Jemena Gas Networks (NSW) Ltd

2020-25 Access Arrangement Proposal

Attachment 6.4

Relative efficiency and forecast productivity growth of JGN

Public—30 June 2019

Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW)

Report prepared for

Jemena Gas Networks

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EXECUTIVE SUMMARY

Jemena Gas Networks (JGN) has commissioned Economic Insights Pty Ltd ('Economic Insights') to provide advice on productivity measurement and benchmarking of its gas distribution network operations in New South Wales (NSW). This report examines the efficiency performance of JGN over the period 1999–2018 within a group of 13 gas distribution businesses (GDBs), of which 11 are from Australia and two from New Zealand.[1] The report has been prepared for JGN as an input to its forthcoming access arrangement proposal for the period July 2020 to June 2025, to be submitted for approval by the Australian Energy Regulator (AER).

Partial Performance Indicators

In Part A, a set of partial performance indicators is presented to compare the opex and capital input efficiency of the thirteen businesses against one another. The Australian and New Zealand GDBs included in the study are: Evoenergy (in the Australian Capital Territory); AGN Albury (NSW); Australian Gas Networks (AGN) Queensland; AGN South Australia; AGN Victoria; AGN Wagga Wagga (NSW); Allgas Energy (Queensland); ATCO Gas Australia (Western Australia); AusNet Services (Victoria); JGN; Multinet (Victoria); Powerco (New Zealand); and Vector (New Zealand). The partial performance indicators presented are:

- Opex per customer relative to customer density
- Opex per mains km relative to customer density
- Asset cost per customer relative to customer density
- Asset cost per mains km relative to customer density
- Total cost per customer relative to customer density
- Total cost per mains km relative to customer density.

While these indicators have the advantage of simplicity, care is needed in interpretation, as individual partial performance indicators may give a misleading impression of overall efficiency. Generally, if a GDB is ranked highly for most indicators this may be taken to suggest that it is performing at levels consistent with industry best practice. If performance on these measures is mixed or unfavourable, more analysis may be warranted. It is also desirable to examine more holistic measures of efficiency, such as total factor productivity (TFP) analysis, or methods of measuring efficiency which can control for differences in scale and other operating environment differences.

The data used in this study has been predominantly sourced from documents in the public domain. These data have been supplemented in some places with information provided by several major Australian GDBs in response to common detailed data surveys.

JGN's operating environment characteristics can be summarised as follows:

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[1] In Part C (the econometric analysis) an additional New Zealand GDB is included in the sample. For details see Appendix A.

- It is the largest GDB in the sample in terms of customer numbers, gas deliveries and network length. Although it is much larger than any of the other GDBs in terms of customer numbers and network length, it is more comparable in size to some of the Victorian GDBs in terms of gas deliveries.
- JGN's customer density (50 customers per km main) is the seventh largest in the sample and not much higher than the sample average (43 customers/km). Most of the GDBs with higher customer densities are relatively large, such as the three Victorian GDBs, AGN SA and ATCO. Most of the smallest GDBs in the sample had customer densities less than JGN's. JGN's customer density increased quite strongly over the sample period, more so than other GDBs.
- JGN's energy density per customer (70 GJ/customer), is below the average for all GDBs (83 GJ/customer). There are no directly comparable GDBs because, amongst the relatively large GDBs, the three Victorian GDBs have significantly higher energy densities (the closest to JGN is Multinet), whereas AGN and ATCO have particularly low energy densities. Energy density per customer has generally declined over time for most GDBs. JGN is no exception, with energy density decreasing by more than 50 per cent (cumulatively) between 1999 and 2018.
- JGN has the fifth largest energy deliveries per km or 'network utilisation', and is close to the average for all GDBs. JGN's network utilisation decreased by 25 per cent (cumulatively) between 1999 and 2018. For most GDBs, network utilisation has declined over the sample period reflecting the fact that declines in energy density per customer have outpaced increases in customer density per km.

Partial indicators of cost efficiency are examined for two broad groups of costs, namely opex and asset costs, as well as total costs. These comparisons do not control for other drivers of opex costs that may be relevant. If a GDB is ranked poorly for most indicators then this may warrant further investigation as to whether that GDB was operating inefficiently. Conversely, if a GDB is ranked highly for most indicators then this may be taken to suggest that it is performing at levels consistent with industry best practice. If a GDB performs well on some indicators but poorly on others then the GDB's performance is harder to assess as it may be making trade–offs between different types of inputs (eg, opex and capital) and more detailed analysis may be required.

The main observations relating to JGN are:

- In regard to the opex-related measures, when differences in customer density are controlled-for, JGN is reasonably efficient in terms of opex per customer, and it has average levels of opex per km of network.
- In terms of asset cost measures, JGN is close to average in terms of asset cost per customer and has relatively higher asset cost per km of mains. These comparisons are influenced among other things by asset age, original network asset valuations, and various factors not controlled-for which influence the quantity of assets per customer, and hence asset cost per customer.
- In terms of total cost measures, JGN's total cost per customer is close to the sample average when differences in customer density are controlled for, whereas its total cost per km is slightly higher than the sample average. Once again, qualification is

necessary because the wide variation in GDBs' total cost per km may suggest that unobserved differences in local conditions are important determinants of these costs.

- Based on these indicators and recognising the nature of their networks, JGN appears to be close to the average for all GDBs for most of the efficiency measures shown.

The partial indicators analysis presented in this report does not enable influences such as scale economies or different mixes of inputs to be controlled for in a rigorous fashion. This means that care needs to be taken when drawing inferences, and only qualified conclusions can be drawn. It is also desirable to have regard to more holistic measures of efficiency, such as total factor productivity (TFP) analysis, and other methods of measuring efficiency such as econometric cost functions which can control for differences in scale and other operating environment differences.

Total Factor Productivity and Partial Factor Productivity

The analysis presented in Part B of this report details analysis of JGN's total factor productivity (TFP) and partial factor productivity (PFP) trends, and comparison against the productivity trends of other Australian gas distribution businesses (GDBs) over time. This report also provides a comparative analysis of JGN's productivity levels against other Australian GDBs using multilateral TFP.

The primary data source for this part of the study is information supplied by seven Australia GDBs, including JGN. The other GDBs are Australian Gas Infrastructure Group (AGIG) in relation to the Australian Gas Networks Limited (AGN) South Australian, Victorian and Queensland gas networks, as well as Multinet Gas in Victoria, ATCO Gas Australia in Western Australia and AusNet in Victoria. The data was provided in response to common detailed data surveys, covering key output and input value, price and quantity information. For JGN this data is available for 1999 to 2018 and for the other GDBs is generally available for the period from 1999 or 2000 to 2017 or 2018 (with the exception of AGN Queensland which is currently only available to 2014).

The TFP measure used includes three outputs (throughput, customer numbers and system capacity) and eight inputs (opex, lengths of transmission pipelines, high pressure pipelines, medium pressure pipelines, low pressure pipelines and services, meters, and other capital). For productivity level comparisons transmission pipelines are excluded to allow more like–with–like comparisons.

TFP indexes are used to measure the *trends* in productivity. In summary, the time series TFP results for JGN are as follows:

- JGN's average rate of TFP growth over the whole period from 1999 to 2018 was 0.7 per cent per year. Most of the productivity growth occurred in the period 1999 to 2007, when there were large reductions in real opex and TFP growth averaged 2.0 per cent per year on average. From 2007 to 2014, TFP declined slightly, at an average rate of 0.4 per cent per year, and from 2014 to 2018, TFP growth was zero. The period since 2007 has seen some small gains in opex PFP offset by some small declines in capital PFP.
- Compared to the other GDBs in the sample, JGN's TFP growth rate over the whole sample period was close to the overall average for all GDBs. The GDBs with the strongest rates of total factor productivity growth were ATCO and AusNet (both with

average annual TFP growth rates of 1.5 per cent over the same period) and AGN–Vic (1.4 per cent). GDBs with similar TFP growth rates to JGN included AGN SA (0.7 per cent) and Multinet (0.6 per cent).

- JGN's output growth in the period 2000 to 2007 was 1.9 per cent per year on average. Output grew at a similar rate in subsequent periods; 1.6 per cent per year from 2007 to 2014, and 1.9 per cent per year from 2014 to 2018. The average rate of output growth over the full sample period (1.8 per cent per year) was close to the average for all GDPs in the study.
- There were divergent trends in JGN's use of real opex and capital input quantities. On average, over the period from 1999 to 2018, the quantity of opex inputs decreased at an annual rate of 1.6 per cent. These reductions were concentrated in the period before 2007. In the period from 2007 to 2014, opex inputs increased at 1.0 per cent per year on average, and in the latest four–year period opex inputs increased at an average rate of 0.4 per cent per year. Given JGN's output growth of 1.8 per cent per year on average from 1999 to 2018, opex partial factor productivity (PFP) increased at a rate of 3.5 per cent per year from 1999 to 2018, although this was heavily focussed in the period before 2007 when opex inputs were decreasing. Over the period 2007 to 2014, opex PFP growth averaged 0.6 per cent per year, and from 2014 to 2018 it averaged 1.6 per cent per year (or 0.9 per cent per year from 2007 to 2018). JGN was among those GDBs with relatively strong growth in Opex PFP (including also AGN Vic, AusNet and ATCO). Other GDBs had a similar pattern over time with high growth in the period 1999 to 2007 and more moderate opex PFP since then.
- Opex PFP changes depend not only on technical change (efficiency frontier shift) but also the effects of changes in the capital stock, scale economies and the effects of operating environment characteristics. Hence the trends in opex PFP are not directly comparable to the rate of frontier shift estimated in Part C of the report. That said, JGN's opex PFP growth rate over the period 2007 to 2018 is not very dissimilar to the estimated rate of frontier shift for GDBs in general over the whole sample period, which is presented in Part C.
- In contrast to opex inputs, the capital inputs quantity index increased over the whole period from 1999 to 2018, averaging an annual increase of 2.2 per cent. This is slightly higher than the average growth of the output index. Consequently the capital PFP decreased at an average rate of 0.4 per cent per year over the period over the same period. A similar trend applied in the latest period from 2014 to 2018. Overall, this is similar with the pattern among the other GDBs, for which capital PFP was either flat or declining moderately over the period 1999 to 2018.

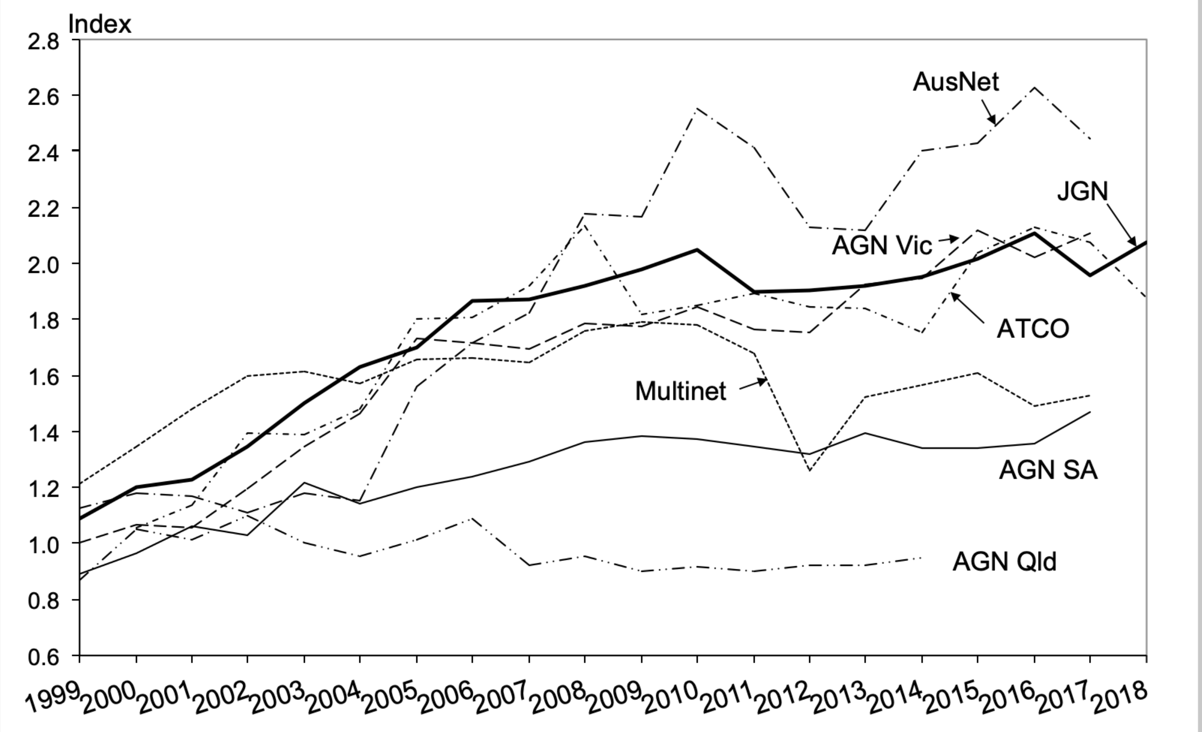
The MTFP index is used to measure comparative productivity *levels*. The MTFP results indicate that in the latest year available, JGN was among those GDBs with comparatively higher levels of TFP. JGN's MTFP index in 2018 was 1.100, which was less than AGN Vic (1.241 in 2017), AusNet (1.136 in 2017), and ATCO (1.116 in 2018); and it was higher than those of Multinet (0.998), AGN SA (1.012), and AGN Qld (0.694).

