	64	3.20	412	12	T 3.625 01/15/10
0.875	04/15/10	5Y	2.259	95-040	1.069	2.6	2.6	-0.09	257.5	264.9	1.05	257.6	0.4	258.2	0.4	98.7	82.6	62	3.59	366	15	T 4.000 04/15/10
3.500	01/15/11	10Y	2.217 (0.4)	105-12+	1.164	-2.0	-1.1	-2.16	260.6	266.2	0.86	261.5	0.1	262.2	-0.0	99.4	83.0	62	4.10	504	20	T 4.250 01/15/11
2.375	04/15/11	5Y	2.249	100-176	1.021	1.8	2.9	-1.63	255.3	260.3	0.84	258.8	0.3	259.3	0.3	100.9	83.7	61	4.38	453	22	T 4.875 04/30/11
3.375	01/15/12	10Y	2.241 (0.2)	105-246	1.141	0.0	-0.4	0.71	256.4	262.2	0.90	257.5	-0.2	258.0	-0.2	97.5	81.8	60	4.96	600	28	T 4.875 02/15/12
3.000	07/15/12	10Y	2.247 (0.1)	104-051	1.127	0.2	0.3	-0.26	255.8	260.7	0.83	257.3	-0.9	257.7	-1.0	92.5	79.0	59	5.42	638	34	T 4.375 08/15/12
1.875	07/15/13	10Y	2.276	97-141	1.103	1.5	0.7	1.87	255.4	260.4	0.86	257.5	-0.4	258.1	-0.5	92.0	76.9	57	6.45	694	46	T 4.250 08/15/13
2.000	01/15/14	10Y	2.291	98-005	1.096	2.0	1.6	1.44	256.2	260.5	0.79	257.4	-0.9	257.8	-0.9	92.4	77.7	56	6.85	738	53	T 4.000 02/15/14
2.000	07/15/14	10Y	2.289	97-291	1.075	1.1	0.5	2.17	258.3	262.5	0.74	257.8	-0.5	258.3	-0.6	92.9	77.5	56	7.28	767	59	T 4.250 08/15/14
1.625	01/15/15	10Y	2.290	94-295	1.061	0.0	-0.5	2.17	261.0	264.9	0.71	258.6	-0.5	259.0	-0.5	95.0	78.1	55	7.80	787	67	T 4.000 02/15/15
1.875	07/15/15	10Y	2.290	96-212	1.041	-0.7	-1.3	1.76	263.1	266.8	0.67	259.3	-0.2	259.6	-0.3	94.3	78.4	55	8.15	822	74	T 4.250 08/15/15
2.000	01/15/16	10Y	2.297	97-156	1.021	-0.9	-0.4	-1.55	264.8	267.3	0.47	259.8	-0.1	260.2	-0.2	99.2	79.9	55	8.53	849	81	T 4.500 02/15/16
2.500	07/15/16	10Y	2.295	101-260	1.003	-1.8	-1.5	*-1.04*	267.0	265.0	*-1.21*	260.6	0.2	261.1	0.1	100.7	100.7	*52*	8.76	896	87	T 5.125 05/15/16
2.375	01/15/25	20Y	2.323	100-246	1.075	-0.3	-0.5	0.45	280.0	281.8	0.27	276.6	0.1	276.7	0.1	93.0	75.0	52	14.86	1612	259	T 7.625 02/15/25
2.000	01/15/26	20Y	2.321	95-002	1.021	0.7	0.3	0.73	280.0	281.7	0.25	276.2	0.2	276.3	0.2	94.3	75.0	52	15.89	1543	293	T 6.000 02/15/26
3.625	04/15/28	30Y	2.275	123-001	1.252	-0.7	-0.4	-0.84	280.9	281.3	0.07	279.5	0.5	279.7	0.5	95.0	75.0	52	15.60	2426	304	T 5.500 08/15/28
3.875	04/15/29	30Y	2.274	128-077	1.232	0.9	0.9	-0.02	279.3	279.6	0.05	279.0	0.6	279.2	0.6	95.1	75.1	52	15.93	2541	321	T 5.250 02/15/29
3.375	04/15/32	30Y	2.196	123-016	1.141	-0.3	-0.4	0.20	281.3	280.0	-0.22	285.2	0.8	285.4	0.7	97.1	75.5	52	17.94	2541	408	T 5.375 02/15/31

Source: Lehman Live.

