ESQUANT
Statistical Consulting

Evaluation of Methods for Extrapolating Australian Corporate Credit Spreads published by the Reserve Bank of Australia

A REPORT PREPARED FOR UNITED ENERGY AND MULTINET GAS.

NEIL DIAMOND, B.SC.(HONS), PH.D., A.STAT.

ESQUANT STATISTICAL CONSULTING

PROFESSOR ROBERT BROOKS, B.EC.(HONS), PH.D.

MONASH UNIVERSITY

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Contents

List of Tables

List of Figures

1 Executive Summary

In its draft decision for Jemena Gas Networks (JGN), the AER has adopted the method, described below, for estimating the return on debt for a benchmark efficient entity[1]:

- Use a trailing average portfolio approach applied to the total return on debt – that is, to estimate the average return that would have been required by debt investors in a benchmark efficient entity, if it raised debt over an historical period prior to the commencement of a regulatory year in the regulatory control period.
- Update the return on debt estimate annually (that is, for each regulatory year).
- Apply equal weights to all the elements of the trailing average.
- Implement transitional arrangements – in moving from the current "on the day" approach to the new "trailing averaging portfolio" approach – consistent with an annual re-pricing of a portion of the notional debt portfolio and a benchmark term of 10 years.

The draft decision has put the stated approach into practice, by applying the following estimation procedure:

- Adopting a 10-year term for the return on debt with a BBB+ credit rating.
- Applying a simple average of independent third party data from the Reserve Bank of Australia (RBA) and Bloomberg as follows:
  - The RBA broad BBB rated 10 year curve (the RBA curve[2]) – extrapolated to better reflect a 10 year estimate, and interpolated to produce daily estimates.
  - The Bloomberg broad BBB rated 7 year BVAL curve (the BVAL curve[3]) – extrapolated to 10 years.

The estimates of the cost of debt which are prepared by the RBA, and published as Table F3, are derived using a Gaussian kernel smoother, which is known to exhibit bias. As was explained by ESQUANT (2014), local constant smoothing delivers a result for the cost of debt which is biased at the boundary regions (meaning at 3 years and at 10 years, in this context), and, potentially also in the interior of the domain[4]. To overcome the bias, an adjustment must be made to the RBA estimates of the cost of debt for non-financial corporate, BBB-rated bonds. One possibility would be for the RBA to apply local linear smoothing to its bond data (rather than the Gaussian kernel, or local constant smoother), because local linear smoothing removes the bias to first order[5]. Another possibility, suggested by Lally (2014), is to use linear extrapolation based on the aggregate credit spreads reported by the RBA (in Table F3) at target tenors of 7 years and 10 years[6]. The Lally (2014) method also makes use of the effective tenors corresponding to the target tenors of 7 years and 10 years. A further possibility

[1] AER (2014), Draft decision, Jemena Gas Networks (NSW) Ltd, Access Arrangement 2015-20, Attachment 3: Rate of return, Australian Energy Regulator, November 2014; page 3-9.

[2] The RBA refers to this curve as "Non-financial corporate BBB-rated bonds".

[3] The Bloomberg ticker for this curve is: BVCSAB07.

[4] ESQUANT (2014), section 3.1.2. Lally (2014a) has also reported that: "The RBA index values for ten-year bonds are biased at the very least because the weightings given to bonds used for this purpose do not have a weighted-average tenor equal to ten years and this point is even acknowledged by the RBA (Arsov et al., 2013, page 10). In fact, across the entire period for which the RBA series is presented (from January 2005), the average tenor of the bonds used to form the index value for ten years is 8.7 years and has been as low as 6.11 years (in August 2005)".

[5] ESQUANT (2014), section 3.2.

[6] Lally (2014), section 7.

is to use a method suggested by the SA Power Networks, which draws upon the RBA aggregate credit spreads for 3, 5, 7, and 10 years[7].

This report evaluates these approaches and also examines Nelson-Siegel yield curves.

- Section 4 provides the algebra for the Gaussian kernel method that is applied by the RBA. An expression for bias is derived which shows that local constant smoothing is biased to first order.
- Section 5 presents an expression for the spread-over-swap at a 10-year tenor that is produced using the method of Local Linear Smoothing. Further formulations are presented showing the methods for calculating bias, variance and the root mean square error, (RMSE), under this method. A similar exposition of Local Linear Smoothing was provided in ESQUANT (2014).
- Section 6 derives an expression for the spread-over-swap function, at a 10-year tenor, when the Lally (2014) extrapolation method is applied to the result from local constant smoothing produced by the RBA. The weights employed under this method will depend, in part, on the Gaussian kernel weights. Further formulations are presented showing the methods for calculating bias, variance and the RMSE under the Lally (2014) method. In Appendix D, a Taylor series expansion is used to show that there is second order bias inherent in the method. Example calculations, which use data from 30th January 2015, are provided in section 7.
- Section 8 analyses the workings of the SA Power Networks (SAPN) extrapolation method and shows that the approach can also be presented as a form of weighted average. The weights depend in part on Gaussian kernel weights. The formulations for bias, variance and RMSE are derived. A Taylor series expansion of the spread function in Appendix F is used to show that the SAPN method is biased to second order.

In order to proceed with the quantification of the bias and variance under the three methods, data on corporate bonds was required. A database was provided by the Competition Economists Group (CEG), which has developed an "RBA replication model". The model contains daily data for a wide range of variables pertaining to corporate bonds. The daily data is currently available on a continuous basis from November 2013 to February 2015. The CEG RBA replication model produces option-adjusted spreads, which are used in the calculations under the Gaussian kernel method. The model applies the filtering and sample selection methods that were described by the RBA in the Bulletin article (Arsov et al. 2013).

The multipliers for bias and variance were worked out using the data supplied by CEG, and are presented in Table 4, section 9. The calculations were performed using end-of-month values over the period from November 2013 to January 2015. A fairly consistent result is that the bias multiplier is higher under the SAPN method than under the two alternative smoothing methods. However, the SAPN method also has the lowest multiplier of variance.

The multipliers allow the bias and variance measures under the three smoothing methods to be calibrated. However, in order to determine the actual numerical values for bias and variance, estimates had to be obtained for:

- The squared second derivative of the true spread function at the target tenor; and,
- The "pure" random variation.

The best way of obtaining high quality estimates of the squared second derivatives, and of the pure random variance terms was to estimate Nelson-Siegel yield curves. Thus, the same database of corporate bonds was used to estimate Nelson-Siegel equations, providing end-of-month results over the 15 month period to January 2015.

The results for the specific variables from the Nelson-Siegel yield curves were combined with the aforementioned multipliers to produce a full set of results for bias, variance and RMSE under each of the three smoothing methods. The outcomes are reported in Table 9, section 12. A graphical representation of RMSE is also shown in Figure 5. A clear finding is that the RMSE under the SAPN method

[7] SA Power Networks (2014), chapter 26, page 340.

is consistently lower over time than under the two methods. The RMSE for Local Linear Smoothing is also marginally lower than under the Lally (2014) method. A shortcoming of the standard RBA Gaussian kernel method is that no adjustments are inserted to control for variations in credit ratings within the broader A or BBB credit rating bands. Previous work by ESQUANT (see ESQUANT, 2013) has shown that there are structural differences between the yield curves estimated for, say, BBB bonds and the yield curves estimated for BBB plus rated bonds, although the differences can be provided for adequately via the use of separate intercept terms.

In view of the importance of the impact of credit ratings within the broad, BBB category, the results from the three extrapolation and smoothing methods under examination were adjusted to allow for the differential effects of credit ratings. The adjustments were undertaken using a back-fitting algorithm produced by Hastie et al. (2009, p. 297-298), with one of the main steps involved being to fit a linear model by regressing the credit spreads for individual bonds on the actual credit ratings reported for those bonds. Vectors of correction factors and amended spreads to swap for individual bonds were then produced. Ultimately, the smoothing methods were applied to the amended spreads. Further details are provided in section 11.1.

A benefit of applying smoothing methods to the amended bond spread observations (rather than to the original bond spreads) was that the accuracy of the empirical methods was thereby enhanced. A bootstrap re-sampling exercise was conducted which involved applying the smoothing methods to thousands of sub-samples of the modified bond data, and then recording both the estimates of the spreads over swap at 10-years, and the standard errors. The bootstrap resampling showed that the SAPN adjustment method produced estimates of the spread to swap at a 10-year tenor which reported the lowest standard error of all of the smoothing methods.

Conclusions

There are benefits to be gained from properly controlling for differences between the credit ratings of bonds within the broad BBB band. The benefits are in terms of improved precision of the estimates of yields and spreads obtained either via parametric methods (such as yield curves), or non-parametric methods (such as smoothing).

A summary of the results from this report is presented in Table 1. The SAPN method for extrapolating the estimates of the spread to swap produced by the RBA appears to produce more precise (less variable) estimates than the Lally (2014) method. Active consideration should therefore be given to the use of the SAPN method when preparing estimates of the cost of debt that are based on the corporate bond series published by the RBA.

The SA Power Networks method delivers a lower RMSE than the Lally (2014) method in every month that has been examined because curves extrapolated under the SAPN technique are relatively straight, while the variability is low when compared against the bias. The SAPN method is therefore superior in totality. An important consideration, however, is that if an historical average of extrapolated results is needed for a period which extends into the past, then there would be merit in using a method that is less susceptible to bias. The Lally (2014) method reports less bias than the SA Power Networks method. The process of arithmetic averaging will bring down variance but will not result in a diminution in bias.

- Consequently, when using the published RBA series on spreads over swap for current and prospective averaging periods, the SAPN extrapolation method is likely to be an appropriate technique to apply because the results from the application of the method have been shown to have low variance. The averaging periods used in regulatory processes are generally relatively short (encompassing 10 to 40 trading days).

- When applying extrapolation methods to the published RBA data for extended timeframes in the past, there is merit in applying the Lally (2014) approach because it is subject to less bias.

There is therefore theoretical and empirical support for the approach that has been taken by CEG (2015) to calculate an historical average spread over swap. CEG has used data from RBA Table F3 to

	Calculated multipliers of the second derivative (Bias measure)	Multipliers of variance	Root mean square error	Bootstrap standard errors (for estimated 10-year spread-to-swap)	Overall assessment of method
Applicable section of report	Table 4	Table 4	Table 9	Table 8	
Local linear smoothing (using sigma=2.4)	Less biased results than with other methods	Variance multipliers are generally slightly below those produced by the Lally (2014) method.	Higher than the values reported under the SAPN method.	The local linear method delivers an estimate of the spread to swap which is downwardly biased to second order.	Local linear smoothing provides an alternative to the SAPN method.
Lally (2014) method	Marginally greater bias over recent time periods than with local linear smoothing	Variance multipliers are higher than those obtained from both local linear smoothing and the SAPN method.	Similar to, but generally slightly greater than for local linear smoothing.	The downward bias is greater than for local linear smoothing.	Results from this method suffer from a greater degree of bias than the results from local linear smoothing and the SAPN method. The bootstrap standard errors are also higher.
SAPN approach	Relatively high on this measure.	Low multipliers of variance.	Lowest of the three approaches.	The estimated spread at 10 years is the closest to the estimated spread obtained by using a yield curve method.	Best of the three non-parametric approaches

Table 1: A qualitative summary of the quantitative performance measures obtained by testing the extrapolation methods. Source: (a) The underlying bond data that was used was for end of month periods from November 2013 to February 2015. The multipliers of the second derivatives were obtained by applying Taylor series expansions to the relevant expressions (under each method) for the expected spread-to-swap at a target tenor of 10 years. The expected spread to swap varies under each of the extrapolation methods. The multipliers of variance were taken from Hastie et al. (2009, page 197). (b) In order to evaluate the root mean squared error (RMSE), it is necessary to use the multipliers from part (a) in conjunction with actual values for the second derivative of the expected spread at 10 years, and for the variance of the error from the model. The values for the second derivative at 10 years, and for the standard error of the regression were taken from Nelson-Siegel yield curves fitted to the data. The Nelson-Siegel yield curves provide the closest proxy for a true model.

calculate spreads over swap for each financial year from 2005-06 to 2013-14[8]. A uniform extrapolation method, notably the Lally (2014) method has been applied over each of the time periods, although CEG has also investigated alternative extrapolation approaches.

The Bloomberg BFV and BVAL curves for bonds with credit ratings in the BBB band have not been evaluated as part of this report. However, the BVAL curve is amenable to extrapolation via the SA Power Networks method.

[8]CEG (2015) has also presented calendar year trailing averages for the spread over swap (Appendix F of CEG report). The same draft decision extrapolation methodology has been employed.

2 Terms of Reference Review of Extrapolation Methods Applied to the RBA Series of Non-Financial Corporate Bond Spreads

Background

In its 2014 draft decision for Jemena Gas Networks (JGN), the AER has adopted an approach to estimating the return on debt for a benchmark efficient entity which makes use of "third party" measures of the cost of debt. You are asked to familiarise yourself with that part of the draft determination and also Rule 6.5.2 (of the National Electricity Rules) concerning the establishment of an allowed rate of return by the AER (see AER, Draft decision, Jemena Gas Networks (NSW) Ltd., Access arrangement 2015 – 20, Attachment 3: Rate of return, November 2014).

The AER's JGN draft determination uses both RBA data (from Table F3) and Bloomberg data (from the Bloomberg BVAL curve for BBB rated bonds). However, neither of the two curves provides cost of debt estimates that are commensurate with a ten year effective tenor. Therefore, to obtain an estimate for a benchmark 10 year corporate bond, the results from the published data sources should be subject to amendment through extrapolation.

A report from CEG titled "Critique of the AER's JGN draft decision on the cost of debt," March 2015, contains an assessment of at least two alternative extrapolation methods: The "AER approach" (which was provided by Martin Lally) and the SA Power Networks (or SAPN) approach. You are asked to also familiarise yourself with that document. A further report to consider is that provided by Martin Lally, (Implementation Issues for the Cost of Debt, Martin Lally, Capital Financial Consultants, November 2014).

Brief

You are requested to undertake a detailed review of the statistical properties of the various extrapolation methods. The properties of the different extrapolation or smoothing methods should also be compared with the attributes of yield curves, such as Nelson-Siegel yield curves. The analysis should be based on theory and also empirical application. If you consider that there are other methods which might be more suitable for use than Nelson-Siegel yield curves, then please provide answers to the questions below in relation to those methods, as well as in respect of Nelson-Siegel regressions.

Please answer the following specific questions:

1. Derive formulae for the weights used in the various extrapolation methods.
2. Provide an assessment of whether any of the methods has a bias, or tendency to report results that are higher or lower than a fair value for a 10 year unexpired tenor. If there is a bias, or a tendency to over or under-estimate the true result, then please explain the causes of the over or under-statement .
3. Provide an analysis of the performance of the methods based on theory.
4. For the Lally (2014) and AER methods, give examples of the calculations involved in the extrapolation.
5. Use empirical methods to demonstrate the practical application of the approaches. If possible, produce a time series of results. The emphasis should be placed on end-of-month data because the RBA produces results for Table F3 that are based on assessments done on or around the last business day of the month.
6. Compare the extrapolations based on yields with those that use spreads to swap, and spreads to Commonwealth Government Securities (CGS).

7. Apply methods based on Nelson-Siegel yield curves. Compare the results from yield curves with those obtained using the Lally and SAPN methods.
8. Evaluate the advantages and disadvantages of the different extrapolation or smoothing methods, drawing upon theory and empirical results.
9. Assess the merits of making adjustments to the underlying data so as to better control for the gradation of credit ratings with the broad BBB band. The credit ratings for bonds should be based on the ratings assigned by Standard and Poor's.

Timeframe

The consultant is to provide a draft report which discusses the results of the analysis by Monday 9th March 2015. A final report should be provided by no later than Monday 23rd March.

Reporting

Jeremy Rothfield will serve as the primary contact for the period of the engagement. The consultant will prepare reports showing the work-in-progress on a regular basis. The consultant will make periodic presentations on analysis and advice as appropriate.

Conflicts

The consultant is to identify any current or potential future conflicts.

Compliance with the Code of Conduct for Expert Witnesses

Attached is a copy of the Federal Court's Practice Note CM 7, entitled Expert Witnesses in Proceedings in the Federal Court of Australia, which comprises the guidelines for expert witnesses in the Federal Court of Australia (Expert Witness Guidelines).

Please read and familiarise yourself with the Expert Witness Guidelines, and comply with them at all times over the course of your engagement with United Energy and Multinet Gas.

In particular, your report prepared for United Energy and Multinet Gas should contain a statement at the beginning of the report to the effect that the author of the report has read, understood and complied with the Expert Witness Guidelines.

Your report must also:

1. Contain particulars of the training, study or experience by which the expert has acquired specialised knowledge.
2. Identify the questions that the expert has been asked to address.
3. Set out separately each of the factual findings or assumptions on which the expert's opinion is based.
4. Set out each of the expert's opinions separately from the factual findings or assumptions.
5. Set out the reasons for each of the expert's opinions; and
6. Otherwise comply with the Expert Witness Guidelines.

The expert is also required to state that each of the expert's opinions is wholly or substantially based on the expert's specialised knowledge. The declaration contained within the report should be that "[the expert] has made all the inquiries that [the expert] believes are desirable and appropriate and that no matters of significance that [the expert] regards as relevant have, to [the expert's] knowledge, been withheld from the report".

Please also attach a copy of these terms of reference to the report.

Fees

The consultant is requested to submit:

- A fixed total fee for the project and hourly rates for the proposed project team should additional work be required; and
- Details of the individuals who will provide the strategic analysis and advice.

Contacts

Any questions regarding this terms of reference should be directed to:
Jeremy Rothfield
telephone (03) 8846 9854
or via email at Jeremy.Rothfield@ue.com.au

3 Declaration

The authors of this report have read, understood and complied with the Expert Witness Guidelines as given by the Federal Court of Australia's Practice Note CM 7, entitled "Expert Witnesses in Proceedings in the Federal Court of Australia".

We have made all the inquiries that we believes are desirable and appropriate and that no matters of significance that we regard as relevant have, to our knowledge, been withheld from this report.

4 Kernel smoothing

Following Arsov et al. (2013), the RBA's Gaussian kernel average credit spread at a target tenor T is given by

$$S(T) = \sum_{i=1}^{N} w_i(T;\sigma)S_i$$

where $w_i(T;\sigma)$ is the weight defined below, S_i is the observed spread over swap for the ith bond, and

$$\begin{aligned} w_i(T;\sigma) &= \frac{K(T_i - T;\sigma)F_i}{\sum_{j=1}^{N} K(T_j - T;\sigma)F_j} \\ &= k_i F_i \end{aligned}$$

where T_i is the tenor of the ith bond, F_i is the face value of the ith bond and $K(T_i - T;\sigma)$ is the Gaussian kernel given by

$$K(T_i - T;\sigma) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(T_i - T)^2}{2\sigma^2}\right],$$

σ is the standard deviation of the Gaussian (Normal) distribution used in the Gaussian kernel and

$$k_i = \frac{K(T_i - T;\sigma)}{\sum_{j=1}^{N} K(T_j - T;\sigma)F_j}.$$

Appendix A shows that the RBA's Gaussian kernel estimate is equivalent to locally fitting a constant. The estimate is biased to first order with the (first-order) bias given by

$$\text{Bias} = (\text{Effective Tenor} - \text{Target Tenor}) \times (\text{Slope at Target Tenor})$$

The RBA estimate will be biased unless the Effective Tenor matches the Target Tenor or the slope of the spread curve at the target tenor is zero.