JGN's level of opex MPFP in 2018 (2.07) was also among the highest of the GDBs included in the study. It was lower than that of AusNet (2.45) and AGN Vic (2.11); and higher than those of ATCO (1.88), Multinet (1.53), AGN SA (1.47) and AGN Qld (0.95). JGN's capital

MPFP index in 2018 of 0.85 was equal second highest among the GDBs. It was equal to AGN SA (0.85) and exceeded only by that of AGN Vic (1.02 in 2017); and it was higher than those of AusNet and ATCO (both 0.82), Multinet (0.80), and AGN Qld (0.61).

The MTFP and MPFP analyses indicate that JGN is a relatively efficient performer in its use of both opex and capital inputs.

Figure A: GDB Opex MPFP indexes, 1999–2018



Source: Economic Insights GDB database

Opex Cost Function

In Part C of the report, we estimate the opex cost function for gas distribution businesses. The principal aims of the analysis are to estimate trends in technical efficiency in the industry and estimate the opex efficiency of JGN relative to other GDBs. The econometric results are used to establish whether JGN is efficient in its use of opex inputs, and also to estimate parameters that can be used in the 'rate of change' method of forecasting JGN's opex for the period 2020 to 2025. These parameters include the average historical rate of frontier shift (or technical change) and the appropriate weights for constructing the output index.

The analysis in this part of the report is similar to those previously undertaken by Economic Insights in 2015 and 2016. This study uses additional data available since the 2016 study was undertaken. It tests specifications developed in those previous studies and tests alternative specifications generally based on the translog variable cost function specification, and simplifications of it. Alternative stochastic specifications are also used.

The main findings of the econometric analysis are as follows:

- JGN's estimated efficiency score is not significantly different from the highest efficiency score in the sample. JGN's efficiency score is 0.93, with a confidence interval of between 0.87 and 0.99. The average efficiency score of all GDBs in the sample is 0.86 and the highest efficiency score of 0.98. Hence, the highest efficiency score is within the confidence interval of JGN's efficiency score. JGN is one of several firms clustered on or close to the efficient frontier with only 5 percentage points separating the efficiency scores of the top six GDBs. This finding suggests that JGN does not have any material inefficiency and does not require an adjustment to its base year opex.

- The estimated average rate of technical change or 'frontier shift' is 0.74 per cent per annum (expressed as a rate of productivity growth). This estimate is close to estimates we obtained in previous studies for JGN in 2015 (0.7 per cent) and for Multinet in 2016 (0.6 per cent), and is slightly higher than the figure of 0.5 per cent per year recently assessed by the AER (2019) for electricity distribution.
- The estimated output index weights for the two outputs used in the preferred econometric model are: (i) customer numbers, 49.4 per cent; and (ii) mains length, 50.6 per cent.

1 INTRODUCTION

1.1 Terms of reference

Jemena Gas Networks (JGN) commissioned Economic Insights Pty Ltd ('Economic Insights') to conduct productivity measurement and benchmarking of its New South Wales gas distribution network operations. The terms of reference are listed in appendix E and request Economic Insights to update three separate economic benchmarking analyses previously undertaken for gas distribution businesses (GDBs). Consequently, this report is presented in three parts as follows:

(a) *Partial Performance Indicators*: Part A of this report presents partial indicator comparisons between a set of 11 Australian and two New Zealand GDBs. These partial performance indicators are analogous to those published by the Australian Energy Regulator for electricity distribution businesses (AER 2014). This report updates similar studies carried out for AGN SA in 2015, the three Victorian GDBs (AGN Vic, AusNet and Multinet) in 2016 and ATCO in 2018 for their respective access arrangement reviews (Economic Insights 2015b, 2016a, 2018).

(b) *Total and Partial Factor Productivity Indexes*: The analysis presented in Part B of this report details JGN's total factor productivity (TFP) and partial factor productivity (PFP) trends, and comparison against the productivity trends of other Australian gas distribution businesses (GDBs) over time. This part of the study also provides a comparative analysis of JGN's productivity levels against other Australian GDBs using multilateral TFP (MTFP). This entails updating and extending analysis that Economic Insights has carried out previously for JGN (Economic Insights 2015a) and other Australian GDBs (Economic Insights 2015c, 2016b).

(c) *Econometric Analysis*: The third part of the study, presented in Part C, is to undertake econometric analysis of gas network real opex as a function of outputs, fixed capital inputs and operating environment factors, similar to studies previously carried out for JGN and Multinet (Economic Insights 2015a, 2016c), and to use this model to:

   - examine JGN's opex efficiency;
   - estimate the past rate of technical change; i.e. the rate of improvement in the efficient production frontier; and
   - estimate output index weights for use in projecting the opex rate of change over the next regulatory period.

1.2 Detailed Outline of the Report

In Part A, chapter 2 presents data on the business operating environment characteristics that influence the observed performance of GDBs. Chapter 3 provides a summary comparison of partial performance indicators relating to costs per customer.

In Part B, chapter 4 briefly explains productivity measurement and its applications in the context of the economic regulation of natural monopolies. It also discusses measurement issues, data sources and the definitions of outputs and inputs used in the study. Chapter 5 presents an analysis of TFP and PFP *trends* for JGN over the period 1999 to 2018 and provides comparative information for other GDBs. Chapter 6 presents a comparative analysis of the TFP *levels* of JGN and the other major Australian GDBs in other states using multilateral TFP analysis. The multilateral TFP method is explained and the results of the analysis of multilateral TFP and PFP are reported.

In Part C, chapter 7 of this report introduces the analysis of the real opex cost function of Australasian GDBs by firstly discussing the regulatory context, and the variable cost function and the variables used in the study. It documents the dataset, including the GDBs and time periods that form the data sample. It then explains the econometric methodologies, including the specification of the variable cost function, the alternative stochastic specifications, and the criteria used for model selection. Lastly, it explains how the results of the model are to be used as part of projecting opex rates of change.

Chapter 8 presents the results of the econometric analysis of the real opex cost function of Australasian GDBs. Only the preferred model is presented in that chapter. More detail relating to the models tested is shown in Appendix D. Chapter 8 also draws out the main inferences from the analysis in relation to JGN's technical efficiency, the industry rate of technical change, and appropriate weights for constructing the output index.

Appendix A briefly describes the operations of the 11 Australian GDBs and two New Zealand GDBs included in this study, and Appendix B describes the databases used in the study. Appendix C documents the derivation of the output cost share weights used in the multilateral TFP analysis. Appendix D details some of the key models tested in deriving the preferred econometric opex cost function. The terms of reference are presented in Appendix E.

1.3 Economic Insights' experience

Economic Insights has been operating in Australia for over 20 years as an economic consulting firm specialising in infrastructure regulation and economic benchmarking. Economic Insights provides strategic policy advice and rigorous quantitative research to industry and government. Economic Insights' experience and expertise covers a wide range of economic and industry analysis topics including:

- infrastructure regulation;
- productivity measurement;
- benchmarking of firm and industry performance;
- infrastructure pricing issues; and
- analysis of competitive neutrality issues.

PART A: PARTIAL PRODUCTIVITY INDICATORS

This part of the report discusses the characteristics and efficiency performance of JGN over the period 1999–2018 within a group of 11 Australian and two New Zealand gas distribution businesses (GDBs). Appendix A briefly describes the operations of the 11 Australian GDBs and two New Zealand GDBs included in this part of the study, and Appendix B describes the database used.

The information presented in this section updates previous similar studies carried out by Economic Insights. These include studies carried out for AGN SA in 2015, the three Victorian GDBs (AGN Vic, AusNet and Multinet) in 2016 and ATCO in 2018 for their respective access arrangement reviews (Economic Insights 2015, 2016, 2018).

Section 2 presents data on the business characteristics that influence the observed performance of GDBs. Section 3 provides a summary comparison of partial performance indicators relating to costs per customer. A set of partial performance indicators is presented to compare the opex and capital input efficiency of the thirteen businesses against one another. These indicators have the advantage of being relatively easy to construct and understand. However, care needs to be exercised in interpreting the results, as individual partial performance indicator results may give a misleading impression of overall efficiency. To gain an indication of overall relative performance, the partial indicators need to be considered together and jointly with key operating environment indicators.

2 OPERATING ENVIRONMENT INDICATORS

This section describes some key characteristics of the 13 GDBs included in this part of the study. The performance indicators discussed in this section are summarised in the Annexure at the end of this section, in Tables 2.1 to 2.4. Descriptive information on each GDB included in this study is presented in Appendix A.

The data covers the years 1999 (or 2000) to 2018 for three of the Australian GDBs, and from 1999 to 2017 for a further five Australian GDBs. For the other GDBs the data are not available for all years in the latter period. Table B.1 in Appendix B shows the data sample periods for each included GDB. Data is available from 1999 to 2018 for Evoenergy and JGN; for 2000 to 2018 for ATCO; for 1998 to 2017 for AGN Albury, AGN Victoria, AusNet Services and Multinet. For AGN SA from 1999 to 2017; for Allgas and AGN Queensland from 2001 to 2016; AGN Wagga from 1999 to 2015; Powerco from 2004 to 2017; and Vector from 2005 to 2017. Availability of earlier data for New Zealand GDBs has been affected by merger and restructuring activity. The comparability of data for Vector in 2016 and 2017 against earlier years is affected by its divestiture of gas pipelines outside Auckland in November 2015. Further information on the dataset used in this analysis is included in Appendix B.

These Australasian gas distribution businesses operate in varying environments often with substantial differences in network size, amount of throughput, demand growth, number and type of customers, and the mix of rural, urban and central business district (CBD) customers. The operating environment indicators presented in this section are:

(a) Energy delivered in terajoules (TJ), number of customers and network kilometres (km) (Figure 2.1)

(b) Customer density—customers per km of mains (Figure 2.2)

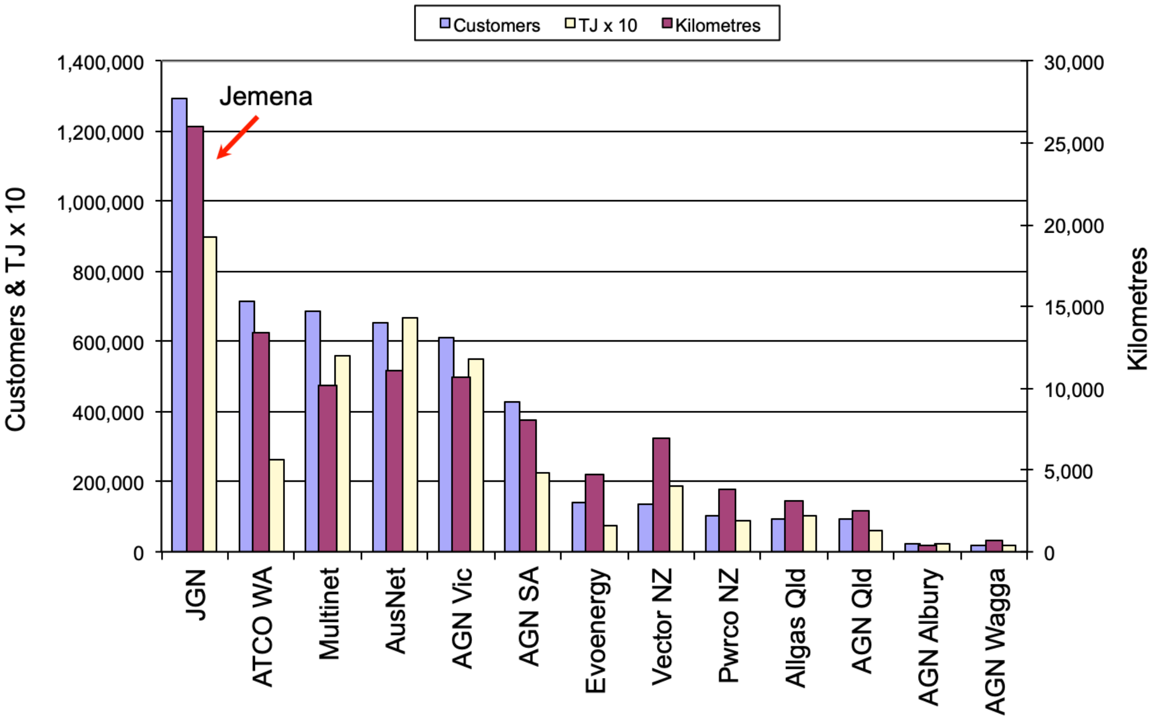
(c) Energy density—TJ per customer (Figure 2.3)

(d) Network utilisation—TJ per km (Figure 2.4).