TIPS Forward Calculator

TIPS forward prices and carries can be obtained on LehmanLive: Fixed Income → Interest Rates → Inflation Products → Bond Calculator. Keyword "Inflation" will also go to the Inflation Products page. After selecting a TIPS bond, the Bond Calculator page allows the user to input the price of the TIPS bond and the price of the corresponding benchmark Treasury, the forward date in number of days (as 25D for 25 days forward) or months (as 3M for three months forward), and the repo rate. For the TIPS 3.375% of 1/07s, priced on 08/04/2006, Figures 11 (forward date input is 0D—regular settlement date of 08/07/2006), 12 (forward date input is 25D—09/01/2006), and 13 (forward date input is 86D—11/01/2006) report the spot and forward breakeven spreads. Note that for the spot, the breakeven spread is 2.29%, for the forward date of 09/01/2006 the breakeven spread is 2.26%, and for the forward date of 11/01/2006, the breakeven spread is 0.63%.

As of the settlement date of 08/07/2006, the CPI index is known only up to 09/01/2006. Therefore, to compute the forward prices beyond 09/01/2006, for example to compute the forward price for 11/01/2006, we would need projections of the NSA CPI-U index for August and September.

BOX 2: TIPS Forward Calculator

Here, we show how to compute the forward price P^f at the forward date t_f of a TIPS bond of price P for settlement on settlement date s (next day settlement). If the forward date $t_f < t_c$ where t_c is the next coupon date, then the forward price is:

$$P^f = \frac{(P + AI(t_0, s))\frac{CPI(s)}{CPI(ref)}(1 + r\frac{d}{360}) - AI(t_0, t_f)\frac{CPI(t_f)}{CPI(ref)}}{\frac{CPI(t_f)}{CPI(ref)}}$$

where t_0 is the date of the last coupon, r is the repo rate, ref is the reference date or dated date of the TIPS bond, $AI(t_1, t_2)$ is the accrued interest from t_1 to t_2, d is the number of days between the forward date t_f and the settlement date s, $CPI(t)$ is the index value at date t. Similarly, if the forward date $t_f \geq t_c$ then the forward price is:

$$P^f = \frac{\left\{(P + AI(t_0, s))\frac{CPI(s)}{CPI(ref)}(1 + r\frac{d_1}{360}) - \left(\frac{c}{2}\right)\frac{CPI(t_c)}{CPI(ref)}\right\}(1 + r\frac{d_2}{360}) - AI(t_c, t_f)\frac{CPI(t_f)}{CPI(ref)}}{\frac{CPI(t_f)}{CPI(ref)}}$$

Where d_1 is the number of days between the next coupon date t_c and the settlement date s, d_2 is the number of days between the forward date t_f and the next coupon date t_c. Obviously, in the case the index value $CPI(t_f)$ is not yet known, a projected or assumed value is used.