5 Local Linear Smoothing

To overcome the bias inherent in local constant smoothing, many authors (see, for example, Hastie, Tibshirani, and Friedman (2009)) suggest that local linear smoothing should be used. In Appendix B, we show algebraically that the estimated spread at the target tenor, $S_{LL}(T)$, is equal to a weighted average of the spreads of the component bonds

$$S_{LL}(T) = \sum_{i=1}^{N} l_i(T;\sigma)S_i$$

but the weights are calculated differently with

$$l_i(T;\sigma) = \frac{k_i F_i (C - TB) + k_i F_i T_i (TA - B)}{AC - B^2}$$

where

$$\begin{aligned} A &= \sum_{i=1}^{N} k_i F_i \\ B &= \sum_{i=1}^{N} k_i F_i T_i \\ C &= \sum_{i=1}^{N} k_i F_i T_i^2. \end{aligned}$$

It is also shown in Appendix B that the Local Linear Smoother is unbiased to first order. This unbiasedness is irrespective of whether the effective tenor matches the target tenor. It is also shown that the bias to second order is given by

$$\text{Bias} = \frac{G''(T)}{2} \sum_{i=1}^{N} l_i(T;\sigma)(Ti - 10)^2,$$

where $G(T)$ denotes the true spread over swap at T years term to maturity, and $G''(10)$ denotes the second derivative of the spread over swap curve at T years; while the variance is given by (see, Hastie, Tibshirani, and Friedman, 2009, p. 197)

$$\text{Variance} = \text{Variance}(\varepsilon_i) \sum_{i=1}^{N} l_i(T;\sigma)^2$$

where ε_i is the error from the model

$$S_i = G(T_i) + \varepsilon_i.$$

Finally the Root Mean Square Error (RMSE) is given by

$$\text{RMSE} = \sqrt{\text{Bias}^2 + \text{Variance}}.$$

As an example, for 30th January 2015 with a target tenor of 10 years, the multipliers of $G''(10)$ and $\text{Variance}(\varepsilon_i)$, are, respectively,

$$\begin{aligned} \frac{1}{2} \sum_{i=1}^{N} l_i(10;\sigma)(Ti - 10)^2 &= -1.992 \\ \sum_{i=1}^{N} l_i(10;\sigma)^2 &= 0.235 \end{aligned}$$

(see Table 10 in Appendix B) and hence the RMSE, to second order, is well approximated by

$$\begin{aligned} \text{RMSE} &\approx \sqrt{(-1.992)^2 \times (G''(10))^2 + 0.235 \times \text{Variance}(\varepsilon_i)} \\ &= \sqrt{3.968 \times (G''(10))^2 + 0.235 \times \text{Variance}(\varepsilon_i)}. \end{aligned}$$

Appendix C shows details of a comparison of the results obtained by the RBA and by us using the database provided by CEG, for their "RBA replication model" for 30th December 2014 and 30th January 2015. The diferences are relatively small.

6 Lally Extrapolation Method

Let $S(7)$ and $S(10)$ be the RBA estimates of the spreads over swap at target tenors of 7 and 10 years, respectively. The effective tenors at 7 and 10 year terms to maturity are given by

$$E(7) = \sum_{i=1}^{N} w_i(7;\sigma)T_i$$

and

$$E(10) = \sum_{i=1}^{N} w_i(10;\sigma)T_i.$$

Lally (2014), suggests that linear extrapolation be used in order to estimate the Debt Risk Premium at 10 years. The formula is

$$\begin{aligned} S_L(10) &= S(10) + \frac{S(10) - S(7)}{E(10) - E(7)} (10 - E(10)) \\ &= \frac{S(10)\,(E(10) - E(7)) + (S(10) - S(7))\,(10 - E(10))}{E(10) - E(7)} \\ &= \frac{S(10)\,(10 - E(7)) - S(7)\,(10 - E(10))}{E(10) - E(7)} \\ &= (1 + a)S(10) - aS(7) \end{aligned}$$

where

$$a = \frac{10 - E(10)}{E(10) - E(7)}$$

since

$$\begin{aligned} 1 + a &= 1 + \frac{10 - E(10)}{E(10) - E(7)} \\ &= \frac{E(10) - E(7) + 10 - E(10)}{E(10) - E(7)} \\ &= \frac{10 - E(7)}{E(10) - E(7)}. \end{aligned}$$

Appendix D shows that the Lally estimate, denoted by $S_L(10)$ is also a weighted average

$$S_L(10) = \sum_{i=1}^{N} u_i(\sigma) S_i$$

with the weights given by

$$u_i(\sigma) = (1 + a)w_i(10; \sigma) - aw_i(7; \sigma).$$

Appendix D also shows that the Lally estimate is unbiased to first order, and, similar to local linear smoothing, the bias to second order is given by

$$\text{Bias} = \frac{G''(10)}{2} \times \sum_{i=1}^{N} u_i(\sigma)(Ti - 10)^2$$

while the variance is given by

$$\text{Variance} = \text{Variance}(\varepsilon_i) \times \sum_{i=1}^{N} u_i(\sigma)^2$$

where ε_i is the error from the model

$$S_i = G(T_i) + \varepsilon_i.$$

As an example, for 30th January 2015, the multipliers of $G''(10)$ and $\text{Variance}(\varepsilon_i)$, are, respectively,

$$\begin{aligned} \frac{1}{2} \sum_{i=1}^{N} u_i(\sigma)(Ti - 10)^2 &= -2.212 \\ \sum_{i=1}^{N} u_i(\sigma)^2 &= 0.287 \end{aligned}$$

(see Table 14 in Appendix D) and hence the RMSE, to second order, is well approximated by

$$\begin{aligned} \text{RMSE} &\approx \sqrt{(-2.212)^2 \times (G''(10))^2 + 0.287 \times \text{Variance}(\varepsilon_i)} \\ &= \sqrt{4.893 \times (G''(10))^2 + 0.287 \times \text{Variance}(\varepsilon_i)}. \end{aligned}$$

7 Example calculations

7.1 Data for 30th January 2015

Table 2 gives the values calculated by the RBA for 30th January 2015, as shown in the RBA's spread sheet workbook for Table F3, (Aggregate measures of corporate bond spreads and yields: Non-financial corporate (NFC) bonds). The results shown are for bonds in the BBB credit rating band. Table 2 also presents corresponding values for the same day from the Bloomberg ADSWAP series, and values of CGS yields, as interpolated from the observations in RBA Table F16 (Indicative mid-rates of selected Commonwealth Government Securities). The interpolation method that has been applied by ESQUANT on this occasion is the same as that normally used by the AER.

					Target Tenor			
Target Tenor	Effective Tenor	Yield	Spreads to Swap	Spreads to CGS	Swap Rate (Bloomberg)	CGS[9]	Swap Rate (Implied by RBA Table F3)	Yields on CGS
3	3.94	3.83	159.59	188.09	2.22	1.941	2.234	1.95
5	5.24	4.17	173.96	214.86	2.418	2.04	2.43	2.02
7	6.66	4.54	195.93	238.93	2.562	2.214	2.581	2.15
10	8.53	4.5	174.13	205.83	2.735	2.427	2.759	2.44

Table 2: RBA results for bonds in the BBB credit rating band, as at 30th January 2015

Note that the RBA, in its explanatory notes to Table F3, provides the following information:

> The spreads to Australian Commonwealth Government securities (CGS) rates are calculated by adding to the credit spread to swap the corresponding swap to CGS spread for each target tenor (the quarterly swap rate for the 3 year tenor and the semiannual rate otherwise).
>
> Yields are calculated by adding the aggregate credit spread to swap to the corresponding swap rate at each target tenor.

Lally (2014) has used the data from the RBA Tables F3 and F16 to illustrate his recommended method. Lally (2014) has also used swap rates from the Bloomberg ADSWAP series, but has limited himself to using the published daily rates at tenors of 5, 7 and 10 years only. In practice, the Bloomberg ADSWAP rates are available at tenors in increments of one year, from a one-year swap rate to a 10-year swap rate[10]. Beyond 10 years, the increments become larger.

Lally has avoided the use of a 6-year swap rate, an 8-year swap rate and a 9-year swap rate. By applying linear interpolation between the 5-year and 7-year swap rates, and between the 7 and 10-year swap rates, Lally has, in effect, assumed that the curve for Australian vanilla interest rate swaps is linear between the 5-year and 7-year tenors and linear between 7-year tenors and 10-year tenors.

An examination of the results in Table 2 reveals that the RBA is not using the Bloomberg ADSWAP series, and is also not applying the CGS yields from Table F16. In the calculations below, which follow Lally (2014), we will proceed on the basis that the RBA uses swap rates provided by Bloomberg, and CGS yields from Table F16.

[9] Interpolated yields on CGS, from Table F16, semi-annual basis.

[10] For instance, the Bloomberg ticker for a six-year swap rate is "ADSWAP 6 Curncy". The individual swap rates belong to the interest rate swap curve with Bloomberg ID "YCSW0303 Index". As explained by Bloomberg: This curve represents Australian dollar-denominated interest-rate swaps. The short end of the curve is made up of Australian bank bill short-term cash rates with a day count of Actual/365. Payments on the long end of the curve are based on a fixed-rate versus a floating-rate with the fixed-rate portion on a semi-annual, Actual/365 day-count basis and the floating-rate on a semi-annual, Actual/365 day-count basis from the Australian bank bill three-month short-term rate BBSW3M. Pricing for long-end terms are a best bid/ask composite from latest quotes and the sources include both banks and brokers.

7.2 Calculation Methods for 30th January 2015

Lally (2014) presents two methods, with both based on using yields as the first term on the right hand side of the equation. The first method uses swaps as the base rate, while the second method uses the yields on CGS as the base rate. Lally (2014) does not explain why he uses yields rather than spreads to swap. However, the notes provided by the RBA state clearly that:

> The estimates [in Table F3] are derived from the spreads to swap of a sample of fixed-rate bonds issued in Australian dollars, US dollars and euros, where the foreign currency-denominated bond spreads of individual bonds are hedged into their Australian dollar-equivalent spreads using cross-currency basis swaps and other relevant interest rate adjustments.

Hence, the RBA regards the values of spreads to swap as being the main "premium" or "index" to be calculated, while the yields on bonds, measured in per cent, are then a derived series.

Below, we show the calculations using spreads to swap as well as yields.

7.2.1 Using Spreads with swaps as Base Rate

Compared to the other approaches, this is one of the simplest. The method involves extrapolating the spreads to swap and then adding the swap rate at the target tenor.

First, we need to calculate the value of a, based on the effective tenors:

$$\begin{aligned} a &= \frac{10 - 8.53}{8.53 - 6.66} \\ &= 0.7861. \end{aligned}$$

We then perform the extrapolation to get the estimated spread to swap at 10 years maturity and add the swap rate for 10 years. Using the expression from section 6, $S_L(10) + (1 + a)\text{S}(10) - a\text{S}(7)$,

$$\begin{aligned} \text{Cost of Debt}(10) &= 1.7861(1.7413\%) - 0.7861(1.9593\%) + \text{Swap}(10) \\ &= 1.5699\% + 2.735\% \\ &= 4.305\% \end{aligned}$$

7.2.2 Using Spreads with CGS as Base Rate

From the RBA's notes attached to Table F3, it is clear that we need to make adjustments so that the spread to CGS figures relate to the effective tenors. The RBA adds the swap to CGS spread for each target tenor, rather than for each effective tenor, to the credit spread to swap.

First, the interpolated swap rates and CGS rates at the effective tenors which correspond to the 7-year and 10-year target tenors are required. These are given in Table 3.

		Effective Tenor	
Target Tenor	Effective Tenor	Swap Rate (Bloomberg)[11]	CGS[12]
7	6.66	2.539	2.183
10	8.53	2.653	2.338

Table 3: Interpolated swap rates and CGS rates at at the effective tenors which correspond to the 7-year and 10-year target tenors, for 30th January 2015

[11] Interpolated swap rates, from Bloomberg ADSWAP series

[12] Interpolated yields on CGS, from Table F16, semi-annual basis.

The adjustments required so that the spread to CGS figures relate to the effective tenors are as follows:

$$\begin{aligned}
\text{Adjusted Spread to CGS}(10) &= \text{Spread to CGS}(10) - \text{Swap}(10) + \text{CGS}(10) + \text{Swap(E10)} - \text{CGS(E10)} \\
&= 2.0583\% - 2.735\% + 2.427\% + 2.653\% - 2.338\% \\
&= 2.0645\% \\
\text{Adjusted Spread to CGS}(7) &= \text{Spread to CGS}(7) - \text{Swap}(7) + \text{CGS}(7) + \text{Swap(E7)} - \text{CGS(E7)} \\
&= 2.3893\% - 2.562\% + 2.214\% + 2.539\% - 2.183\% \\
&= 2.3971\%
\end{aligned}$$

We then perform the extrapolation to get the estimated spread to CGS at 10 years maturity and add the CGS rate for 10 years:

$$\begin{aligned}
\text{Cost of Debt}(10) &= 1.7861(2.0645\%) - 0.7861(2.3971\%) + \text{CGS}(10) \\
&= 1.8031\% + 2.427\% \\
&= 4.2301\%
\end{aligned}$$

7.2.3 Using Yields with Swaps as Base Rate

This is one of the two methods that Lally (2014) recommends, although he prefers using yields with CGS as the base rate. The method involves adding the increment to the spread to swap from the extrapolation to the yield at a 10-year term to maturity.

$$\begin{aligned}
\text{Cost of Debt}(10) &= \text{Yield}(10) + a\,(\text{S}(10) - \text{S}(7)) \\
&= 4.5\% + 0.7861(1.7413\% - 1.9593\%) \\
&= 4.3286\%
\end{aligned}$$

7.2.4 Using Yields with CGS as Base Rate

This is Lally's (2014) recommended method. Adjustments are made to the tabulated yield index.

$$\begin{aligned}
\text{Cost of Debt}(10) &= S(10) + aS(10) - aS(7) \\
&= \text{Yield}(10) - \text{Swap}(10) + \text{Swap(E10)} + \text{CGS}(10) - \text{CGS(E10)} + \\
&= \text{Yield}(10) - \text{Swap}(10) + \text{Swap(E10)} + \text{CGS}(10) - \text{CGS(E10)} + \\
&\quad a\,(\text{Yield}(10) - \text{Swap}(10) + \text{Swap(E10)} - \text{CGS(E10)} - \\
&\quad\quad (\text{Yield}(7) - \text{Swap}(7) + \text{Swap(E7)} - \text{CGS(E7)})) \\
&= 4.5\% - 2.735\% + 2.65268\% + 2.427\% - 2.3384561\% + \\
&\quad 0.7861\,(4.5\% - 2.735\% + 2.65268\% - 2.3384561\% - \\
&\quad\quad ((4.54\% - 2.562\% + 2.53922\% - 2.1834139\%)) \\
&= 4.3061\%
\end{aligned}$$

Note that Lally (2014) gives the result of this calculation for 31st July 2014 as 5.58%, but there is an arithmetic error in his calculation – the correct value is 5.55%. See Appendix E.

8 The SA Power Networks Extrapolation Approach

In their regulatory proposal for 2014-2015 (SA Power Networks, 2014, page 340), the SA Power Networks have suggested an alternative approach. Under their approach, the spreads-to-swap published by the RBA at 3, 5, 7, and 10 year terms to maturity are regressed on the corresponding effective tenors, giving a fitted equation

$$S(J) \quad = \quad a + bE(J); \quad J = 3, 5, 7, 10,$$

and the extrapolated spread to swap value is given by

$$S_{SA}(10) \quad = \quad S(10) + b(10 - E(10)),$$

leading to an estimated cost of debt at 10 years' maturity of

$$\text{Cost of Debt}(10) \quad = \quad \text{Swap}(10) + \text{S}(10) + b(10 - \text{E}(10)).$$

For 30th January 2015, the fitted equation is

$$S(J) \quad = \quad 1.5287 + 0.0378E(J); \quad J = 3, 5, 7, 10,$$

and hence the estimate is given by

$$\begin{aligned}
\text{Cost of Debt}(10) &= \text{Swap}(10) + \text{S}(10) + b(10 - \text{E}(10)) \\
&= 2.735\% + 1.7413\% + 0.0377868(10 - 8.53) \\
&= 2.735\% + 1.7968\% \\
&= 4.5318\%.
\end{aligned}$$

Appendix F shows that the SA Power Networks extrapolation method is also a weighted average:

$$S_{SA}(10) = \sum_{i=1}^{N} v_i(\sigma) S_i$$

with the weights given by

$$v_i(\sigma) = w_i(10, \sigma) + W(10 - E(10))$$

where the $w_i(10, \sigma)$ are the weights associated with the Gaussian kernel, and

$$W = \frac{((4E(3) - D)w_i(3;\sigma) + (4E(5) - D)w_i(5;\sigma) + (4E(7) - D)w_i(7;\sigma) + (4E(10) - D)w_i(10;\sigma))}{4F - D^2}$$

where

$$\begin{aligned}
D &= E(3) + E(5) + E(7) + E(10) \\
F &= E(3)^2 + E(5)^2 + E(7)^2 + E(10)^2.
\end{aligned}$$

Appendix F also shows that the SA Power Networks extrapolation estimate is unbiased to first order, and the bias to second order is given by

$$\text{Bias} = \frac{G''(10)}{2} \times \sum_{i=1}^{N} v_i(\sigma)(Ti - 10)^2$$

while the variance is given by

$$\text{Variance} = \text{Variance}(\varepsilon_i) \times \sum_{i=1}^{N} v_i(\sigma)^2$$

where ε_i is the error from the model

$$S_i = G(T_i) + \varepsilon_i.$$

As an example, for 30th January 2015, the multipliers of $G''(10)$ and Variance(ε_i), are, respectively,

$$\begin{aligned} \frac{1}{2}\sum_{i=1}^{N} v_i(\sigma)(Ti-10)^2 &= -3.964 \\ \sum_{i=1}^{N} v_i(\sigma)^2 &= 0.193 \end{aligned}$$

(see Table 15 in Appendix F) and hence the RMSE, to second order, is well approximated by

$$\begin{aligned} \text{RMSE} &\approx \sqrt{(-3.964)^2 \times (G''(10))^2 + 0.193 \times \text{Variance}(\varepsilon_i)} \\ &= \sqrt{15.713 \times (G''(10))^2 + 0.193 \times \text{Variance}(\varepsilon_i)}. \end{aligned}$$

9 A comparison of Local Linear Smoothing, and the Lally and SA Power Networks Extrapolation Methods

The values of the root mean square errors (RMSEs) obtained under Local Linear Smoothing, the Lally (2014) extrapolation method, and the SA Power Networks extrapolation method depend, to second order, upon the relative sizes of the squared second derivative at the target tenor, and the "pure" random variation. This finding is apparent from the expressions for RMSE presented in sections 5, 6, and 8.

The squared second derivative is, of course, in relation to the spread function at the target tenor. In order to determine the magnitude of the squared second derivative, and the pure random variation, a theoretically correct yield or spread function must first be estimated. The most appropriate yield function to be used was determined to be Nelson-Siegel curves. The Nelson-Siegel yield curve can be differentiated twice with respect to term to maturity, and a further discussion of this issue is provided in section 10. The pure random variation can also be determined from an econometrically estimated Nelson-Siegel yield curve.

The squared second derivative and the pure random variation are multiplied by other factors which are determined using the weights that pertain to each smoothing method. These weights, the expressions for which were provided in in sections 5, 6, and 8, can be regarded as the multipliers for bias and variance.

For the Lally extrapolation method, the weights depend on the kernel used by the RBA (with a standard deviation, $\sigma = 1.5$), and the remaining terms to maturity, and face values of the bonds in the sample. As shown previously, the multipliers for 30th January 2015, are 4.893 and 0.287, respectively. For the SA Power Networks approach, the multipliers are 15.713 and 0.193, respectively.

For Local Linear Smoothing, we can also choose the smoothing parameter, σ. Figure 1 shows a plot of the two multipliers for various values of σ between 1 and 3. Smaller values of σ (less smoothing), reduce the bias but increase the variance. In contrast, higher values of σ (more smoothing), increase the bias but reduce the variance. Based on the work performed in ESQUANT (2014), the value of σ was set to be 2.4.