Figure 2.1 shows, for each GDB in the sample, average customer numbers, gas energy throughput (TJ) and mains length (km) over the five years to 2018 (or the latest five year period available). GDBs are ranked in terms of number of customers and the position of JGN is highlighted.

JGN is the largest GDB in the sample in terms of all three measures shown. In terms of customer numbers, JGN is approximately 80 per cent larger than ATCO, which has the second largest customer base. ATCO is only slightly larger than the three Victorian GDBs, Multinet, AusNet Services and AGN Victoria in terms of customer numbers. In terms of gas throughput, JGN is approximately 20 per cent larger than AusNet, which has the second largest gas throughput. Multinet and AGN Vic are also among the larger GDBs in terms of gas throughput. ATCO is the fifth largest GDB in terms of gas throughput, and only slightly larger AGN SA and Powerco. In terms of network length, JGN is approximately 90 per cent larger than ATCO, which has the second largest network in the sample. The three Victorian GDBs and AGN SA all have substantial networks. Six of the GDBs in the sample are relatively small: Vector, Evoenergy, Allgas, AGN Queensland, AGN Albury and AGN Wagga Wagga.

Figure 2.1: Key features of the operating environment (average 2014-2018*)



* Or latest five-year period. For AGN Albury, AGN Vic, Multinet, AusNet, AGN SA, Powerco and Vector the period ending 2017. For AGN Qld, Allgas and Evoenergy the period ending 2016. For AGN Wagga the period ending 2015.

Source: Economic Insights gas utility database.

Two of the key operating environment characteristics influencing energy distribution business productivity levels and costs are *customer density*, measured by the number of customers per km of mains, and *energy density* measured by energy throughput (i.e. TJ) per customer. A GDB with lower customer density requires more pipeline length to reach its customers, on average, than a GDB with higher customer density and the same consumption per customer. This would make the lower density distributor appear less efficient unless the differing densities are allowed for. Being able to deliver more energy to each customer means that a GDB requires less capital and non-capital inputs to deliver a given volume of gas as input requirements are more influenced by customer numbers than energy quantities.

These two density measures for all companies in the sample for all available years are presented in Figures 2.2 and 2.3. When the foregoing two measures are multiplied together, the result is the ratio of energy throughput per km, or 'network utilisation'. This measure is presented in Figure 2.4.

Figure 2.2 shows the three Victorian GDBs have the highest customer densities in the sample. On average for the five years ending 2018 (or the latest year available), the customer densities of Multinet, AusNet and AGN Vic were 68, 59 and 58 customers per km respectively. Other GDBs with relatively high customer density include AGN Albury, AGN SA and ATCO, with 54, 53 and 53 customers per km respectively. JGN has the seventh highest customer density in the sample (50 customers per km), which is higher than the average for all GDBs (43). GDBs with lower customer density are AGN Qld (36), Allgas (30), Evoenergy (30), Powerco (27), AGN Wagga (27) and Vector (20). That is, the two New Zealand businesses and most of the smaller Australian GDBs (excepting AGN Albury) have comparatively low customer densities.

JGN's customer density has increased quite strongly over the sample period—more so than other GDBs. It increased at an average annual rate of 2.5 per cent. Other GDBs that have enjoyed significant increases customer density over the sample period include ATCO and Evoenergy. With the main exception of Vector, whose customer density decreased as a consequence of divesting part of its business, most of the other GDBs have had either relatively static levels of customer density or minor growth. Other exceptions are AGN Wagga and Powerco, which had average declines in customer density of 0.4 and 0.7 per cent per year respectively. This can occur, for example, where reticulation extends to urban areas of lower density.

Figure 2.3 shows the energy densities of each GDB over the sample period. On average over the five years to 2018 (or latest year available) JGN's energy density was 70 gigajoules (GJ) per customer, which was below the average for all GDBs (83 GJ per customer).[2] By comparison, AusNet and AGN Vic had higher energy densities of 102 and 90 GJ per customer respectively. Powerco and Multinet had similar energy densities to JGN; 84 and 81 GJ per customer respectively. AGN SA hand ATCO have particularly low energy densities of 53 and 37 GJ per customer respectively. There is considerable diversity in the energy densities of the smaller GDBs, reflecting wide variation in climates and the competitiveness of alternative fuels. Examples of small GDBs with high energy density include, Vector (136), Allgas (108) and AGN Albury (111). Examples of small GDBs with relatively low energy density include Evoenergy (54) and AGN Qld (66).

Energy use per customer has generally declined over the period from 1999 to 2018. JGN's energy density more than halved from 135 GJ/customer in 1999 to 64 GJ/customer in 2018 (a 53 per cent cumulative decrease). This was the largest decrease in energy density among the GDBs in the sample. Other GDBs with similarly large declines in energy density include ATCO, with energy density decreasing from 67 GJ/customer in 2000 to 34 GJ/customer in 2018 (a 49 per cent cumulative decrease) and AusNet, a decrease from 164 GJ/customer in 1999 to 98 GJ/customer in 2018 (a 40 per cent cumulative decrease). The energy density declines for AGN Vic and AGN SA were also substantial, but not quite as large.

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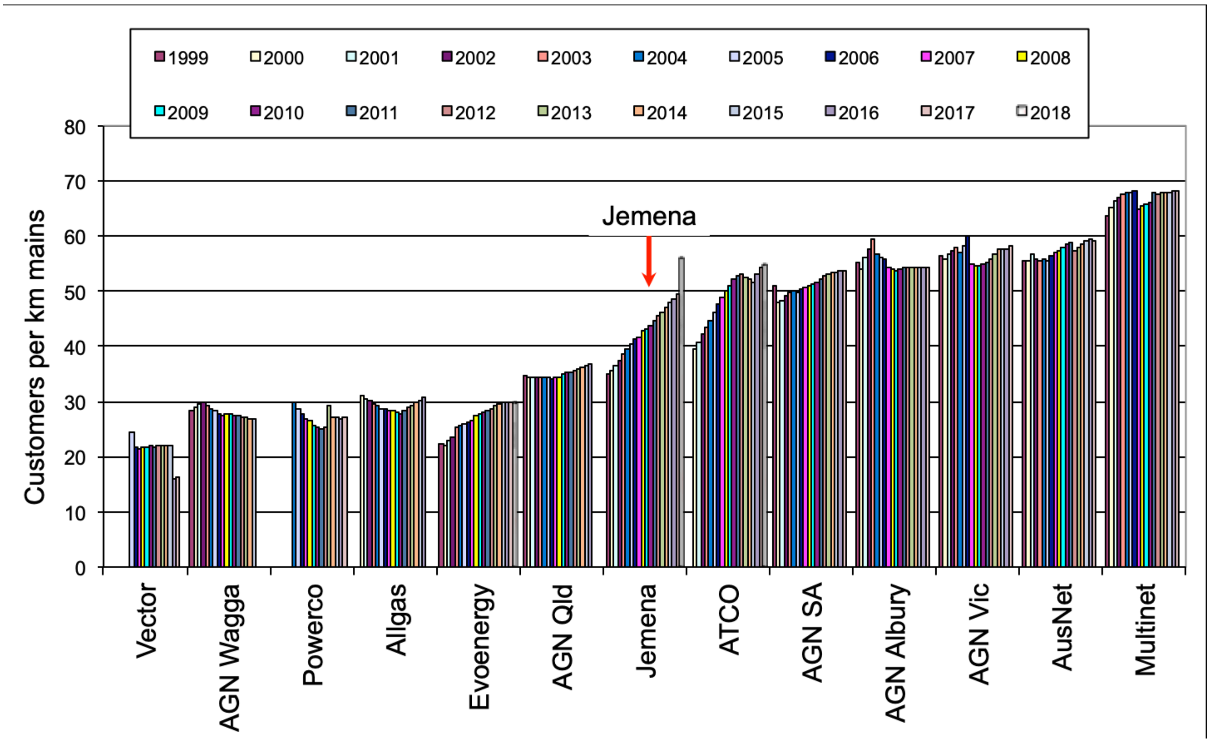
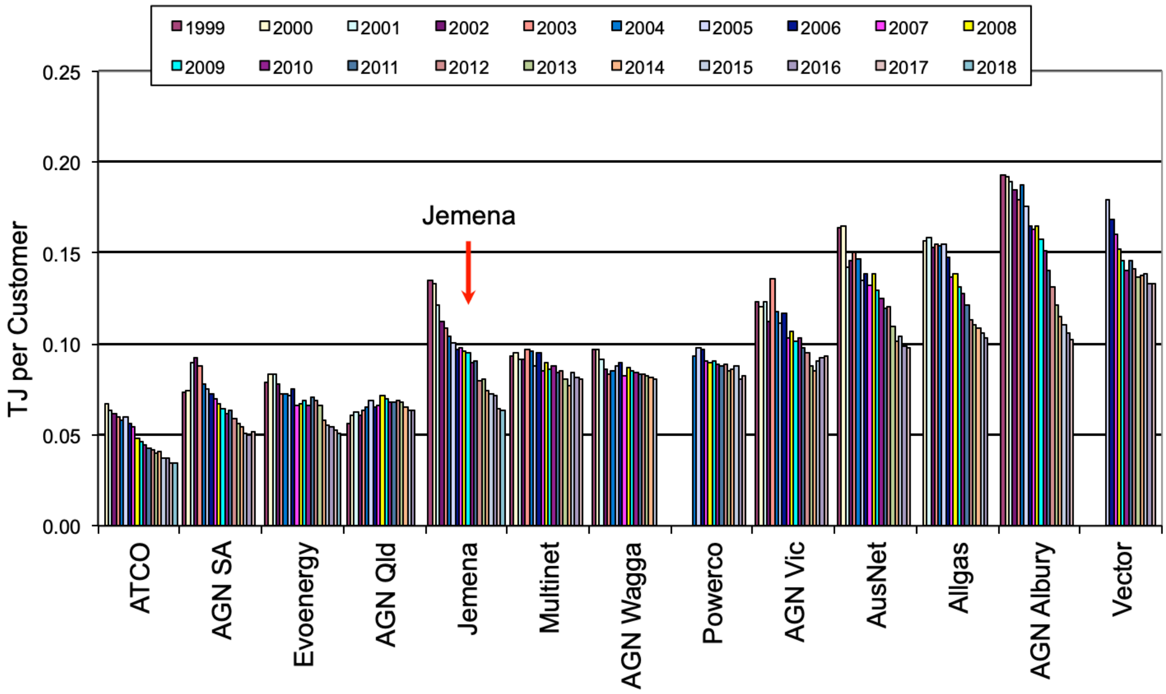
[2] A GJ is one thousandth of a TJ (i.e. 1,000 GJ = 1 TJ).