Figure 11. TIPS 3.375% of 1/07s Spot Breakeven on August 4, 2006

Inflation Products (Keyword: Inflation)

Overview | Trade Tracker | Live Swaps | Swap Calculator | EUR | USD | GBP | JPY | Bond Calculator | Forecast

Inflation Bond Calculator: TIPS 3.375% 15-Jan-07 — TIPS 3.375% 15-Jan-07

Pricing

Trade Date	04-Aug-2006	Settle Date	07-Aug-2006
Closing Price	100.202	Index Ratio	1.27861

Trade Analysis — Cashflows

	Quantity	Price	Accrued	Dirty Price	Inv Amt
Buy TIPS 3.375% 15-Jan-07	100MM	100.20	0.21	128.389	128,388,986
Sell TBond 6.250% 15-Feb-07	108,410,274	100.539	2.99	103.526	112,232,689
PV01	1.0841			Net	-16,156,297

Yield & Sensitivites

	Mod Dur	Convexity	PV01	Yield	B/E Inf.
TIPS 3.375% 15-Jan-07	0.432	0.004	0.434	2.901	2.286
TBond 6.250% 15-Feb-07	0.494	0.005	0.512	5.187	

Forward Calculations & Carry — Inflation Forecasts

Term	Date	Real Yield	Breakeven	Yield Carry	B/E Carry	Repo (Inf)	Repo (Nom)
1M	07-Sep-2006	2.960	2.157	5.8	12.9	5.230	5.230
3M	07-Nov-2006	4.426	0.372	152.5	191.4	5.280	5.280
0D	07-Aug-2006	2.901	2.286	0.0	0.0	5.280	5.280

Source: LehmanLive.

The last line in Figure 11 shows the settlement date of 08/07/2006, the spot yield, and the spot breakeven.

Figure 12. TIPS 3.375% of 1/07s Forward Breakeven for Settlement Date of September 1, 2006

Inflation Products (Keyword: Inflation)

Overview | Trade Tracker | Live Swaps | Swap Calculator | EUR | USD | GBP | JPY | Bond Calculator | Forecast

Inflation Bond Calculator: TIPS 3.375% 15-Jan-07 — TIPS 3.375% 15-Jan-07

Pricing

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1M	07-Sep-2006	2.960	2.157	5.8	12.9	5.230	5.230
3M	07-Nov-2006	4.426	0.372	152.5	191.4	5.280	5.280
25D	01-Sep-2006	2.869	2.257	-3.2	2.8	5.280	5.280

Source: LehmanLive.

Figure 13: TIPS 3.375% of 1/07s Forward Breakeven for Settlement Date of November 1, 2006

Inflation Products (Keyword: Inflation)

Overview | Trade Tracker | Live Swaps | Swap Calculator | EUR | USD | GBP | JPY | Bond Calculator | Forecast

Inflation Bond Calculator: TIPS 3.375% 15-Jan-07 — TIPS 3.375% 15-Jan-07

Pricing

Trade Date	04-Aug-2006	Settle Date	07-Aug-2006
Closing Price	100.202	Index Ratio	1.27861

Trade Analysis — Cashflows

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Forward Calculations & Carry — Inflation Forecasts

Term	Date	Real Yield	Breakeven	Yield Carry	B/E Carry	Repo (Inf)	Repo (Nom)
1M	07-Sep-2006	2.960	2.157	5.8	12.9	5.230	5.230
3M	07-Nov-2006	4.426	0.372	152.5	191.4	5.280	5.280
86D	01-Nov-2006	4.210	0.631	130.9	165.5	5.280	5.280

Source: Lehman Live.

Similarly, the last line of Figure 12 shows the forward date of 09/01/2006, the corresponding forward real yield, the forward breakeven spread, the yield carry, and the breakeven carry. The last line of Figure 13 shows an example of forward rate calculation for the forward date of 11/01/2006, which is beyond the last date the CPI index is known as of the regular settlement date of 08/07/2006. As mentioned above, to compute the forward rate, we would need to assume some NSA CPI-U index values for August and September.

Constant Maturity-Fitted Rates and Breakevens

For time series analysis (see Figure 14), the constant maturity fitted rates are available at the link Fixed Income → Fixed Income Toolkit → Time Series Plotter (keyword search: plot) → Constant Maturity Fitted Yields → US Government → TIPS Zero Fitted (or Par Fitted). The rates can also be obtained on the CurveLab (see Figure 15) page at the link Fixed Income → Fixed Income Toolkit → CurveLab → Government → US TIPS.