The mechanical calculations to be applied under the Lally (2014) extrapolation method, and the SA Power Networks extrapolation method can be implemented using the data published by the RBA in Table F3. Figure 2 presents a comparison of the results obtained by applying the Lally (2014) and SA Power Networks techniques over the period from January 2005 to February 2015. The graph shows,

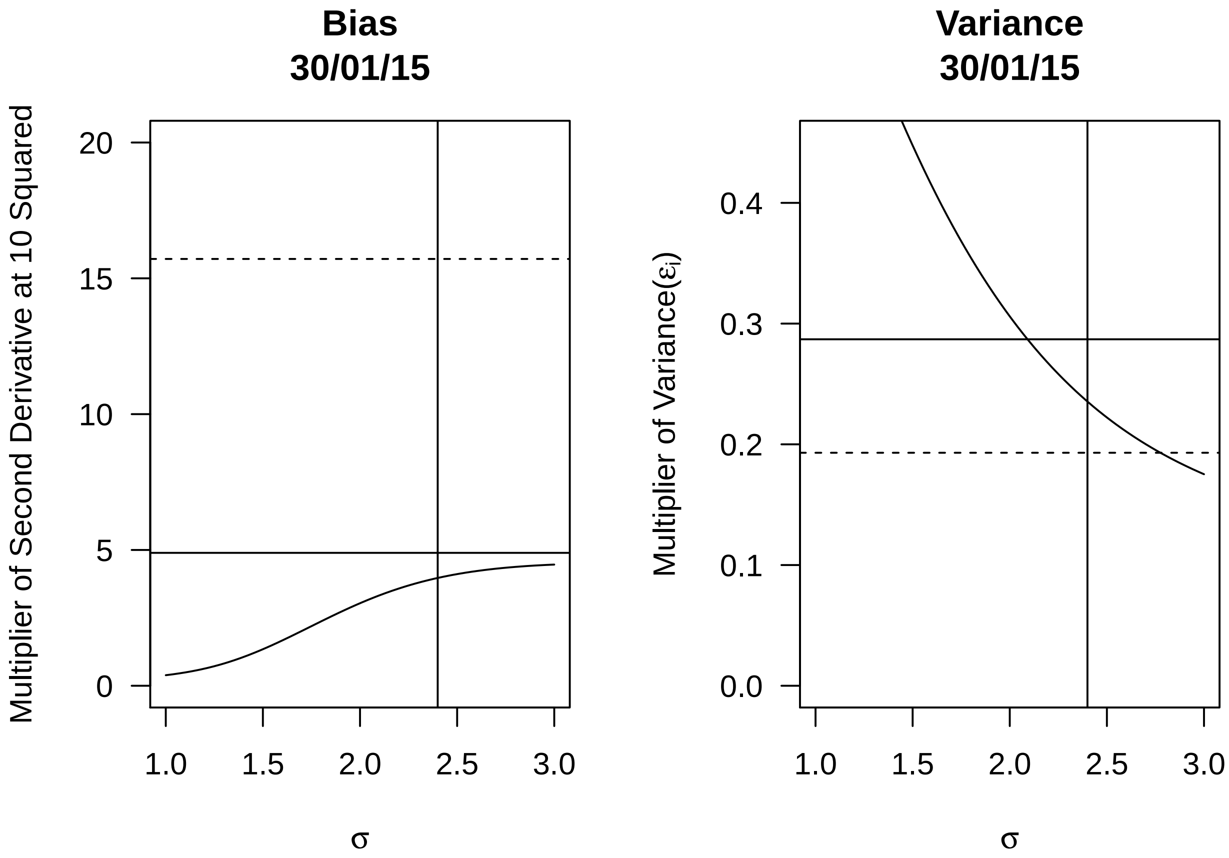

Figure 1: Bias and Variance as a function of the smoothing parameter σ for local linear smoothing, for 30th January 2015. The horizontal lines give the corresponding values on the y-axis for the Lally method (solid line) and for the SA Power Networks method (dotted line). Note that the Lally method and the SA Power Networks method do not make use of smoothing parameters.

for each month, the extent of the extrapolation. The plot suggests that the Lally (2014) method can, on occasion, produce more pronounced results than the SA Power Networks method.

Local linear smoothing, the Lally (2014) method and the SA Power Networks extrapolation method were implemented in full using bond data from the CEG RBA replication model. The model contains data on option adjusted spreads, and on a range of other variables, with daily observations available on a continuous basis from 1st November 2013 to 30th January 2015. A sample of the Gaussian kernel results from the CEG RBA replication model is provided in Appendix C. A further discussion of those results, and of the methods employed in the RBA replication model, is available in Appendix A, CEG (2015). The empirical work that was undertaken for this report by ESQUANT made use of the end-of-month results from the RBA replication model. Thus, the data on corporate bonds was sourced for a single day for each month from November 2013 to January 2015.

There would be no means of testing the three extrapolation methods without detailed bond data. The information published by the RBA in Table F3 would, in and by itself, not be adequate. The variables that were used from the CEG model included: Bloomberg identifiers for the component bonds; the coupon type (only fixed rate bonds conform to the RBAs selection criteria); credit rating on the day in question; currency of denomination; remaining term to maturity; issue date; option-adjusted spread and implied yield; and the size of the bond issue (in Australian dollars).

By way of example, a total of 62 corporate bonds with broad BBB credit ratings from Standard and Poors, were available for analysis in respect of 30th January 2015. These bonds satisfied the RBAs stated selection criteria.

The weights to be applied under the three smoothing methods were calculated and the results are reported in Table 10 (for Local Linear Smoothing), Table 14 (the Lally extrapolation method), and

Table 15 (the SA Power Networks extrapolation method). These tables show the outcomes for 30th January 2015 alone, and therefore provide only a snapshot of the results for the period as a whole (November 2013 to January 2015).

For the longer time series data, Table 4 presents a comparison of the bias and variance multipliers under Local Linear Smoothing, the Lally (2014) method, and the SA Power Networks method. The results for successive months indicate that the SA Power Networks approach has a lower variance than the Lally method, although the lower variance appears to have been "traded off" for more bias. However, as is demonstrated in a later section, the variance is more important than the bias in the context of the overall research performed for this report.

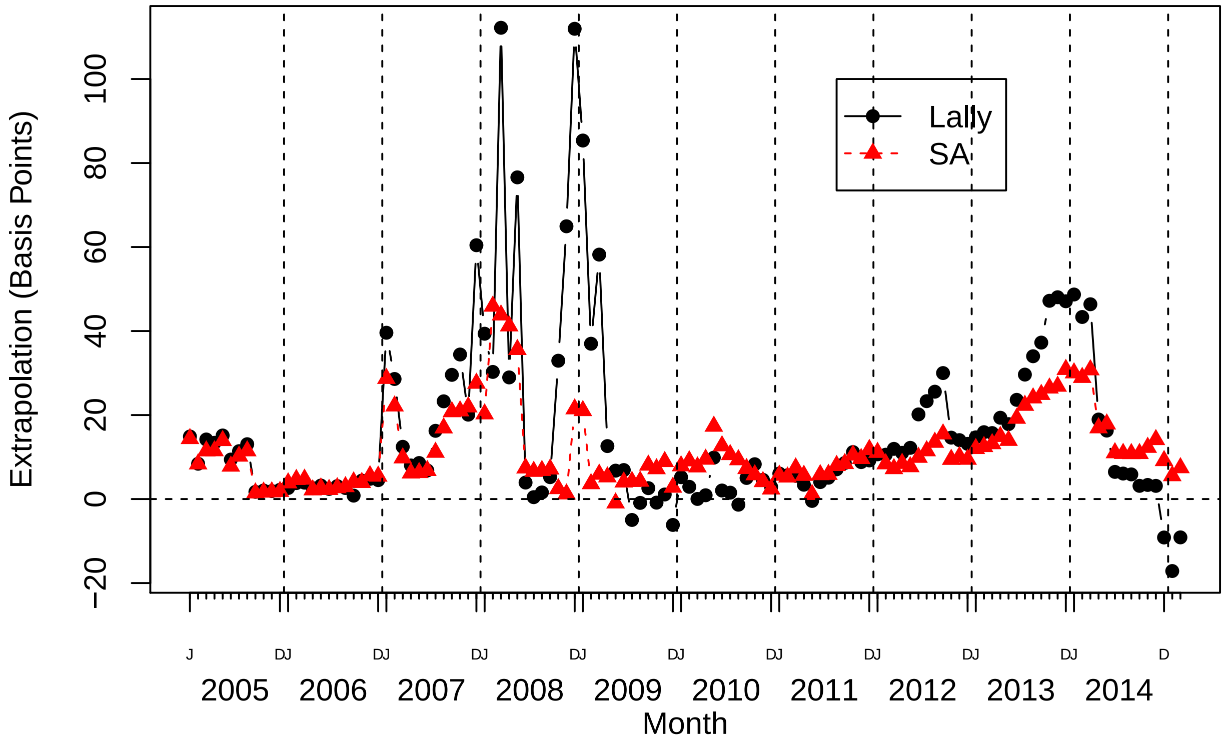

Figure 2: Comparison of Lally extrapolation approach (Black) and SA Power Networks method (Red) over time

Table 4 shows a comparison of the bias and variance multipliers for Local Linear Smoothing, the Lally method, and the SA Power Networks method. It is not surprising that the SA Power Networks approach has a lower variance than the Lally method, although this comes at the cost of more bias. However, as shown in a later section, in this case the variance is more important than the bias.

10 Nelson-Siegel Models

Non-parametric methods, such as the kernel smoothing method proposed by the RBA (Arsov et al., 2013) do not assume a functional form for the relationship between the dependent variable and the independent variable, in this case the average bond spread and term to maturity, respectively. Generally, non-parametric methods are not as precise as parametric methods but they do avoid the possible bias that can occur if the assumed parametric model is incorrect (See, for example, James et al., 2013, p 23).

The most commonly used parametric technique is that due to Nelson and Siegel (1987). The Nelson-Siegel model is non-linear and must generally be estimated using the method of maximum

	Bias			Variance		
	Multiplier of 2nd Deriv			Multiplier of Variance(ε)		
	Local Linear	Lally	SA	Local Linear	Lally	SA
Nov13	-2.67	-2.20	-4.89	0.17	0.19	0.12
Dec13	-2.80	-2.33	-5.05	0.19	0.22	0.13
Jan14	-2.99	-2.49	-5.30	0.20	0.23	0.14
Feb14	-3.16	-2.63	-5.53	0.21	0.25	0.14
Mar14	-3.35	-2.78	-5.88	0.23	0.27	0.14
Apr14	-2.21	-1.90	-4.49	0.24	0.25	0.15
May14	-2.37	-2.02	-4.67	0.26	0.27	0.16
Jun14	-1.68	-1.74	-4.14	0.20	0.22	0.14
Jul14	-1.71	-1.83	-4.03	0.22	0.24	0.15
Aug14	-1.84	-1.96	-4.20	0.23	0.26	0.16
Sep14	-1.54	-1.68	-3.43	0.19	0.22	0.15
Oct14	-1.65	-1.79	-3.65	0.20	0.23	0.16
Nov14	-1.77	-1.93	-3.78	0.21	0.25	0.17
Dec14	-1.87	-2.06	-3.81	0.23	0.27	0.18
Jan15	-1.99	-2.21	-3.96	0.23	0.29	0.19

Table 4: Multipliers for Bias and Variance, end-of-month periods for Local Linear Smoothing ($\sigma = 2.4$), the Lally extrapolation method, and the SA Power Networks extrapolation approach.

likelihood. Arsov et al. (2013) report difficulties with fitting the Nelson-Siegel model. Annaert et al. (2013) explain methods which can be used to help overcome these computational problems.

In separate exercises, CEG (Hird, 2013c) and ESQUANT (Diamond et al., 2013b) have successfully estimated Nelson-Siegel yield curves for large groups of corporate bonds in credit rating bands from A minus to BBB. The data samples were comprised of bonds issued by Australian corporations in Australian dollars and in foreign currencies, as well as Australian dollar bonds placed in the domestic market by foreign corporations. Fixed rate, bullet bonds were considered, as were bonds with optionality features, and floating rate notes. A number of different specifications of the Nelson-Siegel yield curve were trialed.

The Nelson-Siegel model (Nelson and Siegel, 1987) relates the expected yield of a bond, $R(m)$, to its remaining term to maturity, m, as

$$R(m) = \beta_0 + (\beta_1 + \beta_2)\left(\frac{1 - \exp(-m/\tau)}{m/\tau}\right) - \beta_2 \exp(-m/\tau)$$

where $\tau, \beta_0, \ldots, \beta_2$ are parameters to be estimated. The parameter τ is described as the shape parameter, with its value sometimes motivated by prior knowledge about the curvature of spot rates.

Diebold and Li (2006) suggest an alternative parameterization:

$$y(\tau) = \beta_1 + \beta_2\left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\right) + \beta_3\left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right)$$

where $y(\tau)$ is the expected yield of a bond with maturity τ, β_1 is interpreted as the loading on the "long-term" factor, β_2 is interpreted as the loading on the "short-term" factor, and β_3 is interpreted as the loading on the "medium-term" factor.

The equivalence between the two specifications is given below:

Nelson-Siegel	Diebold and Li
$R(m)$	$y(\tau)$
β_0	β_1
β_1	β_2
β_2	β_3
m	τ
τ	$\frac{1}{\lambda}$

Note that τ is used as a parameter in the Nelson and Siegel formulation but as the Maturity in the Diebold and Li formulation.

Diebold and Li's (2006) specification can be written as a function of three components, F_1, F_2, and F_3, called the 'long-term', 'short-term', and 'medium-term' components with

$$\begin{aligned} y(\tau) &= \beta_1 F_1 + \beta_2 F_2 + \beta_3 F_3 \\ F_1 &= 1 \\ F_2 &= \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) \\ F_3 &= \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right) \end{aligned}$$

Diebold and Li (2006) suggest that, if the maturity is measured in months, that λ be set at 0.0609, since at that value the medium term factor (denoted by F_3) is at a maximum when the maturity is 30 months[13]. Diebold and Li (2006) stated that most of the humps and troughs in the spot rate function are between the second and third years. Fixing λ allows the Nelson-Siegel model to be fitted by Ordinary Least Squares. If λ is estimated, then non-linear least squares is required.

Following CEG (Hird, 2013) and ESQUANT (Diamond et al., 2013b), dummy terms were added to take into account the different credit ratings. The model fitted was then

$$y(\tau) = \beta_1 + \beta_2 \left(\frac{1 - e^{-\tau e^{\beta_0}}}{\tau e^{\beta_0}} \right) + \beta_3 \left(\frac{1 - e^{-\tau e^{\beta_0}}}{\tau e^{\beta_0}} - e^{-\tau e^{\beta_0}} \right) + \beta_4 \text{BBB-} + \beta_5 \text{BBB+}$$

where BBB- is a dummy variable taking the value 1 for BBB- stocks and 0 elsewhere; and similarly BBB+ is a dummy variable taking the value 1 for BBB+ stocks and 0 elsewhere, and the λ parameter, which should be positive, has been reparameterised as

$$\lambda = e^{\beta_0}.$$

The model assumes that the curves for the different credit ratings are parallel, an assumption that has been validated using a statistical hypothesis test by Diamond et al. (2013, section 4.3). See also, Appendix G.

The Nelson-Siegel yield curve can be differentiated twice with respect to term to maturity. The second derivative of the Nelson-Siegel yield equation, with respect to trem to maturity, measures the rate of change of the slope (in percentage terms). This number would be expected to be small. The squared second derivative can be calculated using the D function in R, and the result shown below was produced:

---

[13] Dr Li has confirmed that the correct number should be 0.0598, rather than the value 0.0609 quoted in the paper and the following literature. For daily data, the maximum was in fact 0.001964-this was rounded to 0.002. Multiplying 0.002 by 365.25/12, the value 0.0609 was obtained. For maturities measured in years the implied value of λ is 0.7176 using the correct 0.0598.

$$
\begin{aligned}
(y''(\tau))^2 = {} & (-(\beta_3 * (\exp(-\exp(\beta_0) \times \tau) \times \exp(\beta_0) \times \exp(\beta_0) + (\exp(-\exp(\beta_0) \times \tau) \times \\
& \exp(\beta_0) \times \exp(\beta_0)/(\exp(\beta_0) \times \tau) + \exp(-\exp(\beta_0) \times \tau) \times \\
& \exp(\beta_0) \times \exp(\beta_0)/(\exp(\beta_0) \times \tau)^2 + (\exp(-\exp(\beta_0) \times \tau) * \\
& \exp(\beta_0) \times \exp(\beta_0)/(\exp(\beta_0) \times \tau)^2 - (1 - \exp(-\exp(\beta_0) \times \tau)) * \\
& \exp(\beta_0) \times (2 \times (\exp(\beta_0) \times (\exp(\beta_0) \times \tau)))/((\exp(\beta_0) \times \tau)^2)^2))) + \\
& (\beta_2 \times (\exp(-\exp(\beta_0) \times \tau \times \exp(\beta_0) \times \\
& \exp(\beta_0))/(\exp(\beta_0) \times \tau) + \beta_2 \times (\exp(-\exp(\beta_0) \times \tau) \times \\
& \exp(\beta_0)) \times \exp(\beta_0)/(\exp(\beta_0) \times \tau)^2 + (\beta_2 \times \\
& (\exp(-\exp(\beta_0) \times \tau) \times \exp(\beta_0)) \times \exp(\beta_0)/(\exp(\beta_0) \times \tau)^2 - \\
& \beta_2 \times (1 - \exp(-\exp(\beta_0) \times \tau)) \times \exp(\beta_0) \times \\
& (2 \times (\exp(\beta_0) \times (\exp(\beta_0) \times \tau)))/((\exp(\beta_0) \times \tau)^2)^2))))^2
\end{aligned}
$$

The curves were fitted to the data supplied by CEG, using the nlsLM command in the minpack.lm package in R (Elzhov et al. 2013). Initially, the empirical work was done for a single day only, 30th January 2015. The curves were estimated using yield data rather than the spreads-to-swap data. The estimated parameters are given in Table 5 (unadjusted for credit ratings) and Table 6 (adjusted for differences in credit ratings), while the sample bond yields and fitted Nelson-Siegel curves are plotted in Figure 3. The fitted values for yield at a 10-year tenor could be converted back into spreads-to-swap by subtracting 10-year tenor swap rates from the predicted yields. The swap rates for specific tenors were themselves calculated by applying an interpolation method to the observed data on vanilla interest rate swaps (which, as described elsewhere, was sourced from Bloomberg)[14].

	Estimate	Std. Error	t value	Pr(>|t|)
beta0	0.18	0.53	0.34	0.73
beta1	5.38	0.51	10.57	0.00
beta2	5.94	9.76	0.61	0.54
beta3	-13.60	11.08	-1.23	0.22

Table 5: Estimated parameters for the Nelson-Siegel curve for 30th January 2015. The units of the parameters β_1, β_2, and β_3 are per cent.

	Estimate	Std. Error	t value	Pr(>|t|)
beta0	-0.06	0.34	-0.18	0.86
beta1	5.64	0.47	12.09	0.00
beta2	3.74	4.43	0.84	0.40
beta3	-12.04	5.04	-2.39	0.02
beta4	1.18	0.18	6.73	0.00
beta5	-0.32	0.14	-2.27	0.03

Table 6: Estimated parameters for the Nelson-Siegel curve for 30th January 2015 after adjusting for credit ratings. The units of the parameters $\beta_1, \ldots, \beta_5$ are per cent.

To obtain the estimated spread at 10 years, the fitted values for BBB bonds, BBB- bonds, and BBB+ bonds were weighted by the number of bonds in the three credit ratings, in this case 37, 9, and 16, respectively. The results are given in Table 7.

[14]For the period under consideration, daily values of swap rates were obtained for the Australian dollar swaps curve. The relevant series in Bloomberg includes, as its constituents, variables such as "ADSWAP10 Curncy".