Figure 2.2: Customer density, 1999–2018



Source: Economic Insights gas utility database

Figure 2.3: Energy density, 1999–2018



Source: Economic Insights gas utility database

The cumulative decreases in average energy use per customer for these two GDBs were 24 per cent and 29 per cent respectively between 1999 and 2017. One of the smaller declines in average energy use per customer was for Multinet. In 1999 its energy density was 94 GJ/customer and it declined to 81 GJ/customer in 2017 (a cumulative decline of 13 per cent). The energy densities of the smaller Australian GDBs (Allgas, AGN Albury, AGN Wagga, AGN Qld and Evoenergy) decreased on average by 24 per cent cumulatively over the sample period. The energy densities of the New Zealand GDBs did not decrease as strongly as those in Australia. These trends reflect a combination of decreased gas demand by energy-intensive industries, residential energy efficiency improvements, and greater competition in the domestic heating market from electric split systems (e.g. split system air-conditioning and heating).

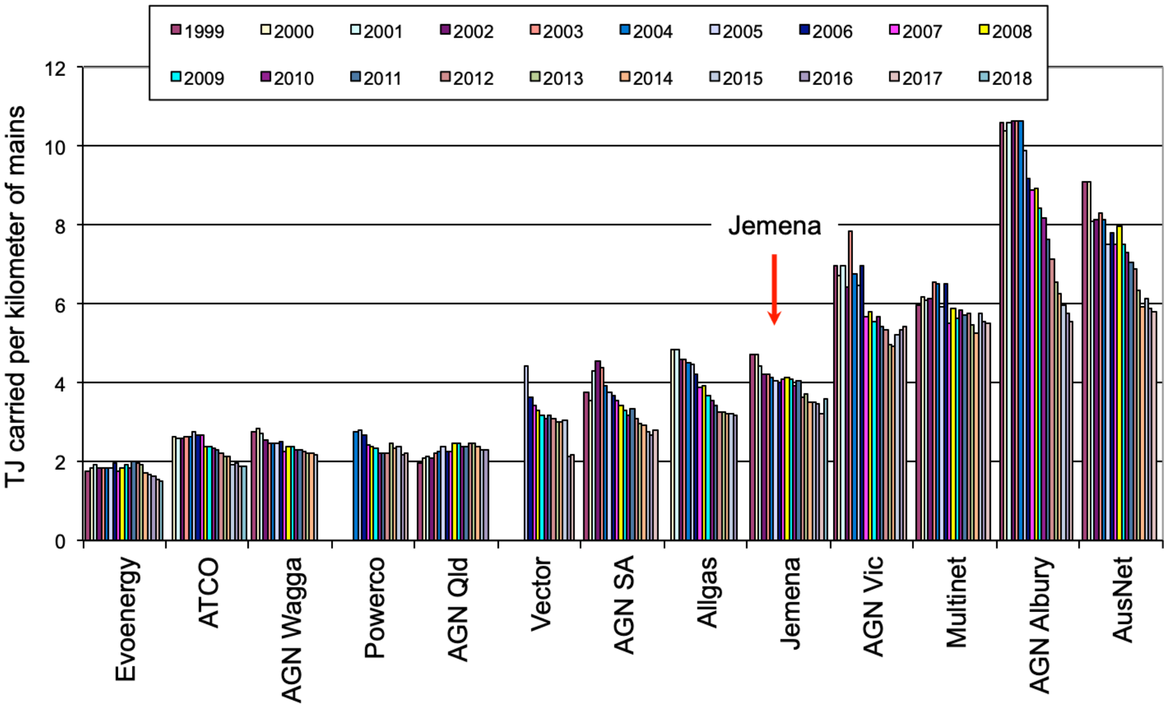
The combined effect of customer density and energy density is the energy delivered per km of mains or ‘network utilisation’, shown in Figure 2.4. Using the average over the five years to 2018 (or latest year available), JGN’s network utilisation was 3.5 TJ/km, which is the fifth highest of the GDBs, and equal to the average over all of the GDBs. For comparison, the Victorian GDBs had higher levels of network utilisation: AusNet, 6.0 TJ/km; Multinet, 5.5 TJ/km; and AGN Vic, 5.2 TJ/km. AGN SA and ATCO have lower levels of network utilisation, 2.8 and 2.0 TJ/km respectively. With the exception of AGN Albury (6.0 TJ/km), the smaller Australian GDBs had relatively lower levels of network utilisation: Allgas (3.2 TJ/km), AGN Qld (2.4 TJ/km), AGN Wagga (2.2 TJ/km) and Evoenergy (1.6 TJ/km). The New Zealand GDBs, Vector and Powerco have network utilisation rates of 2.7 and 2.3 TJ/km respectively.

For most GDBs, network utilisation has declined over the sample period, reflecting the fact that declines in energy density per customer have typically outpaced increases in customer density per km. JGN’s network utilisation decreased from 4.7 TJ/km in 1999 to 3.6 TJ /km in 2018 (a cumulative decrease of 25 per cent). For comparison, the average network utilisation over all other GDBs in the sample decreased by 24 per cent (cumulatively), between the first and last years of the sample. This shows that declines in network utilisation were a general phenomenon across the Australian and New Zealand GDBs. Indeed, there were substantial decreases in network utilisation over the sample period for all but one of the GDBs included in the study.

Table 2.2 in the Annexure to this section shows the averages over the latest five years of data for each operating environment indicator presented in Figures 2.1 to 2.4, for each GDB. It also shows a number of additional partial performance indicators including:

- Opex per customer, per TJ and per mains km
- Capex per customer, per TJ and per mains km
- Assets per customer, per TJ and per mains km
- Asset cost per customer, and
- Total cost per customer.

Figure 2.4: Network Utilisation (Energy per kilometre), 1999–2018



Source: Economic Insights gas utility database

Table 2.3 in the Annexure shows the average growth rates of each of these partial performance indicators for each GDB over the whole sample period available for that GDB. Table 2.4 shows the average growth rates of each partial performance indicator for each GDB over the last five years of the data sample.

The performance of businesses in relation to the partial indicators presented in section 3 can be influenced by the customer mixes of GDBs. Table 2.4 shows information on the customer mixes of the GDBs, in terms of 'volumetric' and 'demand' customers, and for each customer type shows the TJ per customer and TJ per km of mains. This information may assist to interpret outcomes reported in section 3.

2.1 Summary Conclusions

JGN's operating environment characteristics can be summarised as follows:

- It is the largest GDB in the sample in terms of customer numbers, gas deliveries and network length. Although it is much larger than any of the other GDBs in terms of customer numbers and network length, it is more comparable in size to some of the Victorian GDBs in terms of gas deliveries.
- JGN's customer density (50 customers per km main) is the seventh largest in the sample and not much higher than the sample average (43 customers/km). Most of the GDBs with higher customer densities are relatively large, such as the three Victorian GDBs, AGN SA and ATCO. Most of the smallest GDBs in the sample had customer

densities less than JGN's. JGN's customer density increased quite strongly over the sample period, more so than other GDBs.

- JGN's energy density per customer (70 GJ/customer), is below the average for all GDBs (83 GJ/customer). There are no directly comparable GDBs because, amongst the relatively large GDBs, the three Victorian GDBs have significantly higher energy densities (the closest to JGN is Multinet), whereas AGN and ATCO have particularly low energy densities. Energy density per customer has generally declined over time for most GDBs. JGN is no exception, with energy density decreasing by more than 50 per cent (cumulatively) between 1999 and 2018.
- JGN has the fifth largest energy deliveries per km or 'network utilisation', and is close to the average for all GDBs. JGN's network utilisation decreased by 25 per cent (cumulatively) between 1999 and 2018. For most GDBs, network utilisation has declined over the sample period reflecting the fact that declines in energy density per customer have outpaced increases in customer density per km.

Annexure to Section 2: Detailed Tables

Table 2.1: Operating and performance indicators, Australian and New Zealand GDBs, average*

Company	Period	TJ	Cust.	Km	Cust/ km	TJ/ km	TJ/ cust	Opex/ TJ	Opex/ cust	Opex/ km
AGN Albury	2013-17	2,355	21,259	392	54	6.02	0.111	859	95	5,151
AGN Vic	2013-17	55,234	613,252	10,656	58	5.18	0.090	966	87	4,994
Multinet	2013-17	55,844	688,925	10,128	68	5.51	0.081	1,051	85	5,792
AusNet	2013-17	66,592	651,366	11,070	59	6.02	0.102	701	72	4,222
AGN SA	2013-17	22,678	429,906	8,040	53	2.82	0.053	2,265	119	6,383
AGN Qld	2012-16	6,055	92,100	2,548	36	2.38	0.066	3,686	242	8,757
Allgas Qld	2012-16	10,110	93,397	3,133	30	3.23	0.108	1,751	190	5,649
AGN Wagga	2011-15	1,609	19,554	723	27	2.23	0.082	1,443	119	3,214
JGN	2014-18	89,797	1,294,269	25,985	50	3.46	0.070	1,293	90	4,466
Evoenergy	2014-18	7,596	140,444	4,708	30	1.62	0.054	3,247	175	5,224
ATCO WA	2014-18	26,132	712,652	13,389	53	1.95	0.037	1,868	69	3,645
Pwrco NZ	2013-17	8,796	104,156	3,793	27	2.32	0.084	1,624	137	3,763
Vector NZ	2013-17	18,670	136,993	6,906	20	2.68	0.136	734	100	1,968
Average		28,574	384,482	7,805	43	3.49	0.083	1,653	121	4,864

Company	Period	Capex/ TJ	Capex/ cust	Capex/ km	Assets/ TJ	Assets/ cust	Assets/ km	Asset cost/ cust	Total cost/ cust
AGN Albury	2013-17	525	58	3,137	13,950	1,544	83,755	157	252
AGN Vic	2013-17	1,657	148	8,535	21,896	1,970	113,385	213	299
Multinet	2013-17	933	76	5,150	18,767	1,520	103,379	152	237
AusNet	2013-17	1,196	122	7,192	19,228	1,965	115,581	186	258
AGN SA	2013-17	3,683	194	10,378	55,445	2,917	156,016	334	453
AGN Qld	2012-16	4,751	314	11,320	61,296	4,025	145,532	399	641
Allgas Qld	2012-16	2,563	278	8,269	45,677	4,947	147,381	499	689
AGN Wagga	2011-15	2,609	215	5,817	41,221	3,391	91,773	389	507
JGN	2014-18	1,887	131	6,526	29,745	2,062	102,771	282	371
Evoenergy	2014-18	2,598	141	4,202	42,005	2,268	67,645	229	404
ATCO WA	2014-18	2,615	95	5,072	39,000	1,425	75,898	138	207
Pwrco NZ	2013-17	1,245	105	2,866	36,965	3,119	85,723	308	445
Vector NZ	2013-17	1,099	149	2,897	22,633	3,070	59,689	369	468
Average		2,105	156	6,259	34,448	2,633	103,733	281	403

Note: * Average for period indicated. TJ is terajoules, km is kilometres, cust is customers, opex/unit is opex per unit of a comprehensive output index, assets is the regulatory value of fixed assets. All costs in 2010 dollars.