Figure 14. Time Series of Forward Breakeven Spreads

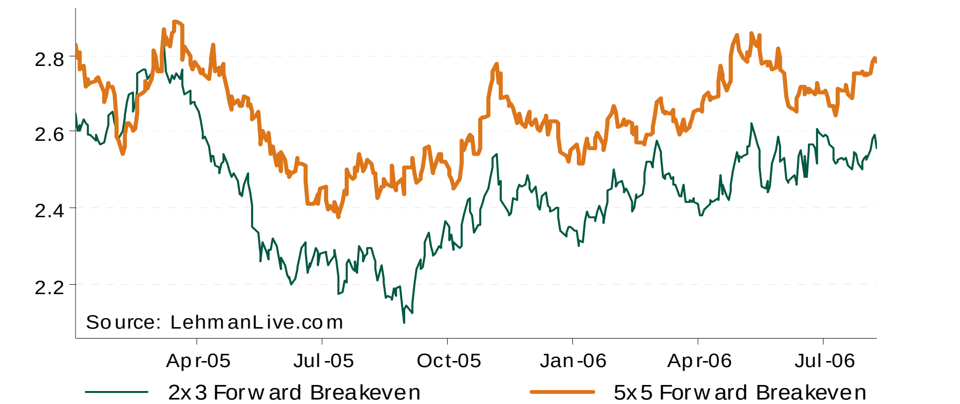
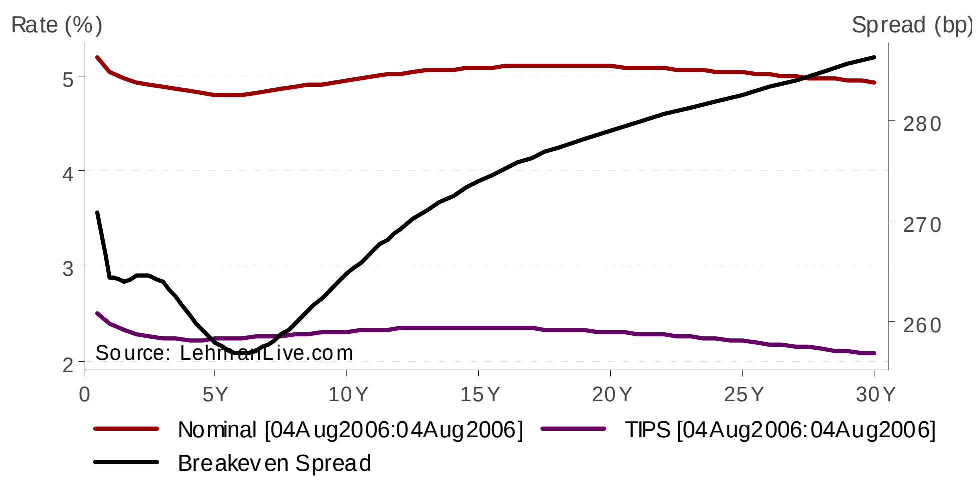


Figure 15. Constant Maturity Fitted Par Rates on August 4, 2006



TIPS Forward Report

Similar to the U.S. Treasury forward curve report, the TIPS forward curve report presents both a table and graphs of forward rates of different maturities and horizons. The TIPS are assumed to finance at General Collateral (GC). The TIPS forward curve report can be accessed at: Fixed Income → Interest Rates → US Treasuries → Forward Reports