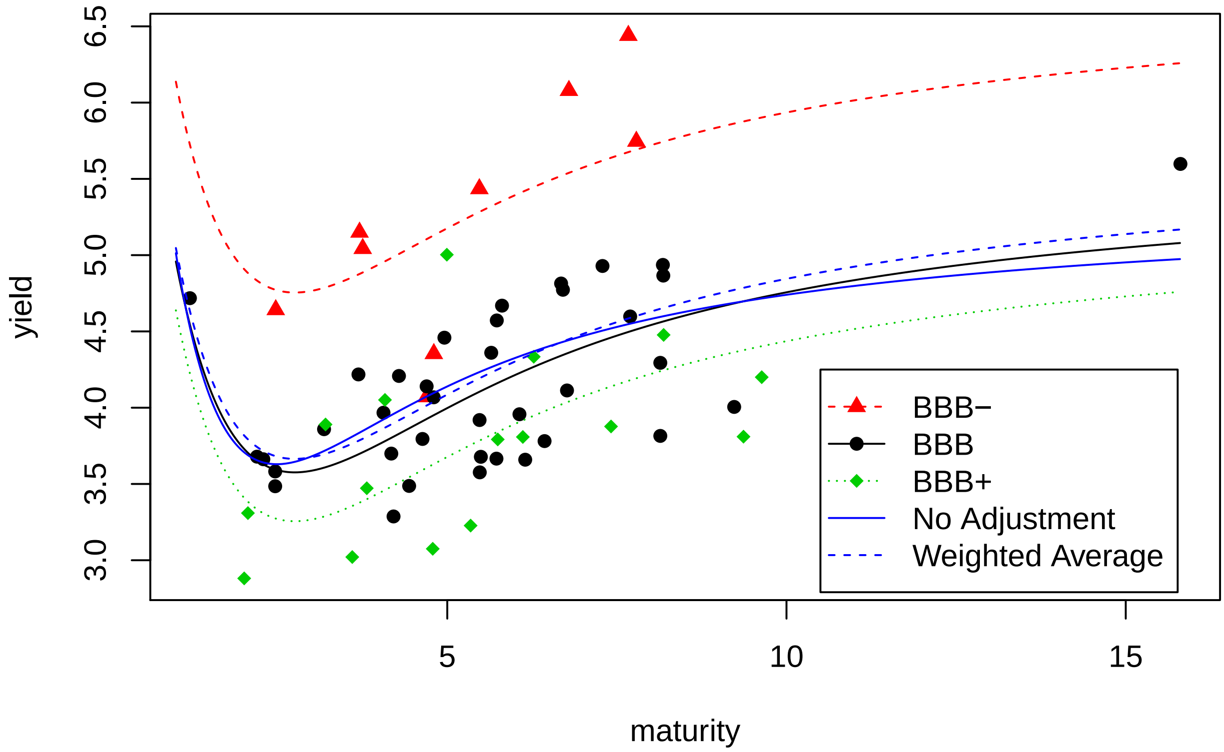

Figure 3: Fitted Nelson-Siegel curve for 30 January 2015

	Yield(10)	Swap(10)	Spread(10)	Weight
BBB-	5.935	2.735	3.200	0.145
BBB	4.756	2.735	2.021	0.597
BBB+	4.436	2.735	1.701	0.258
Weighted Average	4.845	2.735	2.110	

Table 7: Predicted Spread at 10 years from Nelson-Siegel model, for 30th January 2015. The units for Yield(10), Swap(10), and Spread(10) are per cent.

11 Some comparisons

11.1 Adjusting the results from the smoothing methods

Measures were taken to adjust the results from the different smoothing methods for differences between bonds in terms of their credit rating within the broad BBB band. The backfitting algorithm given by Hastie et al. (2009, p 297-298) was used to determine adjusted spreads. Using the amended spreads should improve the estimation of the smoothers.

The steps of the backfitting algorithm are as follows:

1. Calculate the average spread across the whole sample and subtract the result from all of the data.
2. Set "oldd"=0 and "olds"=0. These are vectors of the adjustments for the credit ratings and the corrected smoothed value respectively.
3. Cycle the following steps until convergence:
   (a) Fit a linear model of (demeaned Credit Spread from step 1 minus olds) versus Credit rating. Save the demeaned fitted values and call them "newd".

(b) Fit the smoother to the (demeaned Credit Spread minus oldd) versus Term to Maturity. Save the demeaned fitted values and call them "news".

(c) Set oldd=newd and olds=news.

It only takes a small number of iterations (typically less than 20) for the algorithm to converge to a solution. The adjusted spreads are given by the (average spread − oldd).

11.2 Bootstrap standard errors

Any statistic should have a standard error attached to it, so that the user can evaluate the information that the statistic is supposed to convey. To determine the standard errors, bootstrap resampling was applied. Case-based resampling was conducted: 1,000 data sets were sampled with replacement from the original data set, and for each data set, each of the methods was applied. The results are given in Table 8.

	Estimate	Standard Error
Nelson-Siegel No Adjustment	2.005	0.238
Lally No Adjustment	1.521	0.338
Local Linear No Adjustment	1.623	0.305
SA No Adjustment	1.750	0.291
Nelson-Siegel Adjustment	2.110	0.194
Lally Adjustment	1.685	0.224
Local Linear Adjustment	1.761	0.226
SA Adjustment	1.848	0.223

Table 8: Comparison of Predicted Spreads at 10 years' maturity, with bootstrap standard errors (N=1,000). Results are for 30th January 2015.

The relative sizes of the standard errors are as would be predicted from the expressions for the variances of the respective smoothers. It is clear that adjusting for credit ratings is worthwhile, with more precision obtained when adjusting than otherwise. The results also show that the smoothers are relatively imprecise when assessed in relation to the fitted Nelson-Siegel yield curves.

The results from the smoothing methods are biased downwards relative to the results from the Nelson-Siegel method. An *a priori* expectation was that the SA Power Networks method would be more biased than Local Linear Smoothing and the Lally approach, but that particular outcome has not been recorded from this exercise.

12 Analysis of Monthly Data

Bond data for the last working day of the month, from November 2013 through to January 2015, was analysed using Nelson-Siegel methods as well as the Lally (2014) method, Local Linear Smoothing, and the SA Power Networks approach. As was mentioned in section 5, the bond data was supplied by CEG and was sourced from CEG's RBA replication model. Figure 4 presents the data as well as the fitted Nelson Siegel yield curves.

From month to month, the movements in the Nelson-Siegel yield curves are quite steady. In addition, for many months, the curvature is relatively minor and the curves could be adequately represented by straight lines. The standard deviation of the residuals from the Nelson-Siegel regressions, and the second derivatives of the fitted curves were calculated using the data for each month, and the results are shown in the first two columns of Table 9. These values were combined with the bias and variance multipliers given in Table 4 to estimate the RMSE, which is shown in the last three columns of Table 9, and has also been plotted in Figure 5.

From an examination of Figure 5, it is clear that

- Local Linear smoothing (with $\sigma = 2.4$) performs better than the Lally (2014) method.

- The SA Power Networks method shows superior performance by comparison with the Lally (2014) method over all of the months that have been considered.

Note that the performance of local linear smoothing could be improved by comparison with the SA Power Networks method, if σ were increased.

The SA Power Networks method delivers a lower RMSE than the Lally (2014) method in every month that has been examined because curves extrapolated under the SA Power technique are relatively straight, and the variability is low when compared against the bias. The SAPN method is therefore better overall. An important consideration, however, is that if an historical average of extrapolated results is needed for a period which extends into the past, then there would be merit in using a method that is less susceptible to bias. The Lally (2014) method reports less bias than the SA Power Networks method. The process of arithmetic averaging will bring down variance but will not result in a diminution in bias.

There is therefore theoretical and empirical support for the approach that has been taken by CEG (2015) to calculate an historical average spread over swap. CEG has used data from RBA Table F3 to calculate spreads over swap for each financial year from 2005-06 to 2013-14[15]. A uniform extrapolation method, notably the Lally (2014) method has been applied over each of the time periods, although CEG has also investigated alternative extrapolation approaches. CEG has concluded that (CEG, 2015, paragraph 243):

> The AER draft decision extrapolation methodology is the most appropriate over the 9 years from 2005/06 to 2013/14.

Note that CEG is referring to the Lally (2014) method when it describes the "AER draft decision extrapolation methodology"[16].

			RMSE		
	$\mathrm{sd}(\epsilon_i)$	$G''(10)$	Local Linear	Lally	SA
Nov13	0.628	-0.014	0.262	0.276	0.224
Dec13	0.600	-0.015	0.266	0.281	0.230
Jan14	0.590	-0.006	0.266	0.284	0.220
Feb14	0.468	-0.012	0.220	0.234	0.189
Mar14	0.482	-0.018	0.237	0.253	0.211
Apr14	0.509	-0.008	0.250	0.254	0.200
May14	0.492	-0.011	0.250	0.255	0.203
Jun14	0.458	-0.004	0.206	0.215	0.171
Jul14	0.517	-0.000	0.241	0.255	0.202
Aug14	0.503	-0.002	0.239	0.255	0.202
Sep14	0.479	-0.005	0.211	0.223	0.187
Oct14	0.458	-0.009	0.208	0.222	0.185
Nov14	0.418	-0.015	0.195	0.210	0.180
Dec14	0.421	-0.026	0.206	0.226	0.206
Jan15	0.468	-0.017	0.229	0.253	0.216

Table 9: $\mathrm{sd}(\epsilon_i)$, Second Derivatives at 10 years term to maturity, and RMSE for Nelson-Siegel curves. The units for the second derivative are percent. The $\mathrm{sd}(\epsilon_i)$ are measured by the standard errors of the regressions.

[15]CEG (2015) has also presented calendar year trailing averages for the spread over swap (Appendix F of CEG report). The same draft decision extrapolation methodology has been employed.

[16]The draft decisions to which CEG is referring are the draft decisions made by the Australian Energy Regulator for NSW regulated distribution and transmission businesses in November 2014. See, for instance: AER, Draft decision, Jemena Gas Networks (NSW) Ltd., Access arrangement 2015 – 20, Attachment 3: Rate of return, November 2014.

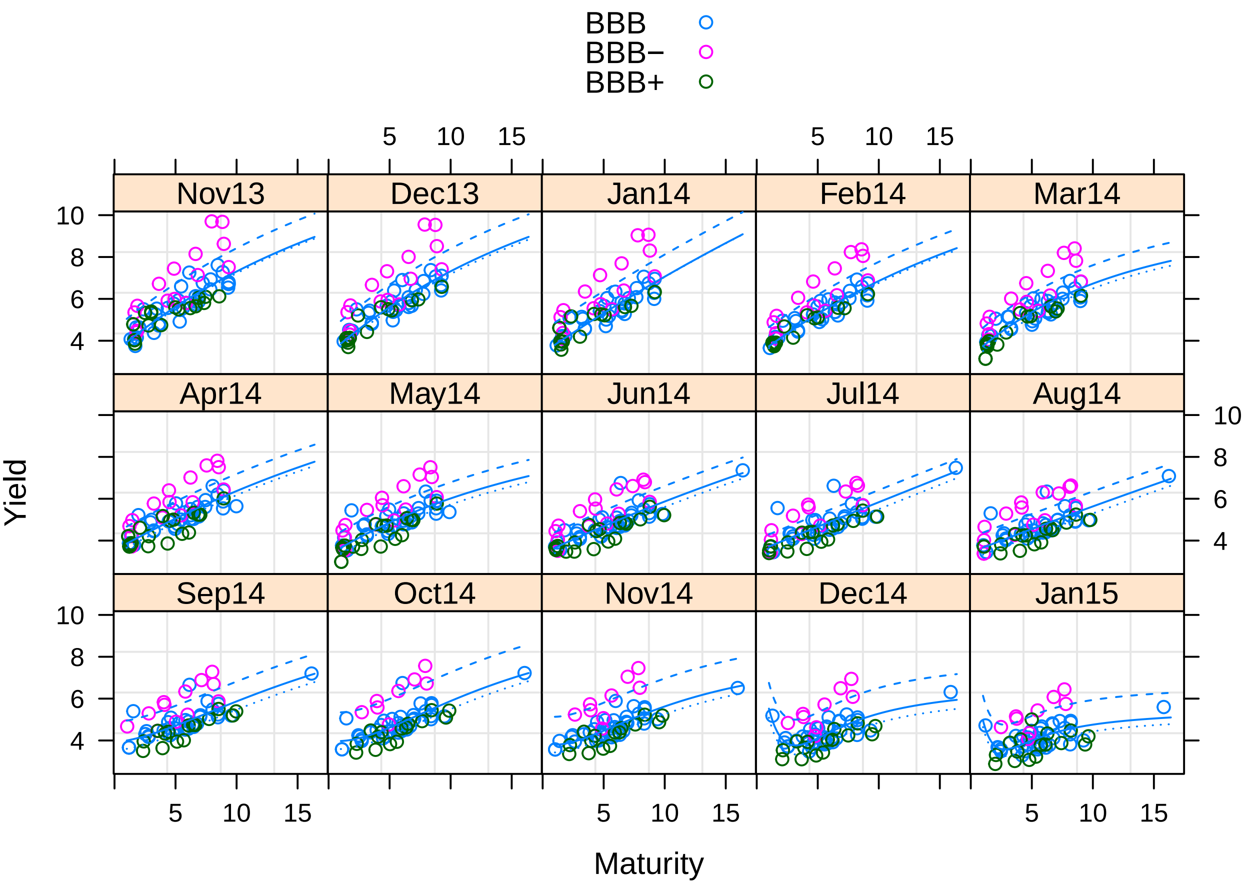

Figure 4: Data for the last business day of the month, November 2013 to January 2015, with fitted Nelson-Siegel yield curves.

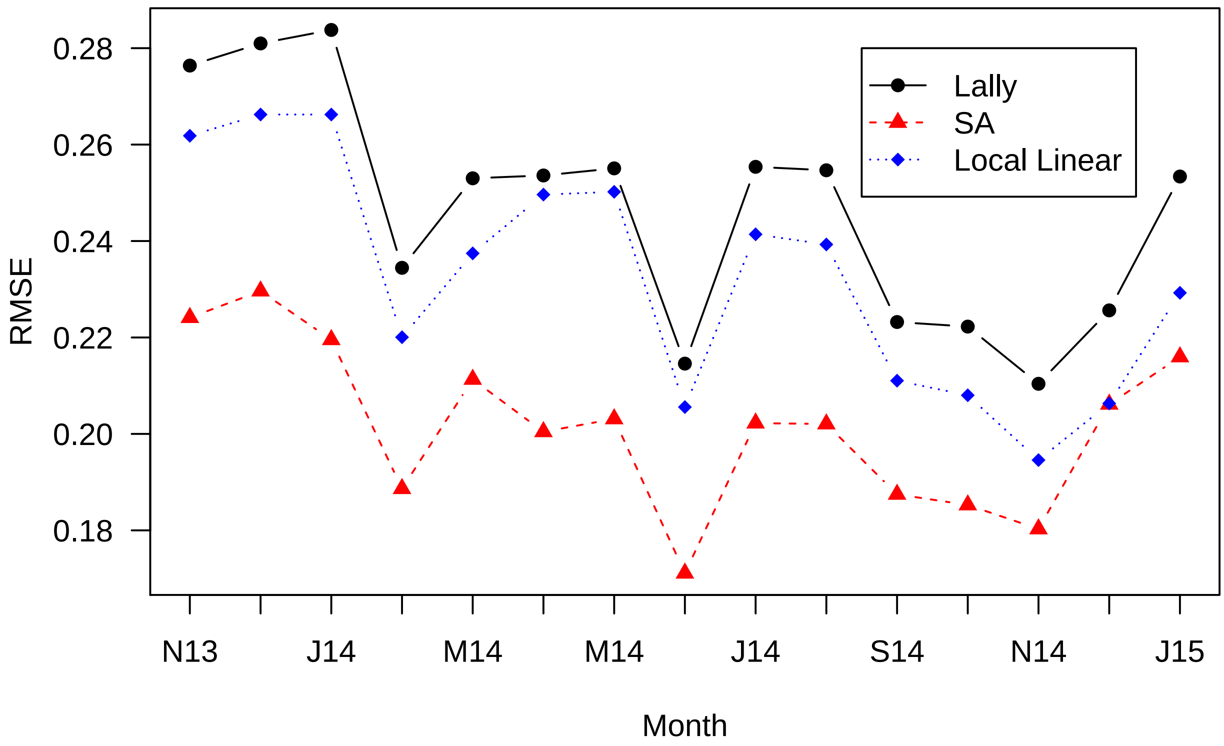

Figure 5: Comparison of RMSE for the Lally Method, SA Power Networks Method, and Local Linear Smoothing from November 2013 to January 2015; based on variance and second derivative at a 10-year term to maturity of the fitted Nelson-Siegel model.

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A Properties of the RBA Gaussian Kernel average credit spread

The RBA's Gaussian Kernel average credit spread is a solution of a least squares problem given by

$$\min_{S(T)} \sum_{i=1}^{N} F_i K(T_i - T; \sigma) \left[S_i - S(T)\right]^2,$$

that is, for each Tenor the assumption is that a constant is to be estimated. The derivative of the function with respect to $S(T)$ is given by

$$-2 \sum_{i=1}^{N} F_i K(T_i - T; \sigma) \left[S_i - S(T)\right].$$

and setting this to zero

$$\sum_{i=1}^{N} F_i K(T_i - T; \sigma) S_i = S(T) \sum_{i=1}^{N} F_i K(T_i - T; \sigma)$$

leading to

$$\begin{aligned} S(T) &= \frac{\sum_{i=1}^{N} F_i K(T_i - T; \sigma) S_i}{\sum_{j=1}^{N} F_j K(T_j - T; \sigma)} \\ &= \sum_{i=1}^{N} w_i(T; \sigma) S_i \end{aligned}$$

with

$$w_i(T; \sigma) = \frac{F_i K(T_i - T; \sigma) S_i}{\sum_{j=1}^{N} F_j K(T_j - T; \sigma)}.$$

Let the true spread curve be $G(t)$ with derivative $G'(t)$, where t denotes a term to maturity. The expected value of the local constant smoother at the target maturity T is given by

$$\begin{aligned} E[S(T)] &= \sum_{i=1}^{N} w_i(T; \sigma) G(T_i) \\ &= \sum_{i=1}^{N} w_i(T; \sigma) \left(G(T) + (T_i - T) G'(T) + \text{higher order terms}\right) \\ &= G(T) \sum_{i=1}^{N} w_i(T; \sigma) + \sum_{i=1}^{N} w_i(T; \sigma)\,(T_i - T)\, G'(T) + \text{higher order terms} \\ &= G(T) + \sum_{i=1}^{N} w_i(T; \sigma)\,(T_i - T)\, G'(T) + \text{higher order terms} \\ &= G(T) + (\text{Effective Tenor} - \text{Target Tenor}) \times G'(T) + \text{higher order terms} \end{aligned}$$

Hence the bias (to first order) is given by

$$(\text{Effective Tenor} - \text{Target Tenor}) \times (\text{Slope at Target Tenor})$$

as given by Arsov et al. (2013).