Table 2.2: Operating and performance indicators, average annual growth rate since 1999 or earliest year

Company	Year/ Period	TJ	Cust.	Km	Cust/ km	TJ/ km	TJ/ cust	Opex/ TJ	Opex/ cust	Opex/ km
AGN Albury	1999-2017	-1.5	2.1	2.2	-0.1	-3.5	-3.4	3.0	-0.5	-0.6
AGN Vic	1999-2017	0.9	2.5	2.3	0.2	-1.4	-1.5	-1.0	-2.5	-2.3
Multinet	1999-2017	0.1	0.9	0.5	0.4	-0.4	-0.8	-0.7	-1.4	-1.1
AusNet	1999-2017	-0.4	2.4	2.1	0.4	-2.4	-2.8	-1.0	-3.8	-3.4
AGN SA	1999-2017	-0.2	1.8	1.5	0.3	-1.6	-1.9	0.2	-1.7	-1.5
AGN Qld	2001-2016	2.6	1.9	1.6	0.3	1.0	0.7	-0.9	-0.2	0.1
Allgas Qld	2001-2016	0.7	3.3	3.4	-0.1	-2.6	-2.5	2.8	0.2	0.2
AGN Wagga	1999-2015	0.8	2.0	2.4	-0.4	-1.5	-1.1	-0.6	-1.8	-2.1
JGN	1999-2018	-0.7	3.3	0.8	2.5	-1.5	-3.9	-1.8	-5.6	-3.2
Evoenergy	1999-2018	1.1	3.5	1.9	1.5	-0.8	-2.3	1.5	-0.8	0.7
ATCO WA	2000-2018	-0.5	3.3	1.4	1.8	-1.9	-3.6	0.6	-3.1	-1.3
Pwrco NZ	2004-2017	-0.9	0.0	0.8	-0.7	-1.7	-1.0	-1.3	-2.3	-3.0
Vector NZ	2005-2017	-4.3	-1.9	1.6	-3.4	-5.8	-2.5	-4.2	-6.6	-9.8
Average		-0.2	1.9	1.7	0.2	-1.9	-2.1	-0.3	-2.3	-2.1

Company	Year/ Period	Capex/ TJ	Capex/ cust	Capex/ km	Assets/ TJ	Assets/ cust	Assets/ km	Asset cost/ cust	Total cost/ cust
AGN Albury	1999-2017	3.8	0.2	0.1	1.7	-1.8	-1.9	-2.7	-1.9
AGN Vic	1999-2017	2.9	1.3	1.5	1.4	-0.1	0.0	1.2	0.0
Multinet	1999-2017	3.4	2.6	3.0	-0.1	-0.9	-0.5	-0.6	-0.9
AusNet	1999-2017	4.6	1.7	2.1	2.6	-0.3	0.1	-0.4	-1.5
AGN SA	1999-2017	4.5	2.5	2.8	2.5	0.5	0.8	0.6	-0.3
AGN Qld	2001-2016	1.3	2.0	2.3	0.9	1.6	1.9	6.1	3.0
Allgas Qld	2001-2016	4.5	1.5	1.6	3.2	0.6	0.5	1.1	0.9
AGN Wagga	1999-2015	2.1	0.9	0.5	2.6	1.4	1.0	0.6	0.0
JGN	1999-2018	3.3	-0.8	1.7	2.2	-1.8	0.7	-2.1	-3.3
Evoenergy	1999-2018	4.8	2.3	3.9	0.5	-1.8	-0.3	-3.5	-2.3
ATCO WA	2000-2018	5.6	1.8	3.6	2.5	-1.2	0.6	-3.0	-3.1
Pwrco NZ	2004-2017	9.5	8.4	9.7	-1.4	-2.4	-3.1	-2.0	-2.1
Vector NZ	2005-2017	8.4	6.4	3.5	3.2	0.6	-2.8	-1.3	-2.8
Average		4.5	2.4	2.8	1.7	-0.4	-0.2	-0.5	-1.1

Note: TJ is terajoules, km is kilometres, cust is customers, opex/unit is opex per unit of a comprehensive output index, assets is the regulatory value of fixed assets. All costs in 2010 dollars.

Table 2.3: Average annual indicator growth rate, latest 5 years

Company	Year/ Period	TJ	Cust.	Km	Cust/ km	TJ/ km	TJ/ cust	Opex/ TJ	Opex/ cust	Opex/ km
AGN Albury	2013-2017	-3.4	1.5	1.6	-0.1	-4.9	-4.9	7.6	2.3	2.3
AGN Vic	2013-2017	1.9	2.3	1.5	0.8	0.4	-0.4	-2.1	-2.5	-1.7
Multinet	2013-2017	-0.5	0.6	0.4	0.2	-0.9	-1.1	-5.3	-6.4	-6.2
AusNet	2013-2017	-1.7	2.3	1.6	0.7	-3.3	-4.0	1.0	-3.0	-2.3
AGN SA	2013-2017	-1.0	1.5	1.1	0.4	-2.1	-2.5	0.7	-1.8	-1.4
AGN Qld	2012-2016	1.1	2.5	1.7	0.8	-0.6	-1.4	3.4	1.9	2.7
Allgas Qld	2012-2016	0.2	3.4	1.7	1.7	-1.5	-3.1	3.4	0.3	1.9
AGN Wagga	2011-2015	0.7	1.5	2.0	-0.5	-1.3	-0.8	0.8	0.0	-0.5
JGN	2014-2018	-1.3	3.4	-0.5	3.9	-0.8	-4.5	0.4	-4.2	-0.4
Evoenergy	2014-2018	-2.9	2.4	2.0	0.4	-4.8	-5.2	6.1	0.6	1.0
ATCO WA	2014-2018	-1.0	2.3	1.4	0.9	-2.3	-3.2	1.6	-1.6	-0.7
Pwrco NZ	2013-2017	-0.9	0.6	-0.8	1.4	0.0	-1.4	0.9	-0.6	0.9
Vector NZ	2013-2017	-8.3	-7.2	-1.4	-5.9	-7.0	-1.2	-2.4	-3.6	-9.3
Average		-1.3	1.3	0.9	0.4	-2.2	-2.6	1.2	-1.4	-1.1

Company	Year/ Period	Capex/ TJ	Capex/ cust	Capex/ km	Assets/ TJ	Assets/ cust	Assets/ km	Asset cost/ cust	Total cost/ cust
AGN Albury	2013-2017	19.7	13.9	13.8	3.4	-1.7	-1.7	-6.2	-3.2
AGN Vic	2013-2017	-6.9	-7.2	-6.5	2.7	2.3	3.1	4.2	2.2
Multinet	2013-2017	0.1	-1.0	-0.8	0.5	-0.7	-0.4	0.3	-2.1
AusNet	2013-2017	1.3	-2.8	-2.1	4.6	0.4	1.1	-4.4	-4.0
AGN SA	2013-2017	6.6	4.0	4.4	5.9	3.3	3.6	1.4	0.3
AGN Qld	2012-2016	9.0	7.5	8.4	4.2	2.8	3.6	7.0	5.1
Allgas Qld	2012-2016	0.8	-2.3	-0.7	3.0	-0.2	1.5	7.2	5.2
AGN Wagga	2011-2015	3.8	2.9	2.5	2.3	1.5	1.0	5.0	3.7
JGN	2014-2018	6.5	1.7	5.7	3.9	-0.8	3.1	-5.2	-4.9
Evoenergy	2014-2018	2.7	-2.7	-2.3	5.7	0.1	0.6	-9.8	-5.1
ATCO WA	2014-2018	4.5	1.2	2.2	5.1	1.7	2.7	-8.2	-5.9
Pwrco NZ	2013-2017	5.3	3.8	5.2	1.4	-0.1	1.4	2.4	1.5
Vector NZ	2013-2017	7.2	6.0	-0.3	4.6	3.4	-2.7	-2.1	-2.5
Average		4.7	1.9	2.3	3.6	0.9	1.3	-0.6	-0.7

Note: TJ is terajoules, km is kilometres, cust is customers, opex/unit is opex per unit of a comprehensive output index, assets is the regulatory value of fixed assets. All costs in 2010 dollars.

Table 2.4: Market decomposition, Australian and New Zealand GDBs, average*

Company	Period	TJ Tariff V	TJ Tariff D	TJ Tariff V %	Cust. Tariff V	Cust. Tariff D
AGN Albury	2013-17	1,069	1,287	45.4	21,250	9
AGN Vic	2013-17	36,516	18,718	66.1	612,999	253
Multinet	2013-17	44,061	11,783	78.9	688,643	282
AusNet	2013-17	36,779	29,812	55.2	651,092	274
AGN SA	2013-17	10,506	12,173	46.3	429,779	127
AGN Qld	2012-16	2,082	3,973	34.4	92,027	73
Allgas Qld	2012-16	3,110	7,000	30.8	93,293	104
AGN Wagga	2011-15	928	681	57.7	19,539	15
JGN	2014-18	37,459	52,338	41.7	1,293,864	405
Evoenergy	2014-18	6,406	1,190	84.3	140,404	40
ATCO WA	2014-18	15,225	10,907	58.3	712,577	74
Pwrco NZ	2013-17	4,557	4,238	51.8	103,925	231
Vector NZ	2013-17	9,858	8,813	52.8	136,912	80
Average		16,043	12,532	54.1	384,331	151

Company	Period	TJ/km Tariff V	TJ/km Tariff D	TJ/cust Tariff V	TJ/cust Tariff D
AGN Albury	2013-17	2.73	3.28	0.050	139.840
AGN Vic	2013-17	3.43	1.76	0.060	73.926
Multinet	2013-17	4.35	1.16	0.064	41.857
AusNet	2013-17	3.32	2.69	0.056	108.804
AGN SA	2013-17	1.31	1.51	0.024	95.698
AGN Qld	2012-16	0.82	1.56	0.023	54.428
Allgas Qld	2012-16	0.99	2.23	0.033	67.308
AGN Wagga	2011-15	1.28	0.94	0.048	45.376
JGN	2014-18	1.44	2.01	0.029	129.102
Evoenergy	2014-18	1.36	0.25	0.046	29.910
ATCO WA	2014-18	1.14	0.81	0.021	146.593
Pwrco NZ	2013-17	1.20	1.12	0.044	18.331
Vector NZ	2013-17	1.43	1.28	0.072	109.883
Average		1.9	1.6	0.044	81.620

Note: 'Tariff V' refers to volumetric customers (i.e. residential and small/medium commercial and industrial users); 'Tariff D refers to demand customers (i.e. large industrial users).

3 PARTIAL PERFORMANCE INDICATORS

The AER has said the following in relation to electricity distribution, which applies equally to gas distribution:

> *We consider that the most significant output of distributors is customer numbers. The number of customers on a distributor's network will drive the demand on that network. Also, the comparison of inputs per customer is an intuitive measure that reflects the relative efficiency of distributors (AER 2014, p.23).*

This section presents information on the inputs per customer of GDBs compared to their network customer densities. Information on GDBs' inputs per mains km is also compared to their customer densities. By expressing inputs in per customer or per km values and plotting them against customer density, we seek to control for differences in the size and customer densities of GDBs.

The inputs we present information on include real opex, real asset costs, and total costs (the sum of real opex and real asset costs). All of the input, output and customer density measures presented in this section are averages over the five-year period ending 2018 (or the latest year available). The partial performance indicators we present are:

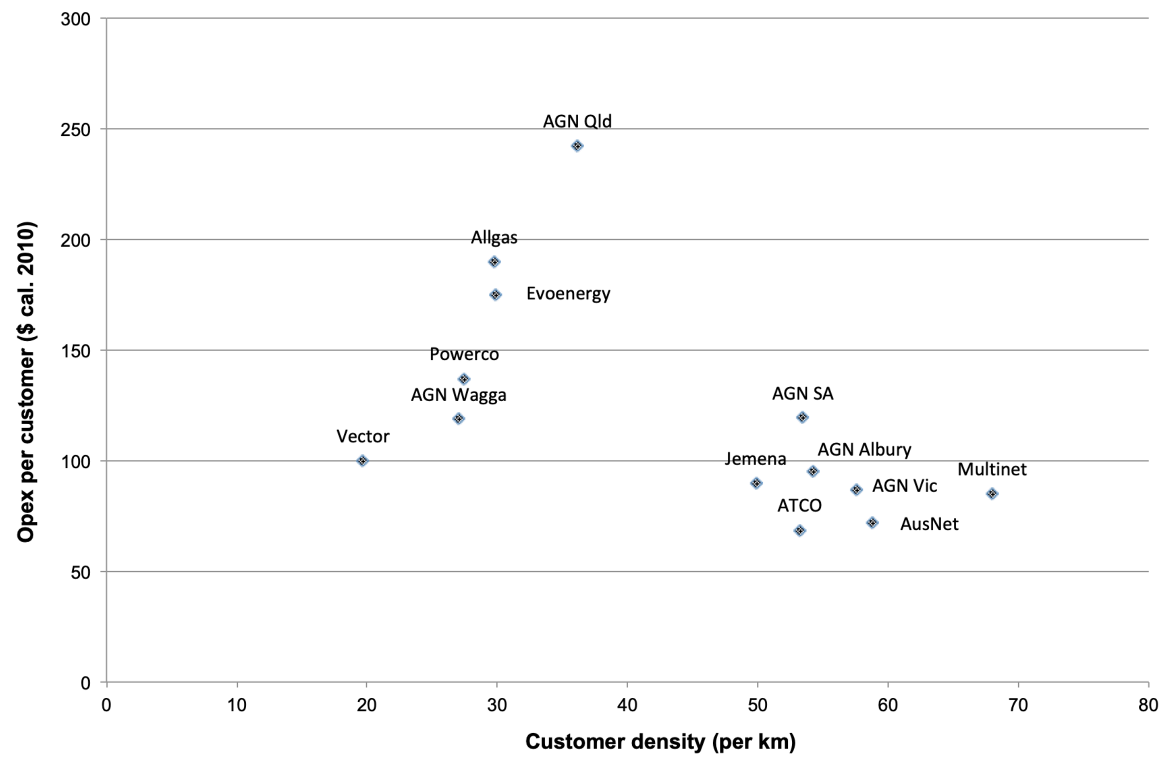
- Opex per customer relative to customer density (Figure 3.1)
- Opex per mains km relative to customer density (Figure 3.2)
- Asset cost per customer relative to customer density (Figure 3.3)
- Asset cost per mains km relative to customer density (Figure 3.4)
- Total cost per customer relative to customer density (Figure 3.5), and
- Total cost per mains km relative to customer density (Figure 3.6).