Figure 16. TIPS Forward Curve Report on August 4, 2006

LEHMAN BROTHERS — U.S. Forward Curve Report -- TIPS

Pricing: 08/04/06

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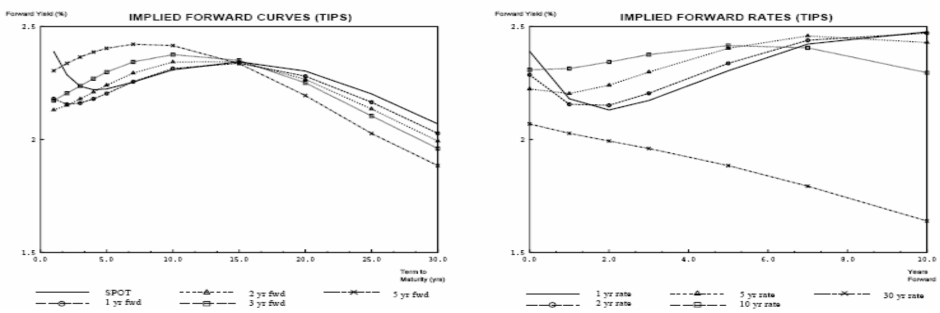
		Par Rates											Curve Spreads			
Forward Horizon	Financing Rate	1 yr	2 yrs	3 yrs	4 yrs	5 yrs	7 yrs	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs	2s-5s	5s-10s	2s-10s	10s-30s
SPOT	-	2.39	2.29	2.24	2.22	2.22	2.25	2.31	2.34	2.30	2.20	2.07	-6.3	8.5	2.2	-23.9
1 year	2.39	2.18	2.16	2.16	2.18	2.20	2.26	2.31	2.34	2.28	2.16	2.03	4.8	11.1	15.9	-28.7
2 years	2.28	2.13	2.15	2.18	2.21	2.24	2.29	2.34	2.34	2.27	2.13	1.99	8.9	10.3	19.2	-35.0
3 years	2.23	2.17	2.20	2.24	2.27	2.30	2.34	2.38	2.35	2.25	2.10	1.96	9.4	7.7	17.1	-41.5
5 years	2.22	2.30	2.34	2.36	2.39	2.40	2.42	2.42	2.34	2.19	2.03	1.88	6.6	1.2	7.9	-53.1
7 years	2.25	2.42	2.44	2.45	2.46	2.46	2.45	2.41	2.28	2.10	1.93	1.79	1.9	-5.3	-3.3	-61.2
10 years	2.31	2.48	2.47	2.46	2.45	2.43	2.38	2.30	2.11	1.90	1.74	1.64	-4.2	-13.3	-17.5	-65.6



Source: LehmanLive.

Breakeven Forward Report

In the Treasury/TIPS Spread forward report, we have both a table and graphs of the spreads between the Treasury forward rates and the TIPS forward rates. The Treasury/TIPS spread forward curve report can be accessed at: Fixed Income → Interest Rates → US Treasuries → Forward Reports.

Figure 17: Breakeven Forward Curve Report on August 4, 2006

LEHMAN BROTHERS — U.S. Forward Curve Report -- Treasury/Tips Spreads

Pricing: 08/04/06

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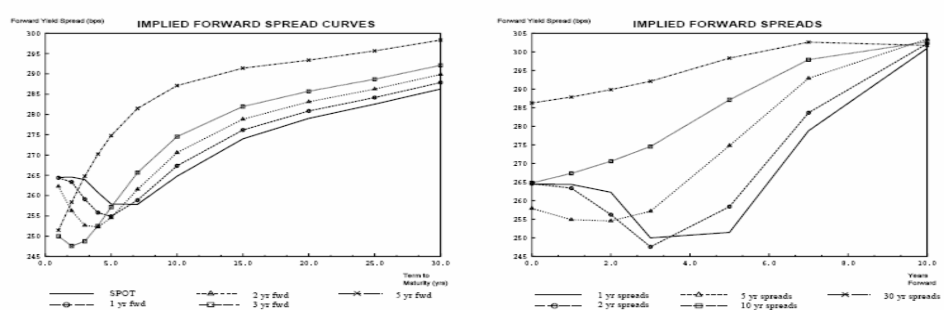
(212) 526-6566