B Properties of Local Linear Smoothing

As pointed out by Hastie et al. (2009, p 195) locally weighted regression solves a separate weighted least squares problem at each target tenor T:

$$S_{LL}(T) = \min_{\alpha(T),\beta(T)} \sum_{i=1}^{N} F_i k_i [S_i - \alpha(T) - \beta(T) T_i]^2$$

Hastie et al (2009, p195) make the following definitions: They define the vector-values function $b(T)' = (1, T)$, the $N \times 2$ "regression matrix" $\mathbf{B}$ with ith row $b(T_i)'$, and $\mathbf{W}(T)$ the $N \times N$ diagonal matrix with ith diagonal element $F_i k_i$. They give (in equations 6.8 and 6.9) the estimate at T as

$$S_{LL}(T) = \sum_{i=1}^{n} l_i(T;\sigma) S_i$$

where

$$l_i(T;\sigma) = b(T)'(\mathbf{B}'\mathbf{W}(T)\mathbf{B})^{-1}\mathbf{B}'\mathbf{W}(T).$$

Note that

$$\mathbf{B}'\mathbf{W}(T)\mathbf{B} = \begin{pmatrix} \sum_{i=1}^{n} F_i k_i & \sum_{i=1}^{n} F_i k_i T_i \\ \sum_{i=1}^{n} F_i k_i T_i & \sum_{i=1}^{n} F_i k_i T_i^2 \end{pmatrix} = \begin{pmatrix} A & B \\ B & C \end{pmatrix}.$$

The inverse is given by

$$\frac{1}{AC - B^2} \begin{pmatrix} C & -B \\ -B & A \end{pmatrix}$$

and therefore

$$b(T)'(\mathbf{B}'\mathbf{W}(T)\mathbf{B})^{-1} = \frac{1}{AC - B^2} \begin{pmatrix} C - TB & AT - B \end{pmatrix}.$$

Also

$$\mathbf{B}'\mathbf{W}(T) = \begin{pmatrix} F_1 k_1 & F_2 k_2 & \dots & F_N k_N \\ F_1 k_1 T_1 & F_2 k_2 T_2 & \dots & F_N k_N T_N \end{pmatrix}.$$

Hence

$$l_i(T;\sigma) = \frac{k_i F_i (C - TB) + k_i F_i T_i (TA - B)}{AC - B^2}.$$

The sum of the weights

$$\begin{aligned} \sum_{i=1}^{N} l_i(T;\sigma) &= \frac{1}{AC - B^2} \left((C - TB) \sum_{i=1}^{N} k_i F_i + (TA - B) \sum_{i=1}^{N} k_i F_i T_i \right) \\ &= \frac{(C - TB)A + (TA - B)B}{AC - B^2} \\ &= 1 \end{aligned}$$

Also,

$$
\begin{aligned}
\sum_{i=1}^{N} l_i(T;\sigma)(T_i - T) &= \sum_{i=1}^{N} l_i(T;\sigma)T_i - T \\
&= \frac{1}{AC-B^2}\left((C-TB)\sum_{i=1}^{N} k_iF_iT_i + (TA-B)\sum_{i=1}^{N} k_iF_iT_i^2\right) - T \\
&= \frac{1}{AC-B^2}\left((C-TB)B + (TA-B)C\right) - T \\
&= \frac{1}{AC-B^2}\left(CB - TB^2 + TAC - BC\right) - T \\
&= \frac{1}{AC-B^2}\left(TAC - TB^2\right) - T \\
&= 0.
\end{aligned}
$$

Using a Taylor Series about the target tenor of 10 years,

$$
\begin{aligned}
E[S_{LL}(10)] &= \sum_{i=1}^{N} l_i(10;\sigma)G(T_i) \\
&= \sum_{i=1}^{N} l_i(10;\sigma)\Bigg(G(10) + G'(10)(T_i - 10) + \\
&\qquad \frac{G''(10)}{2}(t_i - 10)^2 + \text{higher order terms}\Bigg) \\
&= G(10)\sum_{i=1}^{N} l_i(10;\sigma) + G'(10)\sum_{i=1}^{N} l_i(10;\sigma)(T_i - 10) + \\
&\qquad \frac{G''(10)}{2}\sum_{i=1}^{N} l_i(10;\sigma)(Ti - 10)^2 + \text{higher order terms} \\
&= G(10) + G'(10)\sum_{i=1}^{N} l_i(10;\sigma)(T_i - 10) + \\
&\qquad \frac{G''(10)}{2}\sum_{i=1}^{N} l_i(10;\sigma)(Ti - 10)^2 + \text{higher order terms}
\end{aligned}
$$

and as has already been demonstrated,

$$
\begin{aligned}
\sum_{i=1}^{N} l_i(10;\sigma)(T_i - 10) &= \sum_{i=1}^{N} l_i(10;\sigma)T_i - 10 \\
&= 0
\end{aligned}
$$

and hence, to first order, the local linear estimate is unbiased. The bias to second order is therefore given by

$$
\text{Bias} = \frac{G''(10)}{2}\sum_{i=1}^{N} l_i(10;\sigma)(Ti - 10)^2
$$

while the variance is given by (see, Hastie, Tibshirani, and Friedman, 2009, p. 197)

$$
\text{Variance} = \text{Variance}(\varepsilon_i)\sum_{i=1}^{N} l_i(10;\sigma)^2
$$

where ε_i is the error from the model

$$
S_i = G(T_i) + \varepsilon_i.
$$

Finally the Root Mean Square Error (RMSE) is given by

$$
\text{RMSE} = \sqrt{\text{Bias}^2 + \text{Variance}}.
$$

	T_i	Issue Wt.	$w_i(10,\sigma)$	$l_i(10;\sigma)$	$l_i^2(10;\sigma)$	$\frac{1}{2}l_i(\sigma)(T_i-10)^2$
1	1.21	0.0101	0.0000	-0.0002	0.0000	-0.0085
2	2.01	0.0091	0.0000	-0.0005	0.0000	-0.0174
3	2.06	0.0146	0.0000	-0.0009	0.0000	-0.0293
4	2.20	0.0097	0.0000	-0.0007	0.0000	-0.0218
5	2.29	0.0067	0.0000	-0.0006	0.0000	-0.0165
6	2.46	0.0091	0.0000	-0.0009	0.0000	-0.0258
7	2.46	0.0109	0.0000	-0.0011	0.0000	-0.0310
8	2.47	0.0060	0.0000	-0.0006	0.0000	-0.0172
9	3.18	0.0261	0.0000	-0.0053	0.0000	-0.1230
10	3.21	0.0084	0.0000	-0.0017	0.0000	-0.0402
11	3.60	0.0073	0.0000	-0.0021	0.0000	-0.0430
12	3.69	0.0309	0.0000	-0.0095	0.0001	-0.1898
13	3.71	0.0044	0.0000	-0.0014	0.0000	-0.0269
14	3.75	0.0182	0.0000	-0.0059	0.0000	-0.1151
15	3.81	0.0055	0.0000	-0.0019	0.0000	-0.0354
16	4.06	0.0073	0.0000	-0.0029	0.0000	-0.0515
17	4.08	0.0343	0.0001	-0.0139	0.0002	-0.2441
18	4.17	0.0073	0.0000	-0.0031	0.0000	-0.0533
19	4.21	0.0284	0.0001	-0.0124	0.0002	-0.2088
20	4.29	0.0053	0.0000	-0.0025	0.0000	-0.0401
21	4.44	0.0073	0.0000	-0.0036	0.0000	-0.0564
22	4.63	0.0182	0.0002	-0.0100	0.0001	-0.1442
23	4.70	0.0109	0.0001	-0.0062	0.0000	-0.0868
24	4.70	0.0230	0.0003	-0.0129	0.0002	-0.1822
25	4.79	0.0055	0.0001	-0.0032	0.0000	-0.0435
26	4.80	0.0164	0.0002	-0.0096	0.0001	-0.1303
27	4.80	0.0046	0.0001	-0.0027	0.0000	-0.0362
28	4.96	0.0167	0.0004	-0.0103	0.0001	-0.1310
29	4.99	0.0231	0.0005	-0.0145	0.0002	-0.1811
30	5.34	0.0075	0.0004	-0.0050	0.0000	-0.0538
31	5.47	0.0048	0.0003	-0.0032	0.0000	-0.0325
32	5.48	0.0109	0.0007	-0.0073	0.0001	-0.0744
33	5.48	0.0055	0.0004	-0.0036	0.0000	-0.0372
34	5.50	0.0109	0.0007	-0.0073	0.0001	-0.0737
35	5.65	0.0231	0.0021	-0.0150	0.0002	-0.1419
36	5.72	0.0128	0.0013	-0.0081	0.0001	-0.0743
37	5.73	0.0347	0.0037	-0.0220	0.0005	-0.2009
38	5.74	0.0192	0.0021	-0.0121	0.0001	-0.1098
39	5.81	0.0195	0.0024	-0.0121	0.0001	-0.1060
40	6.06	0.0186	0.0036	-0.0097	0.0001	-0.0750
41	6.11	0.0128	0.0027	-0.0063	0.0000	-0.0478
42	6.15	0.0146	0.0033	-0.0069	0.0000	-0.0514
43	6.28	0.0236	0.0066	-0.0093	0.0001	-0.0642
44	6.43	0.0073	0.0026	-0.0019	0.0000	-0.0121
45	6.68	0.0420	0.0221	0.0002	0.0000	0.0009
46	6.71	0.0176	0.0097	0.0007	0.0000	0.0037
47	6.76	0.0219	0.0131	0.0026	0.0000	0.0136
48	6.79	0.0269	0.0167	0.0043	0.0000	0.0219
49	7.29	0.0054	0.0065	0.0058	0.0000	0.0211
50	7.41	0.0265	0.0366	0.0359	0.0013	0.1199
51	7.67	0.0264	0.0483	0.0536	0.0029	0.1457
52	7.70	0.0267	0.0501	0.0562	0.0032	0.1492
53	7.79	0.0175	0.0360	0.0416	0.0017	0.1019
54	8.14	0.0136	0.0386	0.0484	0.0023	0.0836
55	8.14	0.0293	0.0831	0.1042	0.0109	0.1802
56	8.18	0.0069	0.0200	0.0253	0.0006	0.0419
57	8.18	0.0087	0.0256	0.0323	0.0010	0.0533
58	8.19	0.0179	0.0527	0.0667	0.0044	0.1093
59	9.23	0.0380	0.2035	0.3017	0.0910	0.0897
60	9.37	0.0262	0.1466	0.2231	0.0498	0.0448
61	9.63	0.0262	0.1556	0.2512	0.0631	0.0167
62	15.81	0.0109	0.0000	0.0175	0.0003	0.2956
Sum		1.0000	1.0000	1.0000	0.2354	-1.9923

Table 10: Weights for Local Linear Smoothing as at 30th January 2014. Recall that T_i = effective tenor of the bond. The issue weights are a function of the sizes of each of the bond issues in the sample. The $w_i(10,\sigma)$ are the weights used for the Gaussian kernel smoother; these weights are not employed in local linear smoothing and are presented here for the purposes of comparison only.

C RBA replication

As a check of the sample used in our analysis, we have compared our results to those given by the RBA as well as those presented by Hird and Young (2015) for the last business days of December 2014 and January 2015.

Table 11 shows the results for spreads to swap at 3, 5, 7, and 10 year terms to maturity. The results are very similar. The maximum difference between our results and those of the RBA is only 3.25 basis points.

	Spread to swap-3 years	Spread to swap-5 years	Spread to swap-7 years	Spread to swap-10 years
December 2014				
RBA BBB	149.82	163.57	188.35	176.26
CEG Replication	148.38	162.22	187.67	174.47
ESQUANT Replication	148.73	163.28	188.65	174.55
January 2015				
RBA BBB	159.59	173.96	195.93	174.13
CEG Replication	161.99	176.20	195.40	171.37
ESQUANT Replication	162.33	177.21	196.3	171.45

Table 11: Replication of RBA spread to swap

Table12 shows the results for effective tenor. Again the results are very similar.

	Effective maturity-3 years	Effective maturity-5 years	Effective maturity-7 years	Effective maturity-10 years
December 2014				
RBA BBB	3.98	5.26	6.68	8.57
CEG Replication	3.95	5.27	6.68	8.57
ESQUANT Replication	3.95	5.27	6.68	8.57
January 2015				
RBA BBB	3.94	5.24	6.66	8.53
CEG Replication	3.95	5.24	6.63	8.52
ESQUANT Replication	3.95	5.24	6.63	8.52

Table 12: Replication of RBA effective maturity

Finally, Table13 shows that the sample of bonds that we have used is similar in size to the sample used by the RBA.

	Number of bonds 1-4 years	Number of bonds 4-6 years	Number of bonds 6-8 years	Number of bonds 8-12 years	Number of bonds 12+ years
December 2014					
RBA BBB	16	25	16	8	2
CEG Replication	15	23	14	8	4
ESQUANT Replication	15	23	14	8	1
January 2015					
RBA BBB	16	25	16	8	2
CEG Replication	15	24	14	8	4
ESQUANT Replication	15	24	14	8	1

Table 13: Replication of RBA bond sample

An important consideration is that for the analysis undertaken to inform this report, there was no requirement for ESQUANT to precisely replicate the published results of the RBA when applying the Gaussian kernel method to the bond data provided by CEG. The empirical methods applied in this report, both parametric and non-parametric, have not been used by the RBA. The most important consideration, from the perspective of ESQUANT, was that the bond data had to be used consistently across the three smoothing methods, and when estimating Nelson-Siegel yield curves, so as to enable proper comparisons of the results to be made. And so the main criterion to be upheld was that of consistency in the use of the data provided.

D Properties of the Lally Extrapolation Method

The Lally extrapolation estimate at 10 years is a weighted average, since

$$\begin{aligned} S_L(10) &= (1+a)S(10) - aS(7) \\ &= (1+a)\sum_{i=1}^{N} w_i(10;\sigma)S_i - a\sum_{i=1}^{N} w_i(7;\sigma)S_i \\ &= \sum_{i=1}^{N} u_i(\sigma)S_i \end{aligned}$$

where

$$u_i(\sigma) = (1+a)w_i(10;\sigma) - aw_i(7;\sigma).$$

Also note that the sum of the weights add to 1 since

$$\begin{aligned} \sum_{i=1}^{N} u_i(\sigma) &= (1+a)\sum_{i=1}^{N} w_i(10;\sigma) - a\sum_{i=1}^{N} w_i(7;\sigma) \\ &= (1+a) - a \\ &= 1. \end{aligned}$$

Similar to local linear smoothing, using a Taylor Series about the target tenor of 10 years,

$$\begin{aligned} E[S_L(10)] &= \sum_{i=1}^{N} u_i(\sigma)G(T_i) \\ &= \sum_{i=1}^{N} u_i(\sigma)\Bigg(G(10) + G'(10)(T_i - 10) + \\ &\qquad \frac{G''(10)}{2}(t_i - 10)^2 + \text{higher order terms}\Bigg) \\ &= G(10)\sum_{i=1}^{N} u_i(\sigma) + G'(10)\sum_{i=1}^{N} u_i(\sigma)(T_i - 10) + \\ &\qquad \frac{G''(10)}{2}\sum_{i=1}^{N} u_i(\sigma)(Ti - 10)^2 + \text{higher order terms} \\ &= G(10) + G'(10)\sum_{i=1}^{N} u_i(\sigma)(T_i - 10) + \\ &\qquad \frac{G''(10)}{2}\sum_{i=1}^{N} u_i(\sigma)(Ti - 10)^2 + \text{higher order terms} \end{aligned}$$

It can be shown that the middle term above is zero since

$$\begin{aligned} \sum_{i=1}^{N} u_i(\sigma)(T_i - 10) &= \sum_{i=1}^{N} u_i(\sigma)T_i - 10\sum_{i=1}^{N} u_i(\sigma) \\ &= (1+a)\sum_{i=1}^{N} w_i(10,\sigma)T_i - a\sum_{i=1}^{N} w_i(7,\sigma)T_i - 10 \\ &= (1+a)E(10) - aE(7) - 10 \\ &= \frac{10 - E(7)}{E(10) - E(7)}E(10) - \frac{10 - E(10)}{E(10) - E(7)}E(7) - 10 \\ &= \frac{10E(10) - E(10)E(7) - 10E(7) + E(10)E(7) - 10E(10) + 10E(7)}{E(10) - E(7)} \\ &= 0, \end{aligned}$$

and hence, to first order, the extrapolation estimate is unbiased. The bias to second order is therefore given by

$$\text{Bias} = \frac{G''(10)}{2} \sum_{i=1}^{N} u_i(\sigma)(Ti - 10)^2$$

while the Variance is given by (see, Hastie, Tibshirani, and Friedman, 2009, p. 197)

$$\text{Variance} = \text{Variance}(\varepsilon_i) \sum_{i=1}^{N} u_i(\sigma)^2$$

where ε_i is the error from the model

$$S_i = G(T_i) + \varepsilon_i.$$

Finally the Root Mean Square Error (RMSE) is given by

$$\text{RMSE} = \sqrt{\text{Bias}^2 + \text{Variance}}.$$

	T_i	Issue Wt.	$w_i(7,\sigma)$	$w_i(10,\sigma)$	$u_i(\sigma)$	$u_i^2(\sigma)$	$\frac{1}{2}u_i(\sigma)(T_i-10)^2$
1	1.21	0.0101	0.0000	0.0000	-0.0000	0.0000	-0.0003
2	2.01	0.0091	0.0001	0.0000	-0.0001	0.0000	-0.0017
3	2.06	0.0146	0.0001	0.0000	-0.0001	0.0000	-0.0031
4	2.20	0.0097	0.0001	0.0000	-0.0001	0.0000	-0.0026
5	2.29	0.0067	0.0001	0.0000	-0.0001	0.0000	-0.0022
6	2.46	0.0091	0.0002	0.0000	-0.0001	0.0000	-0.0041
7	2.46	0.0109	0.0002	0.0000	-0.0002	0.0000	-0.0049
8	2.47	0.0060	0.0001	0.0000	-0.0001	0.0000	-0.0027
9	3.18	0.0261	0.0020	0.0000	-0.0016	0.0000	-0.0361
10	3.21	0.0084	0.0007	0.0000	-0.0005	0.0000	-0.0120
11	3.60	0.0073	0.0011	0.0000	-0.0008	0.0000	-0.0172
12	3.69	0.0309	0.0053	0.0000	-0.0041	0.0000	-0.0811
13	3.71	0.0044	0.0008	0.0000	-0.0006	0.0000	-0.0116
14	3.75	0.0182	0.0034	0.0000	-0.0026	0.0000	-0.0514
15	3.81	0.0055	0.0011	0.0000	-0.0009	0.0000	-0.0164
16	4.06	0.0073	0.0021	0.0000	-0.0016	0.0000	-0.0281
17	4.08	0.0343	0.0101	0.0001	-0.0077	0.0001	-0.1350
18	4.17	0.0073	0.0024	0.0000	-0.0018	0.0000	-0.0312
19	4.21	0.0284	0.0098	0.0001	-0.0074	0.0001	-0.1248
20	4.29	0.0053	0.0020	0.0000	-0.0015	0.0000	-0.0251
21	4.44	0.0073	0.0033	0.0000	-0.0025	0.0000	-0.0386
22	4.63	0.0182	0.0103	0.0002	-0.0077	0.0001	-0.1104
23	4.70	0.0109	0.0066	0.0001	-0.0049	0.0000	-0.0687
24	4.70	0.0230	0.0138	0.0003	-0.0103	0.0001	-0.1442
25	4.79	0.0055	0.0036	0.0001	-0.0027	0.0000	-0.0361
26	4.80	0.0164	0.0109	0.0002	-0.0081	0.0001	-0.1091
27	4.80	0.0046	0.0030	0.0001	-0.0022	0.0000	-0.0303
28	4.96	0.0167	0.0129	0.0004	-0.0094	0.0001	-0.1193
29	4.99	0.0231	0.0185	0.0005	-0.0134	0.0002	-0.1680
30	5.34	0.0075	0.0079	0.0004	-0.0055	0.0000	-0.0599
31	5.47	0.0048	0.0056	0.0003	-0.0038	0.0000	-0.0387
32	5.48	0.0109	0.0127	0.0007	-0.0087	0.0001	-0.0887
33	5.48	0.0055	0.0064	0.0004	-0.0043	0.0000	-0.0444
34	5.50	0.0109	0.0129	0.0007	-0.0087	0.0001	-0.0888
35	5.65	0.0231	0.0300	0.0021	-0.0196	0.0004	-0.1859
36	5.72	0.0128	0.0174	0.0013	-0.0111	0.0001	-0.1017
37	5.73	0.0347	0.0473	0.0037	-0.0303	0.0009	-0.2759
38	5.74	0.0192	0.0263	0.0021	-0.0168	0.0003	-0.1520
39	5.81	0.0195	0.0278	0.0024	-0.0174	0.0003	-0.1526
40	6.06	0.0186	0.0298	0.0036	-0.0168	0.0003	-0.1299
41	6.11	0.0128	0.0209	0.0027	-0.0115	0.0001	-0.0865
42	6.15	0.0146	0.0242	0.0033	-0.0130	0.0002	-0.0964
43	6.28	0.0236	0.0409	0.0066	-0.0201	0.0004	-0.1397
44	6.43	0.0073	0.0133	0.0026	-0.0056	0.0000	-0.0358
45	6.68	0.0420	0.0800	0.0221	-0.0230	0.0005	-0.1271
46	6.71	0.0176	0.0338	0.0097	-0.0091	0.0001	-0.0495
47	6.76	0.0219	0.0422	0.0131	-0.0096	0.0001	-0.0502
48	6.79	0.0269	0.0520	0.0167	-0.0107	0.0001	-0.0552
49	7.29	0.0054	0.0104	0.0065	0.0034	0.0000	0.0126
50	7.41	0.0265	0.0497	0.0366	0.0264	0.0007	0.0883
51	7.67	0.0264	0.0467	0.0483	0.0495	0.0025	0.1345
52	7.70	0.0267	0.0467	0.0501	0.0527	0.0028	0.1400
53	7.79	0.0175	0.0297	0.0360	0.0409	0.0017	0.1001
54	8.14	0.0136	0.0199	0.0386	0.0531	0.0028	0.0919
55	8.14	0.0293	0.0429	0.0831	0.1144	0.0131	0.1979
56	8.18	0.0069	0.0098	0.0200	0.0280	0.0008	0.0464
57	8.18	0.0087	0.0125	0.0256	0.0358	0.0013	0.0591
58	8.19	0.0179	0.0255	0.0527	0.0739	0.0055	0.1213
59	9.23	0.0380	0.0246	0.2035	0.3428	0.1175	0.1019
60	9.37	0.0262	0.0148	0.1466	0.2493	0.0622	0.0501
61	9.63	0.0262	0.0109	0.1556	0.2683	0.0720	0.0179
62	15.81	0.0109	0.0000	0.0000	0.0001	0.0000	0.0011
Sum		1.0000	1.0000	1.0000	1.0000	0.2874	-2.2121

Table 14: Weights for Lally Extrapolation, calculated as at 30th January 2015. Recall that T_i = effective tenor of the bond. The issue weights are a function of the sizes of each of the bond issues in the sample. The Gaussian kernel weights, $w_i(7;\sigma)$ and $w_i(10;\sigma)$, are used with the Lally extrapolation method. The weights, $u_i(\sigma)$ are predicated on a target tenor of 10 years, and are a function of $w_i(7;\sigma)$ and $w_i(10;\sigma)$.