3.1 Opex per customer

Figure 3.1 plots real opex per customer (in $2010) against customer density. GDBs with lower customer density, such as Vector, Powerco, AGN Wagga, Allgas, Evoenergy and AGN Qld, usually have higher opex per customer, although with considerable variation. For example, opex per customer for AGN Qld, Allgas and Evoenergy averaged $242, $190 and $175 respectively for the latest five-year period (see Table 2.1). Opex per customer for Vector, AGN Wagga and Powerco was not as high, but overall, for the six GDBs with lowest customer density, the average opex per customer was $160 for the latest five-year period.

GDBs with higher customer density—such as JGN, AGN SA, ATCO, AGN Vic, AusNet, Multinet and AGN Albury—tend to have lower opex per customer. For example, the average opex per customer of AGN Vic, Multinet and AusNet over the period 2014 to 2018 was $87, $85 and $72, respectively. The average for Victorian GDBs as a group is $81. Average opex per customer of JGN, AGN SA, AGN Albury and ATCO over the latest five-year period was $90, $119, $95 and $69 respectively. For comparison, although JGN has slightly higher opex per customer than the Victorian GDBs, it has lower customer density, and when customer density is controlled for, its opex per customer is comparable.

Figure 3.1: Opex per customer relative to customer density (avg. 2015–2018*)

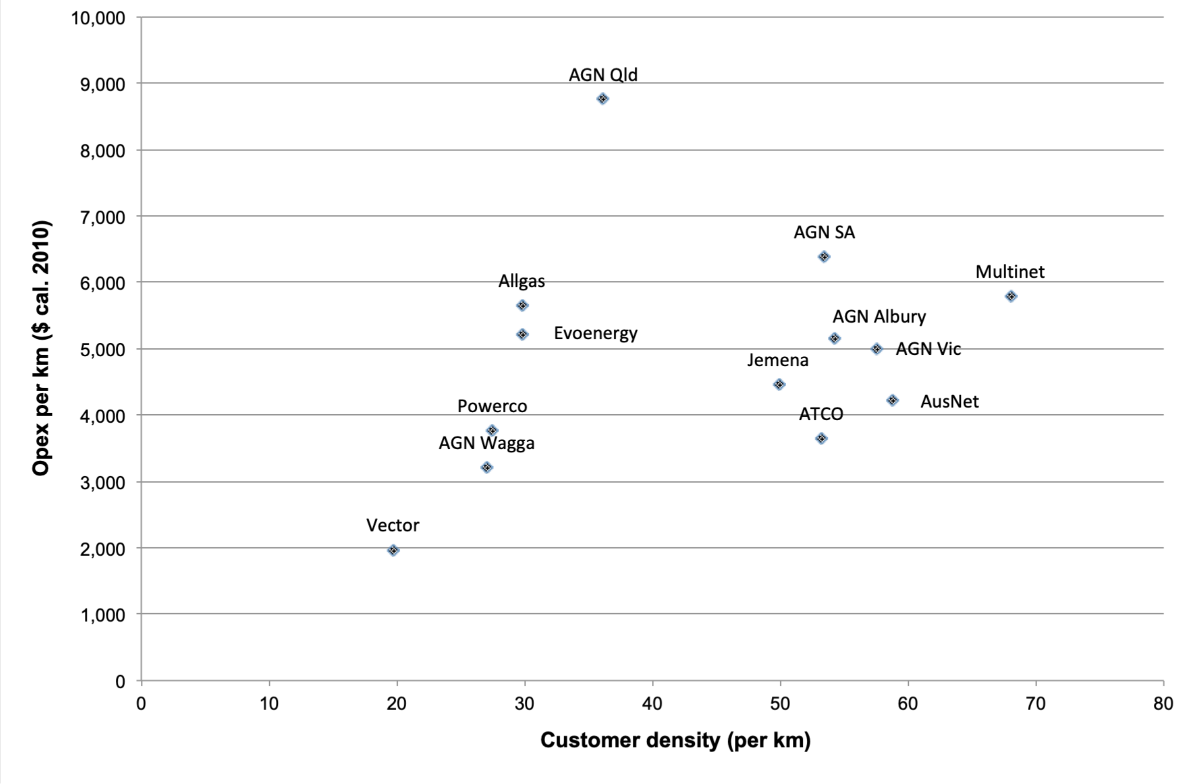


Source: Economic Insights gas utility database. *Or latest 5 year period.

Figure 3.2 plots real opex per mains km against customer density. Among the six GDBs with relatively low customer density, the average opex per km was $4,763 over the five years to 2018 (or latest year available). For the seven GDBs with higher customer density, the average opex per km was $4,950. The similarity of these averages shows that there is little or no systematic relationship between opex per km and customer density, although there is a very wide dispersion of opex per km among the GDBs with relatively low customer density, and much less dispersion among the GDBs with relatively high customer density. JGN's opex per km was $4,466 over the five years to 2018, which is relatively close to the average for the sample.

These observations suggest that JGN is reasonably efficient in terms of opex per customer and has average levels of opex per km of network. A comparison of this kind does not control for other drivers of opex costs that may be relevant, and only qualified conclusions can be drawn from it.

Figure 3.2: Opex per mains km relative to customer density (avg. 2015–2018*)



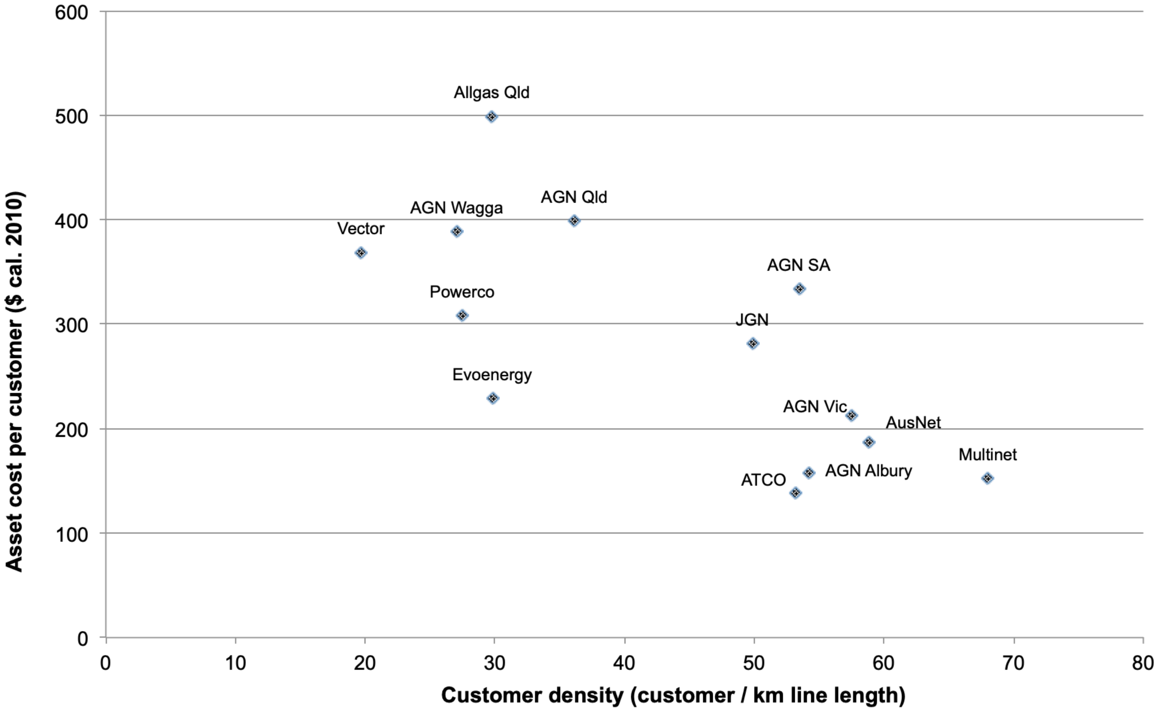
Source: Economic Insights gas utility database. * Or latest 5 year period.

3.2 Capital assets cost per customer

The efficiency of the use of capital inputs is indicated by asset cost per customer, which is based on actual returns to capital rather than a measure based on the opportunity cost of capital and depreciation cost, as used by the AER, because insufficient information is available from public sources to derive a measure based on the latter approach (AER 2013).

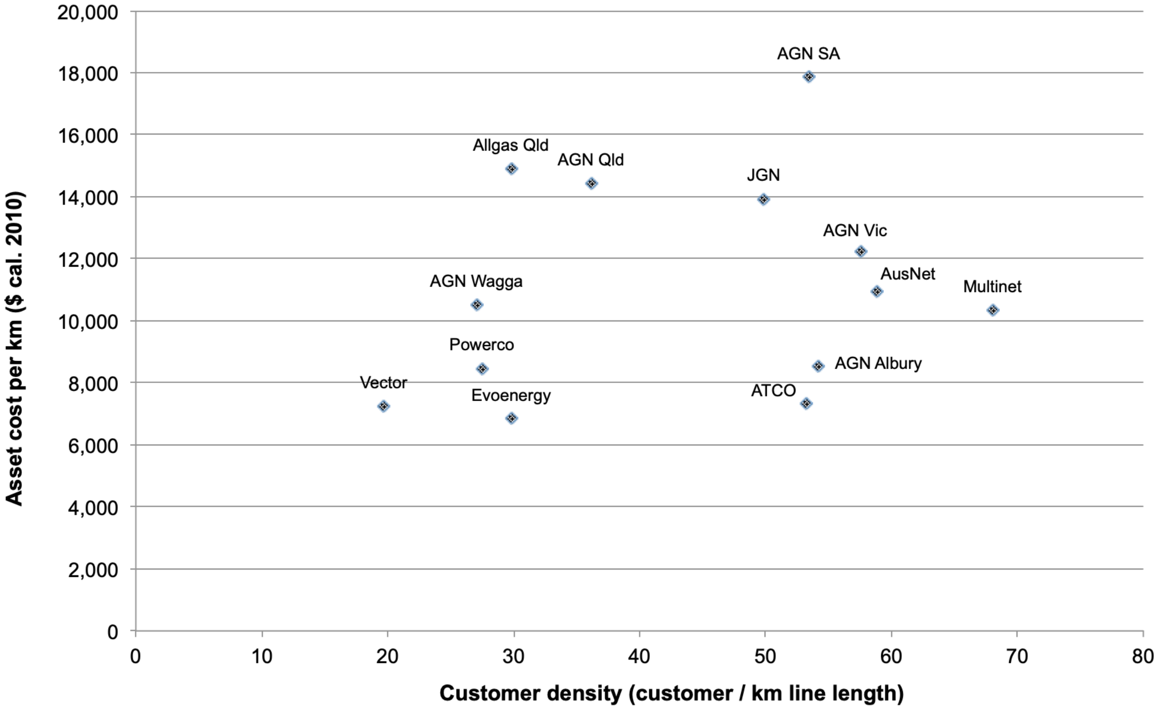
Figure 3.3 plots the average asset cost per customer (in $2010) against average customer density in the period 2014 to 2018 (or latest five-year period available), where asset cost is measured by the actual return to capital including depreciation. The chart shows that GDBs with lower customer density tend to have higher asset cost per customer than the GDBs with higher customer density. JGN's asset cost per customer was $282 in this period. This can be compared to the asset costs per customer of the three Victorian GDBs, which were $152 for Multinet, $186 for AusNet and $213 for AGN Vic; and to AGN Albury, which was $157. The average asset costs per customer of AGN SA and ATCO were $334 and $138 respectively. The average asset cost per customer for the six GDBs with comparatively low customer density was $366 over the latest five-year period.