		Par Spreads											Curve Spreads			
Forward Horizon	Financing Spreads (bps)	1 yr	2 yrs	3 yrs	4 yrs	5 yrs	7 yrs	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs	2s-5s	5s-10s	2s-10s	10s-30s
SPOT	-	264.5	264.6	264.0	260.8	257.9	257.8	264.8	274.0	279.0	282.5	286.3	-6.6	6.9	0.2	21.5
1 year	264.3	264.4	263.4	259.1	255.8	254.9	258.9	267.3	276.2	280.9	284.2	287.9	-8.5	12.5	4.0	20.5
2 years	264.3	262.3	256.2	252.6	252.3	254.5	261.5	270.6	278.8	283.1	286.3	289.9	-1.7	16.1	14.4	19.3
3 years	263.6	250.0	247.6	248.7	252.6	257.2	265.7	274.5	281.9	285.7	288.7	292.1	9.6	17.4	27.0	17.6
5 years	257.2	251.5	258.4	264.8	270.2	274.8	281.5	287.1	291.4	293.4	295.7	298.3	16.4	12.3	28.7	11.2
7 years	257.6	278.8	283.6	287.5	290.6	292.9	295.8	297.9	299.0	299.4	300.9	302.6	9.3	5.0	14.3	4.7
10 years	266.7	300.9	302.2	302.9	303.2	303.4	303.4	302.7	300.9	300.3	301.1	301.7	1.2	-0.7	0.5	-1.0



Source: Lehman Live.

APPENDIX: TWO-FACTOR VASICEK MODEL

Two-Factor Vasicek Model

We estimate the risk premium and convexity values priced into both nominal bonds and TIPS through a two-factor Vasicek model. Under the real world dynamics, we assume that two processes drive the short rate r. The details of the model are as follow:

$$dX_t = \kappa_X (X_\infty - X_t)dt + \sigma_X dW_X$$

$$dY_t = \kappa_Y (Y_\infty - Y_t)dt + \sigma_Y dW_Y$$

$$r = X + Y \quad E[dXdY] = \rho\sigma_X\sigma_Y dt$$

(Eq. 1)

X with usually a lower mean reversion parameter κ_X, is interpreted as a long-lived factor and Y with a higher mean reversion parameter κ_Y, is interpreted as a short-lived factor. Under the risk neutral measure, the above dynamics can be rewritten as:

$$dX_t = \kappa_X (\theta_X - X_t)dt + \sigma_X dW_X$$

$$dY_t = \kappa_Y (\theta_Y - Y_t)dt + \sigma_Y dW_Y$$

$$r = X + Y \quad E[dXdY] = \rho\sigma_X\sigma_Y dt$$

(Eq. 2)

Where $\theta_X = X_\infty + \frac{\lambda_X}{\kappa_X}$, $\theta_Y = Y_\infty + \frac{\lambda_Y}{\kappa_Y}$ and λ_X and λ_Y are the risk premium associated with the state variables X and Y respectively. Standard calculations yield the price of a zero coupon bond at time t with maturity date T:

$$P(t,T) = \exp(-A(t,T) - B_X(t,T)X(t) - B_Y(t,T)Y(t)) \quad \textbf{(Eq. 3)}$$

Where:

$$\begin{aligned} \mathrm{A(t,T)} \quad = \quad & \left(\frac{\sigma_X^2}{2\kappa_X^2} - \theta_X\right)\{B_X(\mathrm{t,T}) - (\mathrm{T - t})\} + \frac{\sigma_X^2}{4\kappa_X}(B_X(\mathrm{t,T}))^2 + \\ & \left(\frac{\sigma_Y^2}{2\kappa_Y^2} - \theta_Y\right)\{B_Y(\mathrm{t,T}) - (\mathrm{T - t})\} + \frac{\sigma_Y^2}{4\kappa_Y}(B_Y(\mathrm{t,T}))^2 + \\ & \frac{\rho\sigma_X\sigma_Y}{\kappa_X\kappa_Y}\{B_X(\mathrm{t,T}) + B_Y(\mathrm{t,T}) - (\mathrm{T - t}) - B_{X+Y}(\mathrm{t,T})\} \end{aligned}$$

$$B_i(t,T) = \frac{1 - \exp(-\kappa_i(T - t))}{\kappa_i}, \quad i = X, Y$$

$$B_{X+Y}(t,T) = \frac{1 - \exp(-(\kappa_X + \kappa_Y)(T - t))}{(\kappa_X + \kappa_Y)}$$