E Lally Calculation Error

On page 40 of Lally (2014), using his equation 4 on page 39, Lally calculates the cost of debt at a 10-year term to maturity as:

$$\begin{aligned}\widehat{RBA}(10)^{17} &= RBA(10e) + Base(10) - Base(10e) + \left[\frac{DRP(10e) - DRP(7e)}{10e - 7e}\right](10 - 10e) \\ &= 5.37\% + 3.53\% - 3.41\% + \left[\frac{1.96\% - 1.88\%}{8.64 - 6.84}\right](10 - 8.64) = 5.58\%.\end{aligned}$$

However, note that if carrying out the arithmetic to two decimal places, the correct answer is 5.55%.

The discrepancy is not explained by going to three decimal places. The values for $RBA(10e)$ and $RBA(7e)$ are

$$\begin{aligned}RBA(10e) &= 5.51\% - Swap(10) + Swap(8.64) \\ &= 5.51\% - 3.878\% + 3.738\% \\ &= 5.370\% \\ RBA(7e) &= 5.13\% - Swap(7) + Swap(6.84) \\ &= 5.13\% - 3.569\% + 3.546\% \\ &= 5.107\%\end{aligned}$$

where $Swap(8.64)$ and $Swap(6.84)$ are obtained using linear interpolation from the Bloomberg swap rates at 5, 7, and 10 year terms to maturity. These swap rates, for 31st July 2014, were 3.28%, 3.569%, and 3.878%, respectively. Note that we would prefer to use the additional Bloomberg swap rates that are available, in particular the 6, 8 and 9 year swap rates.

The debt risk premiums at 8.64 and 6.84 years to maturity are given by

$$\begin{aligned}DRP(10e) &= RBA(10e) - CGS(10e) \\ &= 5.37\% - 3.409\% = 1.961\% \\ DRP(7e) &= RBA(7e) - CGS(7e) \\ &= 5.107\% - 3.226\% = 1.881\%\end{aligned}$$

where CGS(10e) and CGS(7e) are based on interpolating the yields from RBA Table F16.

Using these figures Lally's calculation to three decimal places is given by:

$$\begin{aligned}\widehat{RBA}(10) &= RBA(10e) + Base(10) - Base(10e) + \left[\frac{DRP(10e) - DRP(7e)}{10e - 7e}\right](10 - 10e) \\ &= 5.37\% + 3.527\% - 3.409\% + \left[\frac{1.961\% - 1.881\%}{8.64 - 6.84}\right](10 - 8.64) = 5.542\%.\end{aligned}$$

Note that Lally (2014) gives the result of his calculation as 5.58%.

[17] The notation that Lally uses is different to ours. For example, we use E(10) as the effective tenor at 10 years term to maturity, while Lally uses $10e$.

F Properties of the SA Power Networks Extrapolation Approach

The SA Power Networks extrapolated spread to swap value is given by

$$S_{SA} = S(10) + b(10 - E(10)),$$

where b is the regression coefficient in the fitted equation

$$S(J) = a + bE(J); \quad J = 3, 5, 7, 10,$$

when the RBA published spread to swaps at 3, 5, 7, and 10 years term to maturity are regressed on the corresponding effective tenors.

The regression coefficients are given by

$$\begin{pmatrix} a \\ b \end{pmatrix} = \left(X^T X\right)^{-1} X^T y$$

where

$$X = \begin{pmatrix} 1 & E(3) \\ 1 & E(5) \\ 1 & E(7) \\ 1 & E(10) \end{pmatrix} \text{ and } y = \begin{pmatrix} S(3) \\ S(5) \\ S(7) \\ S(10) \end{pmatrix}.$$

Then

$$X^T X = \begin{pmatrix} 4 & D \\ D & F \end{pmatrix},$$

with

$$\begin{aligned} D &= E(3) + E(5) + E(7) + E(10) \\ F &= E(3)^2 + E(5)^2 + E(7)^2 + E(10)^2, \end{aligned}$$

and

$$\begin{aligned} \left(X^T X\right)^{-1} X^T &= \frac{1}{4F - D^2} \begin{pmatrix} F & -D \\ -D & 4 \end{pmatrix} \begin{pmatrix} 1 & 1 & 1 & 1 \\ E(3) & E(5) & E(7) & E(10) \end{pmatrix} \\ &= \frac{1}{4F - D^2} \begin{pmatrix} F - DE(3) & F - DE(5) & F - DE(7) & F - DE(10) \\ 4E(3) - D & 4E(5) - D & 4E(7) - D & 4E(10) - D \end{pmatrix} \end{aligned}$$

leading to

$$b = \frac{1}{4F - D^2} \left((4E(3) - D)S(3) + (4E(5) - D)S(5) + (4E(7) - D)S(7) + (4E(7) - D)S(10) \right)$$

and hence

$$\begin{aligned} S_{SA}(10) &= S(10) + b(10 - E(10)) \\ &= \sum_{i=1}^{N} w_i(10;\sigma)S_i + \frac{10 - E(10)}{4F - D^2} \sum_{J=3,5,7,10} (4E(J) - D) \left(\sum_{i=1}^{N} w_i(J;\sigma)S_i \right) \\ &= \sum_{i=1}^{N} v_i(\sigma)S_i \end{aligned}$$

with

$$v_i(\sigma) = w_i(10;\sigma) + \frac{10 - E(10)}{4F - D^2} \sum_{J=3,5,7,10} (4E(J) - D) w_i(J;\sigma).$$

Note that the weights add to 1 since

$$\begin{aligned}
\sum_{i=1}^{N} v_i(\sigma) &= \sum_{i=1}^{N} w_i(10,\sigma) + \frac{10-E(10)}{4F-D^2} \sum_{J=3,5,7,10} (4E(J)-D) \left(\sum_{i=1}^{N} w_i(J;\sigma) \right). \\
&= 1 + \frac{10-E(10)}{4F-D^2} \sum_{J=3,5,7,10} (4E(J)-D) \\
&= 1 + \frac{10-E(10)}{4F-D^2} (4D-4D) \\
&= 1.
\end{aligned}$$

Similar to local linear smoothing and the Lally extrapolation method, and using a Taylor series expansion about the target tenor of 10 years,

$$\begin{aligned}
E[S_{SA}(10)] &= \sum_{i=1}^{N} v_i(\sigma) G(T_i) \\
&= \sum_{i=1}^{N} v_i(\sigma) \Big(G(10) + G'(10)(T_i - 10) + \\
&\qquad \frac{G''(10)}{2}(t_i - 10)^2 + \text{higher order terms} \Big) \\
&= G(10) \sum_{i=1}^{N} v_i(\sigma) + G'(10) \sum_{i=1}^{N} v_i(\sigma)(T_i - 10) + \\
&\qquad \frac{G''(10)}{2} \sum_{i=1}^{N} v_i(\sigma)(Ti - 10)^2 + \text{higher order terms} \\
&= G(10) + G'(10) \sum_{i=1}^{N} v_i(\sigma)(T_i - 10) + \\
&\qquad \frac{G''(10)}{2} \sum_{i=1}^{N} v_i(\sigma)(Ti - 10)^2 + \text{higher order terms}
\end{aligned}$$

It can be shown that the middle term above is zero since

$$\begin{aligned}
\sum_{i=1}^{N} v_i(\sigma)(T_i - 10) &= \sum_{i=1}^{N} v_i(\sigma) - 10 \sum_{i=1}^{N} v_i(\sigma) \\
&= \sum_{i=1}^{N} w_i(10;\sigma) T_i + \frac{10-E(10)}{4F-D^2} \sum_{J=3,5,7,10} (4E(J)-D) \left(\sum_{i=1}^{N} w_i(J;\sigma) T_i \right) - 10 \\
&= E(10) + \frac{10-E(10)}{4F-D^2} \sum_{J=3,5,7,10} (4E(J)-D)E(J) - 10 \\
&= E(10) + \frac{10-E(10)}{4F-D^2} (4F-D^2) - 10 \\
&= E(10) + 10 - E(10) - 10 \\
&= 0,
\end{aligned}$$

and hence, to first order, the SA extrapolation estimate is unbiased. The bias to second order is therefore given by

$$\text{Bias} = \frac{G''(10)}{2} \sum_{i=1}^{N} v_i(\sigma)(Ti - 10)^2$$

while the variance is given by (see, Hastie, Tibshirani, and Friedman, 2009, p. 197)

$$\text{Variance} = \text{Variance}(\varepsilon_i) \sum_{i=1}^{N} v_i(\sigma)^2$$

where ε_i is the error from the model

$$S_i = G(T_i) + \varepsilon_i.$$

Finally the Root Mean Square Error (RMSE) is given by

$$\text{RMSE} = \sqrt{\text{Bias}^2 + \text{Variance}}.$$

	T_i	Issue Wt.	$w_i(3,\sigma)$	$w_i(5,\sigma)$	$w_i(7,\sigma)$	$w_i(10,\sigma)$	$v_i(\sigma)$	$v_i^2(\sigma)$	$\frac{1}{2}v_i(\sigma)(T_i-10)^2$
1	1.21	0.0101	0.0152	0.0008	0.0000	0.0000	-0.0042	0.0000	-0.1637
2	2.01	0.0091	0.0225	0.0023	0.0001	0.0000	-0.0064	0.0000	-0.2041
3	2.06	0.0146	0.0368	0.0039	0.0001	0.0000	-0.0105	0.0001	-0.3303
4	2.20	0.0097	0.0257	0.0031	0.0001	0.0000	-0.0074	0.0001	-0.2239
5	2.29	0.0067	0.0185	0.0024	0.0001	0.0000	-0.0053	0.0000	-0.1577
6	2.46	0.0091	0.0262	0.0040	0.0002	0.0000	-0.0076	0.0001	-0.2158
7	2.46	0.0109	0.0315	0.0048	0.0002	0.0000	-0.0091	0.0001	-0.2589
8	2.47	0.0060	0.0174	0.0027	0.0001	0.0000	-0.0050	0.0000	-0.1425
9	3.18	0.0261	0.0796	0.0229	0.0020	0.0000	-0.0241	0.0006	-0.5599
10	3.21	0.0084	0.0256	0.0075	0.0007	0.0000	-0.0078	0.0001	-0.1796
11	3.60	0.0073	0.0207	0.0086	0.0011	0.0000	-0.0065	0.0000	-0.1332
12	3.69	0.0309	0.0852	0.0385	0.0053	0.0000	-0.0271	0.0007	-0.5392
13	3.71	0.0044	0.0120	0.0055	0.0008	0.0000	-0.0038	0.0000	-0.0754
14	3.75	0.0182	0.0493	0.0236	0.0034	0.0000	-0.0158	0.0002	-0.3078
15	3.81	0.0055	0.0145	0.0073	0.0011	0.0000	-0.0047	0.0000	-0.0893
16	4.06	0.0073	0.0174	0.0109	0.0021	0.0000	-0.0058	0.0000	-0.1021
17	4.08	0.0343	0.0812	0.0519	0.0101	0.0001	-0.0270	0.0007	-0.4730
18	4.17	0.0073	0.0165	0.0114	0.0024	0.0000	-0.0055	0.0000	-0.0941
19	4.21	0.0284	0.0629	0.0450	0.0098	0.0001	-0.0213	0.0005	-0.3567
20	4.29	0.0053	0.0113	0.0087	0.0020	0.0000	-0.0039	0.0000	-0.0631
21	4.44	0.0073	0.0141	0.0124	0.0033	0.0000	-0.0049	0.0000	-0.0761
22	4.63	0.0182	0.0309	0.0323	0.0103	0.0002	-0.0110	0.0001	-0.1582
23	4.70	0.0109	0.0177	0.0196	0.0066	0.0001	-0.0063	0.0000	-0.0892
24	4.70	0.0230	0.0372	0.0410	0.0138	0.0003	-0.0133	0.0002	-0.1872
25	4.79	0.0055	0.0083	0.0099	0.0036	0.0001	-0.0030	0.0000	-0.0405
26	4.80	0.0164	0.0245	0.0297	0.0109	0.0002	-0.0088	0.0001	-0.1195
27	4.80	0.0046	0.0068	0.0082	0.0030	0.0001	-0.0025	0.0000	-0.0331
28	4.96	0.0167	0.0218	0.0304	0.0129	0.0004	-0.0079	0.0001	-0.1003
29	4.99	0.0231	0.0293	0.0422	0.0185	0.0005	-0.0106	0.0001	-0.1328
30	5.34	0.0075	0.0068	0.0133	0.0079	0.0004	-0.0023	0.0000	-0.0244
31	5.47	0.0048	0.0038	0.0083	0.0056	0.0003	-0.0011	0.0000	-0.0117
32	5.48	0.0109	0.0086	0.0190	0.0127	0.0007	-0.0026	0.0000	-0.0265
33	5.48	0.0055	0.0043	0.0095	0.0064	0.0004	-0.0013	0.0000	-0.0132
34	5.50	0.0109	0.0084	0.0189	0.0129	0.0007	-0.0025	0.0000	-0.0253
35	5.65	0.0231	0.0149	0.0383	0.0300	0.0021	-0.0034	0.0000	-0.0321
36	5.72	0.0128	0.0075	0.0207	0.0174	0.0013	-0.0013	0.0000	-0.0122
37	5.73	0.0347	0.0203	0.0561	0.0473	0.0037	-0.0035	0.0000	-0.0320
38	5.74	0.0192	0.0110	0.0309	0.0263	0.0021	-0.0018	0.0000	-0.0162
39	5.81	0.0195	0.0104	0.0308	0.0278	0.0024	-0.0011	0.0000	-0.0097
40	6.06	0.0186	0.0071	0.0263	0.0298	0.0036	0.0021	0.0000	0.0159
41	6.11	0.0128	0.0045	0.0177	0.0209	0.0027	0.0019	0.0000	0.0141
42	6.15	0.0146	0.0049	0.0198	0.0242	0.0033	0.0025	0.0000	0.0187
43	6.28	0.0236	0.0067	0.0299	0.0409	0.0066	0.0064	0.0000	0.0447
44	6.43	0.0073	0.0016	0.0084	0.0133	0.0026	0.0030	0.0000	0.0193
45	6.68	0.0420	0.0064	0.0409	0.0800	0.0221	0.0284	0.0008	0.1565
46	6.71	0.0176	0.0026	0.0169	0.0338	0.0097	0.0125	0.0002	0.0679
47	6.76	0.0219	0.0029	0.0200	0.0422	0.0131	0.0171	0.0003	0.0897
48	6.79	0.0269	0.0034	0.0240	0.0520	0.0167	0.0220	0.0005	0.1133
49	7.29	0.0054	0.0003	0.0031	0.0104	0.0065	0.0088	0.0001	0.0324
50	7.41	0.0265	0.0011	0.0132	0.0497	0.0366	0.0498	0.0025	0.1665
51	7.67	0.0264	0.0006	0.0099	0.0467	0.0483	0.0654	0.0043	0.1775
52	7.70	0.0267	0.0006	0.0097	0.0467	0.0501	0.0678	0.0046	0.1799
53	7.79	0.0175	0.0003	0.0057	0.0297	0.0360	0.0486	0.0024	0.1190
54	8.14	0.0136	0.0001	0.0028	0.0199	0.0386	0.0517	0.0027	0.0894
55	8.14	0.0293	0.0003	0.0060	0.0429	0.0831	0.1113	0.0124	0.1926
56	8.18	0.0069	0.0001	0.0013	0.0098	0.0200	0.0268	0.0007	0.0445
57	8.18	0.0087	0.0001	0.0017	0.0125	0.0256	0.0343	0.0012	0.0565
58	8.19	0.0179	0.0001	0.0034	0.0255	0.0527	0.0706	0.0050	0.1157
59	9.23	0.0380	0.0000	0.0013	0.0246	0.2035	0.2686	0.0721	0.0798
60	9.37	0.0262	0.0000	0.0007	0.0148	0.1466	0.1934	0.0374	0.0389
61	9.63	0.0262	0.0000	0.0004	0.0109	0.1556	0.2050	0.0420	0.0137
62	15.81	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008
Sum		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.1931	-3.9635

Table 15: Weights for SA Power Networks Extrapolation, calculated as at 30th January 2015. Recall that T_i = effective tenor of the bond. The issue weights are a function of the sizes of each of the bond issues in the sample. The Gaussian kernel weights, $w_i(3;\sigma)$, $w_i(5;\sigma)$, $w_i(7;\sigma)$, and $w_i(10;\sigma)$ are used with the SA Power Networks Extrapolation method. The weights, $v_i(\sigma)$ are predicated on a target tenor of 10 years, and are a function of $w_i(3;\sigma)$, $w_i(5;\sigma)$, $w_i(7;\sigma)$, and $w_i(10;\sigma)$.

G Testing for Parallelism

The Nelson-Siegel yield curves estimated for this report fit a model for which the intercept terms are different for the different classes of bonds, but the parameters β_0, β_2, and β_3 are common. The assumption that the aforementioned parameters take on the same values for each of the three classes of bonds can be regarded as a restriction. In this section, models where the restriction is relaxed are fitted, and tests are applied to ascertain whether there are statistically significant differences between the restricted and unrestricted versions of the model.