Figure 3.3: Asset cost per customer relative to customer density (avg. 2015–2018*)



Source: Economic Insights gas utility database. Asset cost is defined as real revenue minus real opex. *Or latest 5 year period.

Figure 3.4: Asset cost per mains km relative to customer density (avg. 2015–2018*)



Source: Economic Insights gas utility database. Asset cost is defined as real revenue minus real opex. *Or latest 5 year period.

Figure 3.4 shows average asset cost per km of mains for the period 2014 to 2018 for each GDB, plotted against customer density. There is no apparent relationship between assets cost per km and customer density. JGN's average asset cost per km was $13,933 over the latest five years, which most closely compares to AGN Vic ($12,246), AGN Qld ($14,436) and Allgas ($14,898). AGN SA has a considerably higher asset cost per km ($17,852), whilst AusNet ($10,962), Multinet ($10,350) and AGN Wagga ($11,520) are somewhat lower than JGN, and close to the sample average ($11,046). GDBs with comparatively low asset cost per km of mains include Vector ($7,253), Powerco ($8,464), Evoenergy ($6,838), ATCO ($7,318) and AGN Albury ($8,535).

These comparisons are influenced among other things by asset age, original network asset valuations, and various factors not controlled-for which influence the quantity of assets per customer, and hence asset cost per customer. Thus, only qualified conclusions can be drawn from these two charts. It suggests that JGN is close to average in terms of asset cost per customer and has relatively high asset cost per km of mains.

3.3 Overall cost efficiency

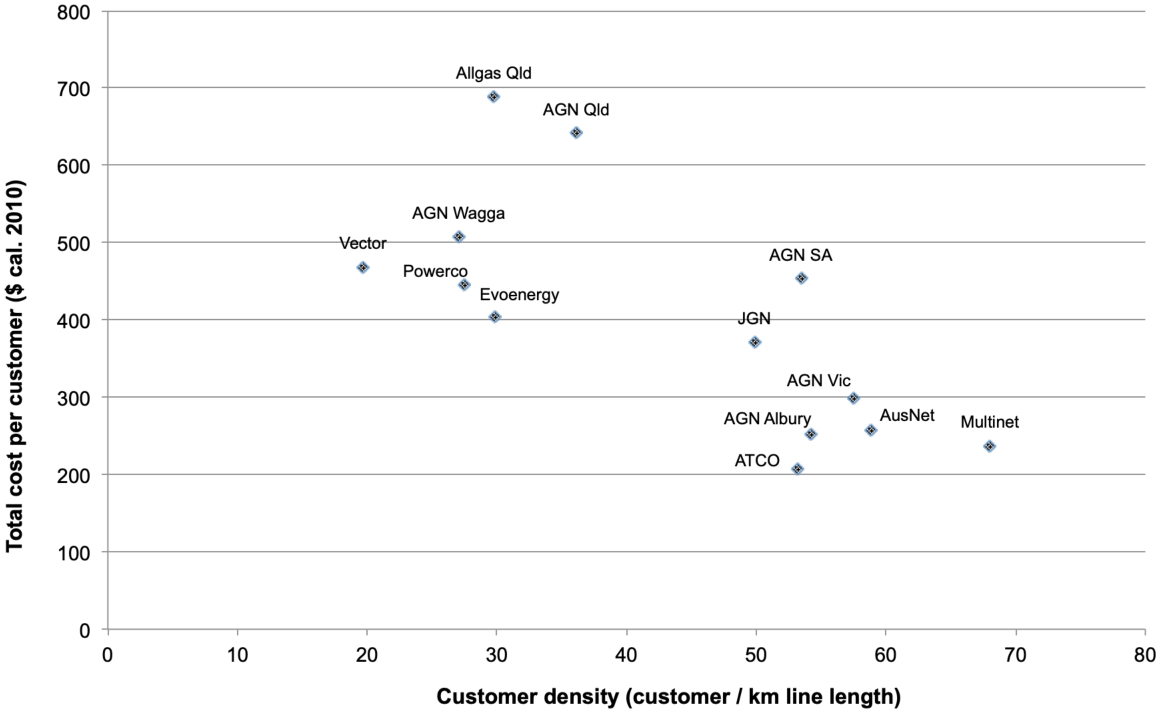
Figure 3.5 plots total cost per customer against customer density, where total cost is the sum of opex and asset cost shown in Figures 3.1 and 3.3 respectively. This chart shows the very clear relationship between cost per customer and customer density. The average cost per customer of JGN in the period 2014 to 2018 (in $2010), was $371.

GDBs of similar customer density, such as AGN SA and ATCO, have average costs per customer of $453 and $207 respectively. GDBs with higher customer density, including AGN Vic, AusNet and Multinet have average costs per customer of $299, $258 and $237 respectively. Total cost per customer is usually larger for the GDBs with lower customer density. These include Vector ($468), Powerco ($445), Evoenergy ($404), AGN Wagga ($507), AGN Queensland ($641) and Allgas ($689). Total cost per customer for this group of GDBs averaged $526 over the latest five-year period.

Figure 3.6 shows total cost per km of mains plotted against customer density. There is considerable variation among the GDBs in cost per km of mains, and no clear relationship with customer density. The sample average for total cost per km is $15,910. JGN's total cost per km is $18,398, which is about 16 per cent higher than the sample average. GDB's with particularly low total cost per km include: Vector ($9,221), Powerco ($12,227), Evoenergy ($12,062), AGN Wagga ($13,734), ATCO ($10,962) and AGN Albury ($13,686). Some GDBs with relatively high total cost per km, include AGN Qld ($23,193), Allgas ($20,547) and AGN SA ($24,236).

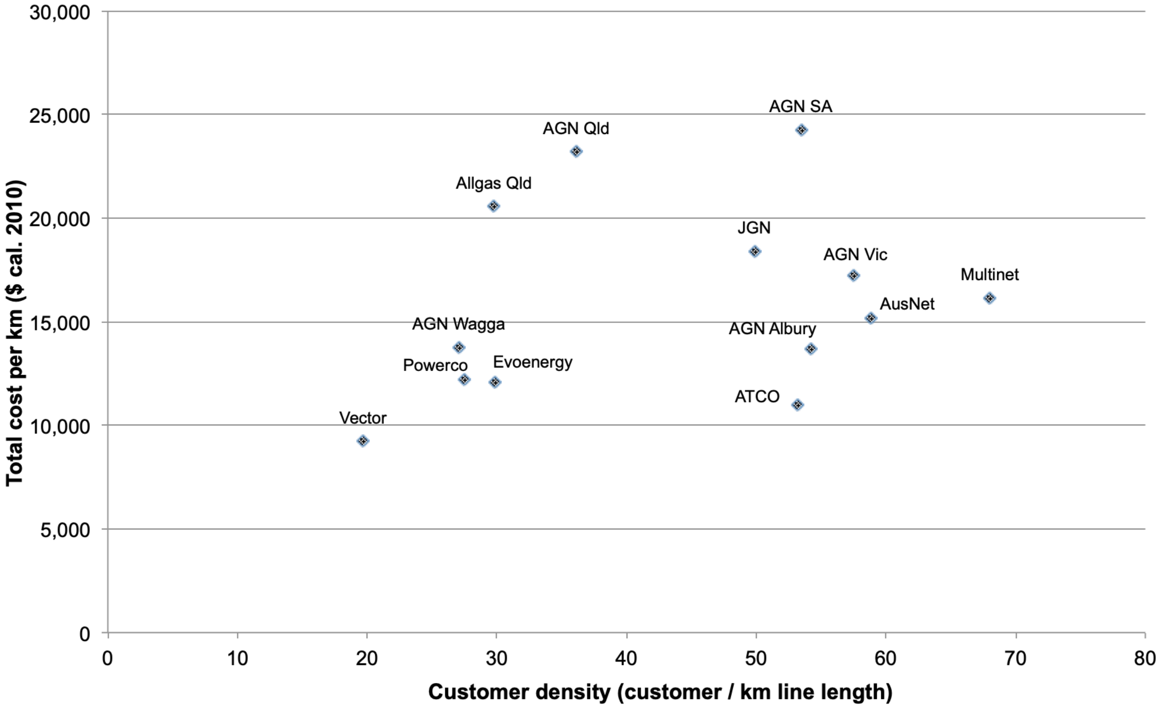
The wide variation shown in total cost per km may suggest that unobserved differences in local conditions are important determinants of these costs. Once again, caution is needed in drawing strong conclusions for these comparisons alone. That said, the results tend to indicate that JGN's total cost per customer is close to the sample average when differences in customer density are controlled for, whereas its total cost per km is slightly higher than the sample average.

Figure 3.5: Total cost per customer relative to customer density (avg. 2015–2018*)



Source: Economic Insights gas utility database. *Or latest 5 year period.

Figure 3.6: Total cost per mains km relative to customer density (avg. 2015–2018*)



Source: Economic Insights gas utility database. *Or latest 5 year period.

3.4 Summary Conclusions

Partial indicators of cost efficiency are examined for two broad groups of costs, namely opex and asset costs, as well as total costs. These comparisons do not control for other drivers of opex costs that may be relevant. If a GDB is ranked poorly for most indicators then this may warrant further investigation as to whether that GDB was operating inefficiently. Conversely, if a GDB is ranked highly for most indicators then this may be taken to suggest that it is performing at levels consistent with industry best practice. If a GDB performs well on some indicators but poorly on others then the GDB's performance is harder to assess as it may be making trade–offs between different types of inputs (eg, opex and capital) and more detailed analysis may be required.

The main observations relating to JGN are:

- In regard to the opex-related measures, when differences in customer density are controlled-for, JGN is reasonably efficient in terms of opex per customer, and it has average levels of opex per km of network.
- In terms of asset cost measures, JGN is close to average in terms of asset cost per customer and has relatively higher asset cost per km of mains. These comparisons are influenced among other things by asset age, original network asset valuations, and various factors not controlled-for which influence the quantity of assets per customer, and hence asset cost per customer.
- In terms of total cost measures, JGN's total cost per customer is close to the sample average when differences in customer density are controlled for, whereas its total cost per km is slightly higher than the sample average. Once again, qualification is necessary because the wide variation in GDBs' total cost per km may suggest that unobserved differences in local conditions are important determinants of these costs.
- Based on these indicators and recognising the nature of their networks, JGN appears to be close to the average for all GDBs for most of the efficiency measures shown.

The partial indicators analysis presented in this section of the report does not enable influences such as scale economies or different mixes of inputs to be controlled for in a rigorous fashion. This means that care needs to be taken when drawing inferences, and only qualified conclusions can be drawn. It is also desirable to have regard to more holistic measures of efficiency, such as total factor productivity (TFP) analysis, and other methods of measuring efficiency such as econometric cost functions which can control for differences in scale and other operating environment differences.

PART B: PRODUCTIVITY INDEXES

This part of the study concentrates on the total and partial factor productivity performance of JGN's NSW gas distribution business for the period from 1999 to 2018. Measures of TFP and PFP are formed in this part of the report using time series and multilateral indexes. These are used to compare JGN's productivity growth rates and productivity levels, respectively, with those of other GDBs in Victoria, South Australia, Western Australia and Queensland.

The primary data source for this part of the study is information supplied by JGN in response to a detailed data survey, covering key output and input value, price and quantity information for financial years 1999 to 2018. Similar data was provided for this study by other GDBs; specifically, Australian Gas Infrastructure Group (AGIG) in relation to the Australian Gas Networks Limited (AGN) South Australian, Victorian and Queensland gas networks, as well as Multinet Gas in Victoria; ATCO Gas Australia in Western Australia; and AusNet in Victoria. The surveys completed by AGN SA, AGN Vic, AusNet and Multinet cover the years 1999 to 2017, while the survey completed by ATCO covers the period 2000 to 2018. A previously completed survey by AGN for its Queensland gas network ('AGN Qld') covers the period 1999 to 2014. Background to the measurement of total factor productivity (TFP) and partial factor productivity (PFP), as well as measurement issues, details of the variables used in productivity measurement, and descriptive information about the GDBs included in this part of the study, are presented in chapter 4.