With the zero coupon bond price formula, we can derive the dynamics of a par rate y_t^τ of maturity τ:

$$y_t^\tau = 2\left(\frac{1-P(t,t+\tau)}{\sum_{i=1}^{2\tau} P(t,t+.5i)}\right) \equiv f\left(X(t),Y(t)\right)$$

(Eq. 4)

From Ito's Lemma, we have:

$$dy_t^\tau = \left\{\frac{1}{2}\sigma_X^2 \frac{\partial^2 f}{\partial X^2} + \frac{1}{2}\sigma_Y^2 \frac{\partial^2 f}{\partial Y^2} + \frac{1}{2}\rho\sigma_X\sigma_Y \frac{\partial^2 f}{\partial X \partial Y} + \kappa_X\left(\theta_X - X_t\right)\frac{\partial f}{\partial X} + \kappa_Y\left(\theta_Y - Y_t\right)\frac{\partial f}{\partial Y}\right\}dt + \sigma_X \frac{\partial f}{\partial X} dW_X + \sigma_Y \frac{\partial f}{\partial Y} dW_Y$$

(Eq. 5)

Thus: $$E\left[dy_t^\tau dy_t^\tau\right] = \left\{\left(\sigma_X \frac{\partial f}{\partial X}\right)^2 + \left(\sigma_Y \frac{\partial f}{\partial Y}\right)^2 + 2\rho\sigma_X\sigma_Y \frac{\partial f}{\partial X}\frac{\partial f}{\partial Y}\right\}dt$$ **(Eq. 6)**

Convexity Component of Interest Rates

The value of convexity in interest rates, due to the mathematical fact that a bond price is a convex function of bond yield, arises because of the uncertainty surrounding the forecast of interest rates.

For any interest rate with known convexity C (the change in duration as a function of interest rate changes) and known basis point volatility σ, the value of convexity is approximately equal to $-\frac{1}{2}C\sigma^2$. First, the percentage Price change $\frac{\Delta P}{P}$ when yield changes by Δy can be approximated by $-D\Delta y + \frac{1}{2}C(\Delta y)^2$ where D is the duration, which measures the percentage change in the price for a unit change in yield. The price change approximation above implies that when C is positive as it is in the case of TIPS and regular nominals, price decreases less than predicted by duration alone when rate increases, and price increases more than predicted by duration when rate decreases. This is an attractive feature for a bond investor and is paid for in the form of lower yield. Convexity or the duration change as a function of interest rate is a decreasing function of coupon rate; this implies that convexity for TIPS is higher than convexity for nominal bonds. We also note that since C increases with the square of maturity, the value of convexity is much higher in longer maturity rates.

Second, to account for interest rate volatility, we observe that in the presence of volatility around interest rate forecasts, the expected payoff of a money market account continuously reinvested at the prevalent interest rate is higher than the payoff if it is invested at the expected interest rate. Therefore, the interest rate for any given maturity must be less than the expected interest rate. This effect is stronger for nominals because the 60-day volatility of nominal is on average higher than the volatility of TIPS.

To estimate the value of convexity component of interest rate, we preliminary need to estimate the volatilities and the parameters of the processes driving interest rates. The convexity is then equal to the difference between the rate estimated with the volatility parameters set equal to zero and the rate estimated with the volatility parameters set to their calibrated values. Given the higher volatility, the value of convexity in nominals is higher than the value of convexity in TIPS.

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