The Nelson-Siegel model is

$$y(\tau) = \beta_1 + \beta_2 \left(\frac{1 - e^{-\tau e^{\beta_0}}}{\tau e^{\beta_0}} \right) + \beta_3 \left(\frac{1 - e^{-\tau e^{\beta_0}}}{\tau e^{\beta_0}} - e^{-\tau e^{\beta_0}} \right) + \beta_4 \text{BBB-} + \beta_5 \text{BBB+}$$

where BBB- is a dummy variable taking the value 1 for BBB- stocks and 0 elsewhere; and similarly BBB+ is a dummy variable taking the value 1 for BBB+ stocks and 0 elsewhere, and the λ parameter, which should be positive, has been reparameterised as

$$\lambda = e^{\beta_0}.$$

An extended model which allows all the parameters to vary is given by

$$y(\tau) = \beta_1^* + \beta_2^* \left(\frac{1 - e^{-\tau e^{\beta_0^*}}}{\tau e^{\beta_0^*}} \right) + \beta_3^* \left(\frac{1 - e^{-\tau e^{\beta_0^*}}}{\tau e^{\beta_0^*}} - e^{-\tau e^{\beta_0^*}} \right)$$

with

$$\begin{aligned} \beta_0^* &= \beta_0 + \beta_6 \text{BBB-} + \beta_7 \text{BBB+} \\ \beta_1^* &= \beta_1 + \beta_4 \text{BBB-} + \beta_5 \text{BBB+} \\ \beta_2^* &= \beta_2 + \beta_8 \text{BBB-} + \beta_9 \text{BBB+} \\ \beta_3^* &= \beta_3 + \beta_{10} \text{BBB-} + \beta_{11} \text{BBB+} \end{aligned}$$

where β_6 and β_7 are deviations of the β_0 parameter for BBB$-$ and BBB+ bonds, respectively; while β_8 and β_9 are corresponding deviations of the β_2 parameter, and β_{10} and β_{11} are corresponding deviations for the β_3 parameter.

The extended model was fitted to the CEG dataset for the 30th September 2014, using `nlsLM`. Figure 6 shows the fitted curves for both the common coefficient case and the varying coefficient case. Note that the the curves do not cross: The BBB+ curve is always below the BBB curve, which, in turn, is always below the BBB$-$ curve.

To test whether the varying curve is justified, a hypothesis test was performed to investigate whether the parameters $\beta_6, \ldots, \beta_{11}$ are significantly different to zero. This was done using Analysis of Variance where the common and extended models were fitted to the data and the change in the residual sum of squares was compared to the residual mean square of the extended model.

In the F-test carried out here, the test statistic is calculated as

$$F = \frac{(\text{RSS Common} - \text{RSS Varying})/g}{(\text{RSS Varying})/(n-k)}$$

where

$$\begin{aligned} \text{RSS Common} &= \text{residual sum of squares with common coefficients} \\ \text{RSS Varying} &= \text{residual sum of squares with varying coefficients} \\ g &= \text{the number of extra parameters} \\ n &= \text{the number of data points} \\ k &= \text{the number of parameters in the model with varying coefficients} \end{aligned}$$

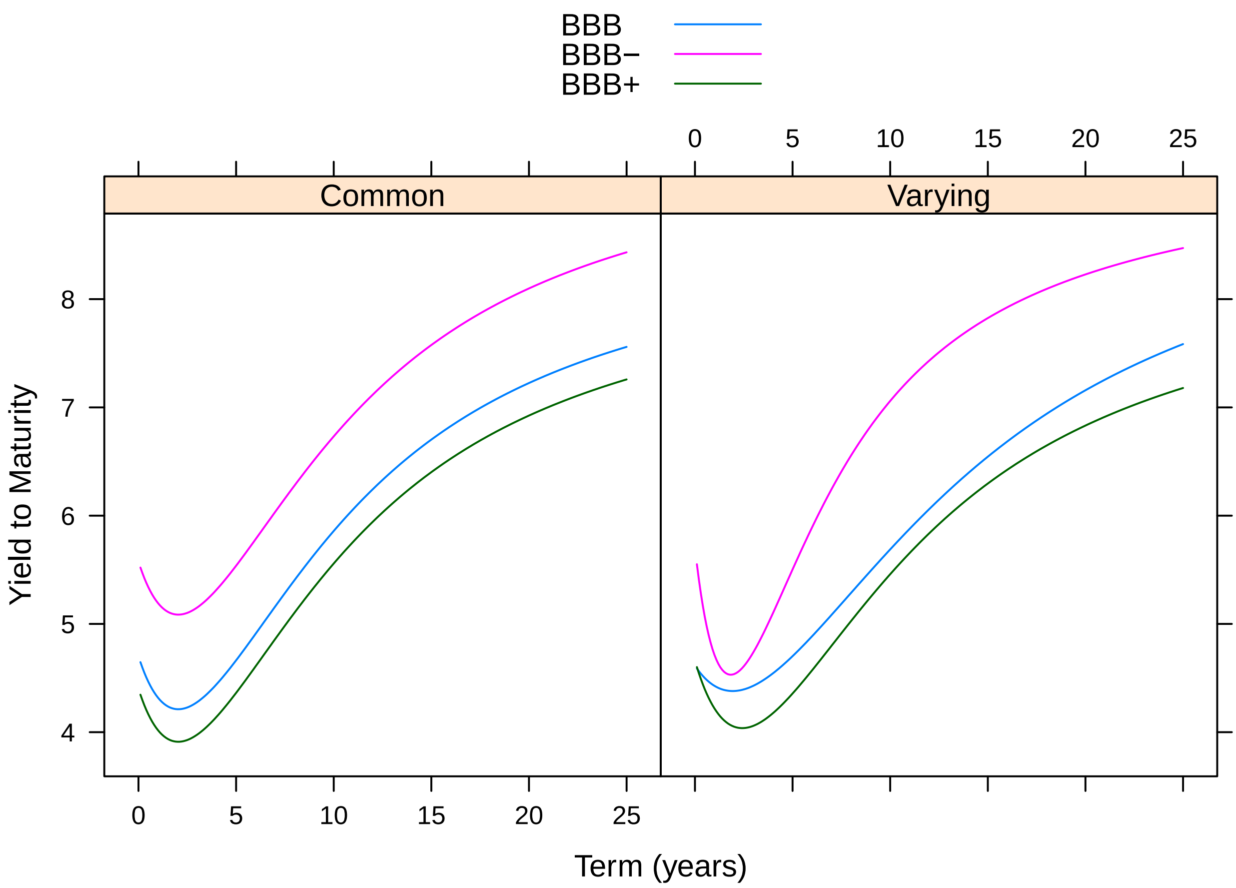

Figure 6: Fitted Nelson-Siegel curve with common and varying parameters for 30 September 2014

The null hypothesis is that the restriction is valid and that all of the additional parameters are equal to zero. Under the null hypothesis, the F statistic has a known distribution and a $p-$value can be calculated, with large values of F and corresponding small values of p indicating that the additional parameters may be required.

The results of the test are given in Table 16. The null hypothesis could not be rejected at the 5% level, indicating that the parallelism assumption is not contradicted by the data.

RSS Common	RSS Varying	Δ RSS	F	df1	df2	$p-$value
17.84	15.74	2.1	6	73	1.62	0.153

Table 16: Test for parallelism for Nelson-Siegel model adjusted for Credit ratings.

The method used in this section was presented and explained in Diamond et al. (2013, section 4.3) using data for February 2013. Note that

- On this occasion, the test for parallelism was undertaken using data for 30th September 2014 (prevously an averaging period had been chosen which was 20 business days in February 2013).
- A key difference between the analysis undertaken for this report, and the analysis described in Diamond et al. (2013, section 4.3) is that larger data samples were used during the previous exercise. On this occasion, the dataset was constrained because the sample of bonds had been chosen in such a way as to correspond with the selection criteria applied by the RBA.

The test could not be performed using data for 30th January 2015 because there were fewer bonds with a BBB minus credit rating in the data sample for that day than there were in the data sample for

30th September 2014. One of the reasons for the reduction in the number of BBB minus bonds available for analysis in the data for 30th January 2015 is that we chose to exclude bonds in the broad BBB band group with remaining terms to maturity in excess of 20 years. The exclusion was done for 30th January 2015 and not for 30th September 2014, and was motivated by a need to ensure consistency between the bond sample used for this report, and the bond sample used by CEG in CEG (2015). As has been reported by CEG (2015) at paragraphs 202 and 203:

> "Of the 7 bonds with maturities above 20 years there are some significant outliers, with one issued by Santos having a maturity of 56 years, a yield of 12.2% and a spread to swap of 869 basis points (this estimate likely reflects the limitatons of extrapolating an estimate of the swap curve to 56 years). A bond issued by Ancora at 21 years to maturity reports a yield of 3.6% and a spread of 30 basis points.
>
> Given the unusual observed spreads to swap on these bonds, and because we consider that the estimated spread to swap at 10 years should be determined by bonds with maturities similar to 10 years and not by outlying bonds at much greater maturities, these 7 bonds are excluded in the Nelson-Siegel analysis presented in this section."

H Authors

Neil Diamond

Neil Diamond CV

December 2014

Academic Qualifications: B.Sc (Hons) (Monash), Ph.D. (Melbourne), A.Stat

Career History

1977-78	Statistician, ICI Explosives Factory, Deer Park
1979-86	Research Officer, Research Scientist, Senior Research Scientist And Statistics and Computing Team Leader, ICI Central Research Laboratories, Ascot Vale
1987-1989	Lecturer, Department of Mathematics, Computing and Operations Research, Footscray Institute of Technology
(1989)	Visiting Scientist, Center for Quality and Productivity Improvement, University of Wisconsin-Madison, USA.
1990-2003	Senior Lecturer, Department of Computer and Mathematical Sciences, Victoria University of Technology
2003-2004	Senior Statistician, Insureware
2004-2006	Senior Lecturer and Deputy Director of Consulting, Department of Econometrics and Business Statistics, Monash University.
2007- 2012	Senior Lecturer and Director of Consulting, Department of Econometrics and Business Statistics, Monash University.
2011- 2012	Associate Professor and Co-ordinator of Statistical Support, Victoria University.
2012-	Director, ESQUANT Statistical Consulting

Research and Consulting Experience

- A Ph.D. from the University of Melbourne entitled "Two-factor interactions in non-regular foldover designs."
- Ten years with ICI Australia as an industrial statistician initially with the Explosives group and eventually with the research group.
- Two six month periods (Professional Experience Program and Outside Studies Program) at the Center for Quality and Productivity Improvement, at the University of Wisconsin-Madison. The Center, founded and directed by Professor George Box, conducts innovative practical research in modern methods of quality improvement and is an internationally recognised forum for the exchange of ideas between experts in various disciplines, from industry and government as well as academia.
- Extensive consulting and training on behalf of the Centre for Applied Computing and Decision Analysis based at VUT for the following

companies:

Data Sciences	Initiating Explosives Systems
Analytical Science Consultants	Saftec
Glaxo Australia	Datacraft Australia
Enterprise Australia	ICI Australia
The LEK partnership	Kaolin Australia
BP Australia	AMCOR
Melbourne Water	Kinhill Group
Australian Pulp and Paper Institute	

- Operated the Statistical Consulting Service at Victoria University of Technology from 1992-2003.

- From 2003-2004 worked as a Senior Statistician with Insureware on the analysis of long-tailed liability data.

- From December 2004 to December 2006, Deputy Director of Consulting of Monash University Statistical Consulting Service based in the Department of Econometrics and Business Statistics.

- From January 2007 to December 2012, Director of Consulting of Monash University Statistical Consulting Service based in the Department of Econometrics and Business Statistics.

- Extensive consulting and training on behalf of the Monash University Statistical Consulting Service for the following companies and organisations:

Australian Tax Office	Department of Human Services
J D McDonald	IMI Research
Port of Melbourne Corporation	Incitec Pivot
Agricola, Wunderlich & Associates	Parks Victoria
Australian College of Consultant Physicians	ANZ
Department of Justice	CRF(Colac Otway)
Australian Football League Players' Association	United Energy
ETSA	ENA

- From May 2011 to February 2013, Associate Professor and Co-ordinator of Statistical Support, Victoria University.

- From February 2013, Extensive consulting and training as Research Director of ESQUANT Statistical Consulting for the following companies and organisations:

United Energy & Multinet Gas
Competition Economists Group
SFG Consulting
Engineered Wood Panels Association of Australasia
DBP
Deakin University Department of Psychology
Choros
Electricity Networks Association
Victoria University Office for Research
Monash University Department of Social Work
MAV

Postgraduate Supervision

Principal Supervisor

Gregory Simmons (1994-1997). M.Sc. completed. "Properties of some minimum run resolution IV designs."

Tony Sahama (1995-2003). Ph.D. completed. "Some practical issues in the design and analysis of computer experiments."

Ewa Sztendur (1999-2005). Ph.D. completed. "Precision of the path of steepest ascent in response surface methodology." [As a result of this thesis, Ewa was awarded the 2006 Victoria University Vice-Chancellor's Peak Award for Research and Research Training-Research Degree Graduate.]

Co-supervisor

Keith Hart (1996-1997). M.Sc. completed. "Mean reversion in asset prices and asset allocations in funds management."

Jyoti Behera (1999-2000). M.Eng. completed. "Simulation of container terminals."

Ray Summit (2001-2004). Ph.D. completed. "Analysis of warranty data for automobile data."

Rob Moore (2001-2007). Ph.D. completed. "Computer recognition of musical instruments.

M.Sc. Minor Theses

Milena Shtifelman (1999). Completed. (Monash University Accident Research Centre). "Modelling interactions of factors influencing road trauma trends in Victoria."

Rohan Weliwita (2002). Completed. "Modelling road accident trauma data."

Theses Examination

One M.Sc. major thesis (University of Melbourne) and one M.Sc minor thesis (Victoria University).

Workshops

Victoria University

- Experimental Design.
- Longitudinal Data Analysis.
- Statistics for Biological Sciences.
- Introductory Statistics for Research.
- Software Packages for Statistics.
- Design and Analysis of Questionnaires and Sample Surveys.
- Introductory SPSS.
- Statistics for Biological Sciences using R.
- Statistics for Biological Sciences using SPSS.
- Research Design and Statistics.

Monash University

- Expert Stats Seminars for higher degree research students on Software Packages for Statistics, Questionnaire Design, Analysis of Survey Data, and Multivariate Statistics.
- Introduction to Statistics for Pharmacy.
- Statistical Analysis for Social Workers.
- Statistical Methods for Social Workers.
- SPSS for Social Workers.

ESQUANT Statistical Consulting

- Introduction to Structual Equation Modelling using Lavaan and R.
- Introduction to Stata.
- Introduction to Structual Equatuon Modelling with Stata.

Other

- Design of Experiments for ICI Australia (One day course).
- Design of Experiments for Quality Assurance-including Taguchi Methods. A 2-day professional development short course on behalf of the Centre for Manufacturing Advanced Engineering Centre.
- Design of Experiments for the Australian Pulp and Paper Institute.
- Statistical Methods for ANZ Analytics.

Teaching Experience

Monash University

- Business Statistics (First Year), Marketing Research Analysis (Second Year), Survey Data Analysis (Third Year-Clayton and Caulfield).

Victoria University of Technology

- Applied Statistics (First Year), Linear Statistical Models, Sampling and Data Analysis (Second Year), Experimental Design (Third Year).
- Statistics for Engineers, Statistics for Nurses, Statistics for Occupational Health.
- Forecasting (Graduate Diploma in Business Science)

Sessional Teaching

- RMIT (1991, 1996-2002) Design of Experiments for Masters in Quality Management.
- AGSM (1993-1997): Total Quality Management for Graduate Management Qualification.
- Various other: The University of Melbourne, Enterprise Australia, Swinburne Institute of Technology.

Industry Projects

Over 30 projects for the following companies and organisations:

Gas and Fuel Corporation
Mobil Australia
ICI Australia
Data Sciences
AMCOR
Davids
Craft Coverings
CSL
Viplas Olympic
Federal Airports Corporation
Ford Australia
Fibremakers
Western General Hospital
Keilor City Council
Composite Buyers
Email Westinghouse
Australian Wheat Board
Holding Rubber
Melbourne Water

Publications

Chapters in Books

1. Sztendur, E.M. and Diamond, N.T., (2001). "Inequalities for the precision of the path of steepest ascent in response surface methodology," in Cho, Y.J, Kim, J.K., and Dragomir, S.S. (eds.) *Inequality Theory and Applications Volume 1*, Nova Publications.

Journal Articles

1. Diamond, N.T., (1991). "Two visits to Wisconsin," *Quality Australia*, **7**, 30-31.
2. Diamond, N.T., (1991). "The use of a class of foldover designs as search designs," *Austral. J. Statist*, **33**, 159-166.
3. Diamond, N.T., (1995). "Some properties of a foldover design," *Austral. J. Statist*, **37**, 345-352.
4. Watson, D.E.R., Hallett, R.F., and Diamond, N.T., (1995). "Promoting a collegial approach in a multidisciplinary environment for a total quality improvement process in higher education, " *Assessment & Evaluation in Higher Education*, **20**, 77–88.
5. Van Matre, J. and Diamond, N.T., (1996). "Team work and design of experiments," Quality Engineering, 9, 343–348.
6. Diamond, N.T., (1999). "Overlap probabilities and delay detonators," *Teaching Statistics*, **21**, 52–53. Also published in "Getting the Best from Teaching Statistics", one of the best 50 articles from volumes 15 to 21 of *Teaching Statistics*.
7. Cerone, P. and Diamond, N.T., (2000). "On summing permutations and some statistical properties," *The International Journal of Mathematical Education in Science and Technology*, **32**, 477-485.
8. Behera, J.M., Diamond, N.T., Bhuta, C.J. and Thorpe, G.R.,(2000). "The impact of job assignment rules for straddle carriers on the throughput of container terminal detectors," *Journal of Advanced Transportation*, **34**, 415-454.
9. Sahama, T. and Diamond, N.T., (2001). "Sample size considerations and augmentation of computer experiments," *The Journal of Statistical Computation and Simulation*, **68**, 307-319.
10. Paul, W. and Diamond, N.T., (2001). "Designing a monitoring program for environmental regulation: Part 1-The operating characteristic curve," *Water*: Journal of Australian Water Association, October 2001, 50-54.
11. Sztendur, E.M. and Diamond, N.T., (2002). "Extension to confidence region calculations for the path of steepest ascent," *Journal of Quality Technology*, **34**, 288-295.
12. Paul, W. and Diamond, N.T., (2002). "Designing a monitoring program for environmental regulation: Part 2-Melbourne Water case study," *Water*: Journal of Australian Water Association, February 2002, 33-36.
13. Steart, D.C., Greenwood, D.R., Boon, P.I. and Diamond, N.T., (2002) "Transport of leaf litter in upland streams of Eucalyptus and Nothofagus forests in South Eastern Australia," *Archiv Für Hydrobiologie,* **156***, 43-61.*
14. Peachey, T. C., Diamond, N. T., Abramson, D. A., Sudholt, W., Michailova, A., and Amirriazi, S. (2008). "Fractional factorial design for parameter sweep experiments using Nimrod/E," *Sci. Program.*, **16**(2-3), 217–230.

15 Sahama, T.R. and Diamond, N.T. (2009) "Computer Experiment-A case study for modelling and simulation of Manufacturing Systems," *Australian Journal of Mechanical Engineering*, **7**(1), 1–8.

16 Booth, R., Brookes, R., and Diamond, N. (2012) " The declining player share of AFL clubs and league revenue 2001-2009: Where has the money gone?," *Labour and Industry* 22:4, 433–446.

17 Booth, R., Brookes, R., and Diamond, N. (2012) "Theory and Evidence on Player Salaries and Revenues in the AFL 2001-2009," Accepted for publication in *Economics and Labour Relations Review.*

18 Chambers, J.D., Bethwaite, B., Diamond, N.T., Peachey, T.C., Ambramson, D., Petrou, S., and Thomas, E.A. (2012) "Parametric computation predicts a multiplicative interaction between synaptic strength parameters controls properties of gamma oscillations," *Frontiers in Computational Neuroscience* Volume 6, Article 53 doi:103389/fncom.2012.00053.

19 Sztendur, E.M. and Diamond, N.T. (2013). "Using fractional factorial designs for variable importance in Random Forest models," *World Academy of Science, Engineering and Technology,* **71**, 1974–1978.

20 de Bruin, C.L., Deppeler, J.M., Moore, D.W., and Diamond, N.T. (2013) "Public school-based interventions for adolescents and young adults with an autism sprectrum disorder: a meta-analysis," *Review of Educational Research* prepublished 17 September 2013. DOI: 10.3102/0034654313498621

21 Jackson, M., Sztendur, E., Diamond, N., Byles, J. and Bruck, D."Sleep Difficulties and the Development of Depression and Anxiety: A Longitudinal Study of Young Australian Women", accepted for publication in *Archives of Women's Mental Health.*

Refereed Conference Papers

1. Behera, J., Diamond, N.T., Bhuta, C. and Thorpe, G., (1999). "Simulation: a decision support tool for improving the efficiency of the operation of road vehicles in container terminals," 9th ASIM Dedicated Conference, Berlin, February 2000, 75-86.

2. Jutrisa, I., Diamond, N.T. and Cerone. P., (1999). "Frame size effects on throughput and return traffic in reliable satellite broadcast transmission, " 16th International Teletraffic Congress, Edinburgh, Scotland.

3. Diamond, N.T. and Sztendur, E.M. (2002). "The use of consulting problems in introductory statistics classes", *Proceedings of the 6th International Conference on the Teaching of Statistics.*

4. Summitt, R.A., Cerone. P., and Diamond, N.T. (2002). "Simula-

tion Reliability Estimation from Early Failure Data, *Proceedings of the Fourth International Conference on Modelling and Simulation*, 368-390.

5. Summitt, R.A., Cerone. P., and Diamond, N.T. (2002). "Simulation Reliability Estimation from Early Failure Data II, *Proceedings of the Fourth International Conference on Modelling and Simulation*, 391-396.
6. Sahama, T. And Diamond, N.T. (2008). "Computer Experiment-A case study for modelling and simulation of Manufacturing Systems," 9th Global Conference on Manufacturing and Management.
7. Jackson, M.L., Diamond, N.T., Sztendur E.M., Bruck, D. (2013). "The Role of Sleep Difficulties in the Subsequent Development of Depression and Anxiety in a Longitudinal Study of Young Australian Women, " *American Professional Sleep Societies Scientific Meeting, Baltimore, MA* (Selected for an Honorable Mention Award) and *25th Annual Scientific Meeting of the Australasian Sleep Association, Brisbane, October.*

Reports

A number of confidential reports for ICI Australia from 1977-1987.

Victoria University

VU1. Diamond, N.T (1990). "Professional Experience Program at the Center for Quality and Productivity Improvement," Footscray Institute of Technology.

VU2. Bisgaard, S. and Diamond, N.T (1991). "A discussion of Taguchi's methods of confirmatory trials," Report No. 60. Center for Quality and Productivity Improvement, University of Wisconsin-Madison.

VU3. Diamond, N.T (1996). "Outside Studies Program at the Center for Quality and Productivity Improvement," Victoria University of Technology.

VU4. Diamond, N.T (1996). "Statistical Analysis of EPA compliance of the western treatment plant," prepared for Melbourne Water on behalf of Kinhill Engineers.

VU5. Diamond, N.T (1996). "Statistical Analysis of EPA compliance of the western treatment plant," prepared for Melbourne Water on behalf of Kinhill Engineers.

VU6. Diamond, N.T (1998). "Statistical Analysis of BOD and SS compliance rates and license limits at ETP and WTP," prepared for Melbourne Water.

VU7. Diamond, N.T (1998). "Fate of pollutants at WTP-method for determining safety margins," prepared for Egis consulting group.

VU8. Bromley, M. and Diamond, N.T (2002). "The manufacture of Laboratory coreboard using various chip furnishes," prepared for Orica adhesives and resins.

Monash University

M1. Hyndman, R.J, Diamond, N.T. and de Silva, A. (2004). "A review of the methodology for identifying potential risky agents," prepared for the Australian Tax Office.

M2. Diamond, N.T. and Hyndman, R.J. (2005). "Sample Size for Maternal and Child Heath Service Evaluation," prepared for the Department of Human Services.

M3. Diamond, N.T. (2005). "Analysis of Customer Satisfaction Survey 2005," prepared for JD Macdonald.

M4. Diamond, N.T. (2005). "Analysis of 2005 Orientation Survey," prepared for Monash Orientation.

M5. Diamond, N.T. (2005). "Analysis of Before and After and Sequential Monadic Concept Consumer Surveys," prepared for IMI-Research.

M6. Diamond, N.T. and Hyndman, R.J. (2005). "The Monash Experience Questionnaire 2003: First Year Students," prepared for CHEQ, Monash University.

M7. Diamond, N.T. and Hyndman, R.J. (2005). "The Monash Experience Questionnaire 2003: The Best and Worst, " prepared for CHEQ, Monash University.

M8. Diamond, N.T. and Hyndman, R.J. (2005). "The Monash Experience Questionnaire 2003: The Best and Worst for First Year Students," prepared for CHEQ, Monash University.

M9. Diamond, N.T. (2005). "Technical Document for DUKC Uncertainty Study," prepared for Port of Melbourne Corporation.

M10. Diamond, N.T. (2005). "DUKC Uncertainty Study-Summary of Results," prepared for Port of Melbourne Corporation.

M11. Diamond, N.T. (2005). "Number of Ship trials for DUKC Uncertainty Study," prepared for Port of Melbourne Corporation.

M12. Diamond, N.T. (2005). "Threshold Criteria for Touch Bottom Probabilities," prepared for Port of Melbourne Corporation.

M13. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: The Best and Worst," prepared for CHEQ, Monash University.

M14. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: The Best and Worst for First Year Students," prepared for CHEQ, Monash University.

M15. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: A Statistical Analysis," prepared for CHEQ, Monash University.

M16. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: 2005 vs. Pre-2005 Students," prepared for CHEQ, Monash University.

M17. Diamond, N.T. (2006). "Agreement of 110/116 and 111/117 items by Consultant Physicians," prepared for the Australian College of Consultant Physicians.

M18. Diamond, N.T. (2006). "Analysis of Statistical Issues regarding Cornish v Municipal Electoral Tribunal, " prepared for Agricola, Wunderlich & Associates.

M19. Diamond, N.T. (2006). "Analysis of Parks Victoria Staff Allocation," prepared for Parks Victoria.

M20. Diamond, N.T. and Hyndman, R.J. (2006). "Summary of Results of IPL Sales Forecasting Improvement Project," prepared for Incitec Pivot.

M21. Sztendur, E.M. and Diamond, N.T. (2007) "A model for student retention at Monash University", prepared for University retention committee.

M22. Sztendur, E.M. and Diamond, N.T. (2007) "An extension to a model for student retention at Monash University", prepared for University review of coursework committee.

M23. Sztendur, E.M. and Diamond, N.T. (2007) "A model for student academic performance at Monash University", prepared for University review of coursework committee.

M24. Diamond, N.T. (2007). "Analysis of IB student 1st year results at Monash University 2003-2005", prepared for VTAC.

M25. Diamond, N.T. (2008). "Effect of smoking bans on numbers of clients utilising problem gambling counselling and problem gambling financial counselling", prepared for Department of Justice

M26. Diamond, N.T. (2008). "Development of Indices Based Approach for Forecasting Gambling Expenditure at a Local Government Area Level", prepared for Department of Justice

M27. Diamond, N.T. (2008). "Orientation 2007- Analysis of Quantitative results", prepared for University Orientation committee.

M28. Diamond, N.T. (2008). "Orientation 2007- Analysis of Qualitative results, prepared for University Orientation committee.

M29. Diamond, N.T. (2008). "Analysis of Clients presenting to Problem Gambling Counselling Services-2002/03 to 2005/06", prepared for the Department of Justice.

M30. Diamond, N.T. (2008). "Analysis of Clients presenting to Problem Gambling Financial Counselling Services-2001/02 to 2005/06", prepared for the Department of Justice.

M31. Diamond, N.T. (2008). "Analysis of Clients presenting to Problem Gambling Counselling and Problem Gambling Financial Counselling Services-2006/07", prepared for the Department of Justice.

M32. Diamond, N.T. (2008). "The effect of changes to Electronic Gaming Machine numbers on gambling expenditure", prepared for the Department of Justice.

M33. Diamond, N.T. (2009). "Adjustment of Mark Distributions", prepared for the Faculty of Law.

M34. Diamond, N.T. (2009). "Summary of Results for Dyno Nobel Sales Forecasting Improvement Project," prepared for Incitec Pivot.

M35. Diamond, N. and Brooks, R. (2010). "Determining the value of imputation credits: Multicollinearity and Reproducibility Issues", prepared for the Victorian Electricity Distributors.

M36. Booth, R., Diamond, N., and Brooks, R. (2010). "Financial Analysis of Revenues and Expenditures of the AFL and of the AFL Clubs", prepared for the Australian Football League Players' Association.

M37. Diamond, N. and Brooks, R. (2010). "Determining the value of imputation credits: Sample Selection, and Standard Errors", prepared for the Victorian Electricity Distributors.

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Professional Service

- President, Victorian Branch, Statistical Society of Australia, 2001-2002.
  - Terms as Council Member, Vice-President, and Past President.
- Referee: *Australian and New Zealand Journal of Statistics*, *Biometrika*, *Journal of Statistical Software*

Professor Robert Brooks

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FEDERAL COURT OF AUSTRALIA

Practice Note CM 7

EXPERT WITNESSES IN PROCEEDINGS IN THE FEDERAL COURT OF AUSTRALIA

Practice Note CM 7 issued on 1 August 2011 is revoked with effect from midnight on 3 June 2013 and the following Practice Note is substituted.

Commencement

1. This Practice Note commences on 4 June 2013.

Introduction

2. Rule 23.12 of the Federal Court Rules 2011 requires a party to give a copy of the following guidelines to any witness they propose to retain for the purpose of preparing a report or giving evidence in a proceeding as to an opinion held by the witness that is wholly or substantially based on the specialised knowledge of the witness (see **Part 3.3 - Opinion** of the *Evidence Act 1995* (Cth)).

3. The guidelines are not intended to address all aspects of an expert witness's duties, but are intended to facilitate the admission of opinion evidence[1], and to assist experts to understand in general terms what the Court expects of them. Additionally, it is hoped that the guidelines will assist individual expert witnesses to avoid the criticism that is sometimes made (whether rightly or wrongly) that expert witnesses lack objectivity, or have coloured their evidence in favour of the party calling them.

<u>Guidelines</u>

1. General Duty to the Court[2]

1.1 An expert witness has an overriding duty to assist the Court on matters relevant to the expert's area of expertise.

1.2 An expert witness is not an advocate for a party even when giving testimony that is necessarily evaluative rather than inferential.

1.3 An expert witness's paramount duty is to the Court and not to the person retaining the expert.

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[1] As to the distinction between expert opinion evidence and expert assistance see *Evans Deakin Pty Ltd v Sebel Furniture Ltd* [2003] FCA 171 per Allsop J at [676].

[2] The "*Ikarian Reefer*" (1993) 20 FSR 563 at 565-566.

2. The Form of the Expert's Report[3]

2.1 An expert's written report must comply with Rule 23.13 and therefore must

(a) be signed by the expert who prepared the report; and

(b) contain an acknowledgement at the beginning of the report that the expert has read, understood and complied with the Practice Note; and

(c) contain particulars of the training, study or experience by which the expert has acquired specialised knowledge; and

(d) identify the questions that the expert was asked to address; and

(e) set out separately each of the factual findings or assumptions on which the expert's opinion is based; and

(f) set out separately from the factual findings or assumptions each of the expert's opinions; and

(g) set out the reasons for each of the expert's opinions; and

(ga) contain an acknowledgment that the expert's opinions are based wholly or substantially on the specialised knowledge mentioned in paragraph (c) above[4]; and

(h) comply with the Practice Note.

2.2 At the end of the report the expert should declare that "[the expert] has *made all the inquiries that* [the expert] *believes are desirable and appropriate and that no matters of significance that* [the expert] *regards as relevant have, to* [the expert's] *knowledge, been withheld from the Court*."

2.3 There should be included in or attached to the report the documents and other materials that the expert has been instructed to consider.

2.4 If, after exchange of reports or at any other stage, an expert witness changes the expert's opinion, having read another expert's report or for any other reason, the change should be communicated as soon as practicable (through the party's lawyers) to each party to whom the expert witness's report has been provided and, when appropriate, to the Court[5].

2.5 If an expert's opinion is not fully researched because the expert considers that insufficient data are available, or for any other reason, this must be stated with an indication that the opinion is no more than a provisional one. Where an expert witness who has prepared a report believes that it may be incomplete or inaccurate without some qualification, that qualification must be stated in the report.

2.6 The expert should make it clear if a particular question or issue falls outside the relevant field of expertise.

2.7 Where an expert's report refers to photographs, plans, calculations, analyses, measurements, survey reports or other extrinsic matter, these must be provided to the opposite party at the same time as the exchange of reports[6].

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[3] Rule 23.13.
[4] See also *Dasreef Pty Limited v Nawaf Hawchar* [2011] HCA 21.
[5] The *"Ikarian Reefer"* [1993] 20 FSR 563 at 565
[6] The *"Ikarian Reefer"* [1993] 20 FSR 563 at 565-566. See also Ormrod *"Scientific Evidence in Court"* [1968] Crim LR 240

3. Experts' Conference

3.1 If experts retained by the parties meet at the direction of the Court, it would be improper for an expert to be given, or to accept, instructions not to reach agreement. If, at a meeting directed by the Court, the experts cannot reach agreement about matters of expert opinion, they should specify their reasons for being unable to do so.

J L B ALLSOP
Chief Justice
4 June 2013

United Energy Distribution Pty Limited
ABN 70 064 651 029

Multinet Gas Distribution Partnership
ABN 53 634 214 009

United Energy and Multinet Gas
6 Nexus Court
Mulgrave VIC3170
PO Box 449
Mt Waverley VIC 3149
T 03 8846 9900
F 03 8846 9999
www.uemg.com.au

Our Reference: UE.SU.01

TERMS OF REFERENCE – REVIEW OF EXTRAPOLATION METHODS APPLIED TO THE RBA SERIES OF NON-FINANCIAL CORPORATE BOND SPREADS

Background

In its 2014 draft decision for Jemena Gas Networks (JGN), the AER has adopted an approach to estimating the return on debt for a benchmark efficient entity which makes use of "third party" measures of the cost of debt. You are asked to familiarise yourself with that part of the draft determination and also Rule 6.5.2 (of the National Electricity Rules) concerning the establishment of an allowed rate of return by the AER (see AER, Draft decision, Jemena Gas Networks (NSW) Ltd., Access arrangement 2015–20, Attachment 3: Rate of return, November 2014).

The AER's JGN draft determination uses both RBA data (from Table F3) and Bloomberg data (from the Bloomberg BVAL curve for BBB rated bonds). However, neither of the two curves provides cost of debt estimates that are commensurate with a ten year effective tenor. Therefore, to obtain an estimate for a benchmark 10 year corporate bond, the results from the published data sources should be subject to amendment through extrapolation.

A report from CEG titled "Critique of the AER's JGN draft decision on the cost of debt," March 2015, contains an assessment of at least two alternative extrapolation methods: The "AER approach" (which was provided by Martin Lally) and the SA Power Networks (or SAPN) approach. You are asked to also familiarise yourself with that document. A further report to consider is that provided by Martin Lally, (Implementation Issues for the Cost of Debt, Martin Lally, Capital Financial Consultants, November 2014).

Brief

You are requested to undertake a detailed review of the statistical properties of the various extrapolation methods. The properties of the different extrapolation or smoothing methods should also be compared with the attributes of yield curves, such as Nelson-Siegel yield curves. The analysis should be based on theory and also empirical application. If you consider that there are other methods which might be more suitable for use than Nelson-Siegel yield curves, then please provide answers to the questions below in relation to those methods, as well as in respect of Nelson-Siegel regressions.

Please answer the following specific questions:

1. Derive formulae for the weights used in the various extrapolation methods.

2. Provide an assessment of whether any of the methods has a bias, or tendency to report results that are higher or lower than a fair value for a 10 year unexpired tenor. If there is a bias, or a tendency to over or under-estimate the true result, then please explain the causes of the over or under-statement .

3. Provide an analysis of the performance of the methods based on theory.

4. For the Lally (2014) and AER methods, give examples of the calculations involved in the extrapolation.

5. Use empirical methods to demonstrate the practical application of the approaches. If possible, produce a time series of results. The emphasis should be placed on end-of-month data because the RBA produces results for Table F3 that are based on assessments done on or around the last business day of the month.

6. Compare the extrapolations based on yields with those that use spreads to swap, and spreads to Commonwealth Government Securities (CGS).

7. Apply methods based on Nelson-Siegel yield curves. Compare the results from yield curves with those obtained using the Lally and SAPN methods.

8. Evaluate the advantages and disadvantages of the different extrapolation or smoothing methods, drawing upon theory and empirical results.

10. Assess the merits of making adjustments to the underlying data so as to better control for the gradation of credit ratings within the broad BBB band. The credit ratings for bonds should be based on the ratings assigned by Standard and Poor's.

Timeframe

The consultant is to provide a draft report which discusses the results of the analysis by 9th March 2015. A final report should be provided by no later than Monday 23rd March, 2015.

Reporting

Jeremy Rothfield will serve as the primary contact for the period of the engagement. The consultant will prepare reports showing the work-in-progress on a regular basis. The consultant will make periodic presentations on analysis and advice as appropriate.

Conflicts

The consultant is to identify any current or potential future conflicts.

Compliance with the Code of Conduct for Expert Witnesses

Attached is a copy of the Federal Court's Practice Note CM 7, entitled "Expert Witnesses in Proceedings in the Federal Court of Australia", which comprises the guidelines for expert witnesses in the Federal Court of Australia (Expert Witness Guidelines).

Please read and familiarise yourself with the Expert Witness Guidelines, and comply with them at all times over the course of your engagement with United Energy and Multinet Gas.

In particular, your report prepared for United Energy and Multinet Gas should contain a statement at the beginning of the report to the effect that the author of the report has read, understood and complied with the Expert Witness Guidelines.

Your report must also:

1. Contain particulars of the training, study or experience by which the expert has acquired specialised knowledge.

2. Identify the questions that the expert has been asked to address.

3. Set out separately each of the factual findings or assumptions on which the expert's opinion is based.

4. Set out each of the expert's opinions separately from the factual findings or assumptions.

5. Set out the reasons for each of the expert's opinions; and

6. Otherwise comply with the Expert Witness Guidelines.

The expert is also required to state that each of the expert's opinions is wholly or substantially based on the expert's specialised knowledge.

The declaration contained within the report should be that "[the expert] has made all the inquiries that [the expert] believes are desirable and appropriate and that no matters of significance that [the expert] regards as relevant have, to [the expert's] knowledge, been withheld from the report".

Please also attach a copy of these terms of reference to the report.

Fees

The consultant is requested to submit:

- A fixed total fee for the project and hourly rates for the proposed project team should additional work be required; and

- Details of the individuals who will provide the strategic analysis and advice.

Contacts

Any questions regarding this terms of reference should be directed to:

Jeremy Rothfield, telephone (03) 8846 9854, or via email at Jeremy.Rothfield@ue.com.au