The TFP (time series) index analysis in chapter 5 involves forming indexes of outputs and inputs using the Fisher index method. These indexes provide the best measures of the relative changes over time of aggregate inputs, aggregated outputs and TFP for each GDB. However, they cannot be used to compare productivity *levels* between GDBs. The analysis includes three outputs (throughput, customer numbers and system capacity) and eight inputs (opex, lengths of transmission pipelines, high pressure pipelines, medium pressure pipelines, low pressure pipelines, and services, meters and other capital). This specification is broadly consistent with the analogous preferred electricity distribution output and input specification presented in AER (2013a). The time series TFP indexes use the first year of data (typically 1999) as the base–year for each individual GDB, and the analysis provides estimates of TFP growth over the period 1999 to 2018 (or latest year) as well as PFP growth for the GDBs. PFP is a partial measure of productivity in which the output index is divided by the quantity of one of the inputs. These measures are useful for understanding trends in TFP.

Multilateral TFP (or MTFP) analysis is presented in chapter 6. Multilateral TFP is a method of measuring the TFP levels of all the GDBs in the sample using a common base and a more complex indexing method. This indexing method allows the TFP levels of different GDBs to be compared against each other. It yields less precise measures of TFP change over time than the Fisher index method used in chapter 5, so the MTFP indexes are only used for comparing TFP levels of GDBs in this report. In this part of the analysis (in chapter 6), transmission pipelines are excluded to allow more like–with–like comparisons across GDBs.

There have been several studies undertaken previously of gas pipeline efficiency performance in Australasia. The earlier studies tended to benchmark selected Australian gas utilities against a sample of overseas gas utilities. These included Bureau of Industry Economics (BIE 1994), Independent Pricing and Regulatory Tribunal (IPART 1999), and Pacific Economics Group (PEG 2001a, 2001b, 2001c). The BIE and IPART studies used data envelopment analysis (DEA) although IPART also tested other methodologies. The IPART study concluded that the Australian GDBs were behind international best practice. The PEG studies were an econometric analysis of opex costs. They concluded that the Victorian GDBs had lower opex than predicted given their scale and operating environment conditions, implying that their opex efficiency was better than the average of the included US comparators.

The productivity index methodologies used in this study were developed in studies by Lawrence in 2004 for the New Zealand Commerce Commission (Denis Lawrence 2004a, 2004b), and in 2007 on behalf of the three Victorian GDBs (Denis Lawrence 2007). The 2004 studies involved a trend analysis of New Zealand gas businesses' TFP, and also used the multilateral TFP index method to examine productivity levels. The 2007 study developed a measure of system capacity to supplement the standard output measures of throughput and customer numbers, and included seven capital input components and presented a range of sensitivity analyses of alternative output and input specifications to assess the influence of specification changes on the results. Subsequently, PEG (2008) carried out a study of TFP trends for Victoria's GDBs on behalf of the Essential Service Commission which has also informed the methods used here.

Economic Insights has since carried out a number of productivity studies on behalf of gas distribution businesses, including for Jemena Gas Networks (JGN) (Economic Insights 2009a, 2015a), for Envestra South Australia and Queensland (Economic Insights 2010), and AGN South Australia (Economic Insights 2015c), and several studies for the three Victorian GDBs (Economic Insights 2012b, 2016b).

4 PRODUCTIVITY BENCHMARKING

This chapter briefly outlines the basics of TFP and why it is of interest to regulators. It then discusses a number of key measurement issues affecting outputs, inputs and describes the data used in the study and the definitions of outputs and inputs. Finally, it provides descriptive information relating to the comparator gas distribution businesses included in the analysis.

4.1 Productivity Measurement and Benchmarking

Productivity is a measure of the physical output produced from the use of a given quantity of inputs. All enterprises use a range of inputs including labour, capital, land, fuel, materials and services. If the enterprise is not using its inputs as efficiently as possible then there is scope to lower costs through productivity improvements. This may come about through the use of better quality inputs including a better trained workforce, adoption of technological advances, removal of restrictive work practices and other forms of waste, and better management through a more efficient organisational and institutional structure. When there is scope to improve productivity, this implies there is technical inefficiency but this is not the only source of economic inefficiency. For example, when a different mix of inputs can produce the same output more cheaply, given the prevailing set of inputs prices, there is allocative inefficiency.

Productivity is measured by expressing output as a ratio of inputs used. There are two types of productivity measures: total factor productivity (TFP) and partial factor productivity (PFP). TFP measures total output relative to an index of all inputs used. Output can be increased by using more inputs, making better use of the current level of inputs and by exploiting economies of scale. The TFP index measures the impact of all the factors affecting growth in output other than changes in input levels. PFP measures one or more outputs relative to one particular input (e.g. labour productivity is the ratio of output to labour input).

Total factor productivity is measured by the ratio of an index of all outputs (Q) to an index of all inputs (I):

$$TFP = Q/I \tag{4.1}$$

The rate of change in TFP between two periods is measured by:

$$T\dot{F}P = \dot{Q} - \dot{I} \tag{4.2}$$

where a dot above a variable represents the rate of change of the variable.[3] In this study the partial productivity of factor *i* is defined as:

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[3] This measure of the change in TFP in terms of the difference between the growth rates of outputs and inputs is known as the Hicks–Moorsteen approach. Alternative methods are based on changes in profitability with adjustment for changes in input and output prices, or on changes in measures of technical efficiency (refer: (Coelli et al. 2005, 64–65).

$$PFP_i = Q/I_i \qquad (4.3)$$

where I_i is the quantity used of factor i. The PFP can be measured with respect to *any* single factor type. It is not a holistic measure, like TFP, but PFP measures can be useful for gaining a better understating of the trends observed in TFP.

TFP indexes have a number of advantages including:

- indexing procedures are simple and robust;
- they can be implemented when there are only a small number of observations;
- the results are readily reproducible;
- they have a rigorous grounding in economic theory;
- the procedure imposes good disciplines regarding data consistency; and
- they maximise transparency in the early stages of analysis by making data errors and inconsistencies easier to spot than using some of the alternative econometric techniques.

As noted in Lawrence (1992), by providing a means of comparing efficiency levels, TFP measurement is an ideal tool for promoting so–called 'yardstick competition' in non–competitive industries. It provides managers with useful information on how their business is performing overall and how it is performing relative to its peers. TFP measurement provides a ready means of 'benchmarking' the business's overall performance relative to other businesses supplying similar outputs.

Forecast future productivity growth rates can play a key role in setting the annual revenue requirement used in building blocks regulation. Productivity studies provide a means of benchmarking GDB performance to assist the regulator in determining whether the GDB in question is operating at efficient cost levels. They also assist the regulator in determining possible future rates of productivity growth to build into annual revenue requirement forecasts.

4.2 Measurement Issues

To measure productivity performance, data on the price and quantity of each output and input is required as well as data on key operating environment conditions. The study requires quantity data because productivity is essentially a weighted average of the change in output quantities divided by a weighted average of the change in input quantities. Although the weights are complex and vary depending on the technique used, for outputs they are derived from the share of each output in total revenue or, alternatively, from output cost shares and for inputs from the share of each input in total costs. To derive the revenue and cost shares the value of each output and input is required, i.e. the input (or output) price times its quantity. Hence, both the price and quantity of each output and input or, alternatively, their values and quantities, or their values and prices is required. To derive output cost shares additional information on how cost drivers link to output components should be obtained. This is usually derived from estimation of econometric cost functions.

In a sense the quantity data are the primary drivers of productivity results while the value or price data are secondary drivers in that they are used to determine the weights for aggregation. Quantity information can be obtained either directly or indirectly. Direct quantity data are physical measures of a particular output or input, e.g. terajoules (TJ) of throughput or full–time equivalent employees. Indirect quantity data are obtained by deflating the revenue or cost of a particular output or input by an average price or a price index. There are arguments in favour of both methods. The indirect method allows greater differences in the quality of outputs or inputs to be captured (e.g. a greater extent of automation reflected in a higher capital value), and it allows for a greater range of items to be captured within the one measure. However, the indirect method places more onus on having both the value and the price data completely accurate. Since price data are generally harder to match to the specific circumstances of a particular firm, there is more scope for error with the indirect method. Hence, it is a good policy to rely on direct quantity data wherever possible and to only use indirect quantity data in those cases where the category is too diverse to be accurately represented by a single quantity (e.g. materials and services inputs).

Measuring the performance of gas pipelines presents a number of challenges being common with other network infrastructure industries. In the following section, a number of difficult measurement issues including how to define GDB outputs and inputs and the likely impact of operating environment conditions are examined.

4.2.1 Measuring GDB outputs

Early energy supply productivity studies simply measured output by system throughput. However, this simple measure ignores important aspects of what pipelines really do. To capture the multiple dimensions of electricity network output, Lawrence (2003) used three outputs: throughput, system line capacity and connection numbers. A similar output specification is appropriate for gas distribution given their functional similarity to electricity networks. Lawrence (2007) developed a capacity output measure for the three Victorian GDBs using detailed data on lengths, diameters and pressures of different mains types for each GDB.

To aggregate the outputs into a total output index using indexing procedures, the method has to allocate a weight to each output. It is long established that the use of revenue share weights in the output index will only be consistent with measuring production efficiency growth if prices are proportionate to marginal costs, a condition of cost minimization (Denny, Fuss, and Waverman 1981; Fuss and Waverman 2002). Economic Insights (2009b) has shown that when the increasing returns to scale nature of energy networks and the role of sunk cost assets are taken into account, allocative efficiency requires that all functional outputs (of which billable outputs will be a subset) be included and the deviation of market prices from marginal costs be allowed for. One way of doing this, using econometrics, is to use the relative shares of cost elasticities derived from an econometric cost function. This approach as used in this study is often used in industries not subject to high levels of competition because the cost elasticity shares reflect the marginal cost of providing an output.

4.2.2 Measuring GDB inputs

Previous studies of pipeline productivity have typically used two or three input categories. For instance, BIE (1994) used labour numbers, kilometres of distribution main and kilometres of transmission main. No allowance was made for materials and services inputs due to lack of data at that time. IPART (1999) used operating expenditure and kilometres of main as its two inputs. Differences in the levels of contracting out between utilities made obtaining labour data problematic either due to its unavailability or lack of comparability. PEG (2001) used a three input specification with labour, other operating expenditure and capital inputs. As labour data is not available for most Australian GDBs and the extent of contracting out makes such a measure problematic, in this study labour inputs are subsumed within operating expenditure.

There are a number of different approaches to measuring both the quantity and cost of capital inputs. The quantity of capital inputs can be measured in physical quantity terms (e.g. using pipeline length measures) or derived from monetary measures, e.g. by using a constant dollar measure of the value of assets. The annual cost of using capital inputs can be measured directly by applying the sum of an estimated depreciation rate and a rate reflecting the opportunity cost of capital to the regulatory asset base (RAB) or indirectly as the residual of revenue less operating costs.

Measuring the quantity of capital by the deflated asset value method has the advantage of include all capital items, not just pipelines, and may better reflect the quality of capital. There are two potential problems with this approach. Firstly, it is better suited to more mature systems where the asset valuations are very consistent over time and across organisations. In Victoria and NSW there has been only one full asset valuation done in each state. In the case of Victoria, these asset values were further 'adjusted' before privatisation for political considerations and so, while the adjusted values form the basis of the current regulatory asset base, they are inappropriate for comparing capital input quantities. Second, it usually incorporates some variant of the straight–line approach to measuring depreciation. Gas pipeline assets tend to be long lived and produce a relatively constant flow of services over their lifetime. Consequently, their true depreciation profile is more likely to reflect the 'one hoss shay' or 'light bulb' assumption than that of a straight–line approach. That is, they produce the same service each year of their life and until the end of their specified life rather than producing a less service every year. In these circumstances it may be better to proxy the quantity of capital input by the physical quantity of the principal assets. This approach is also invariant to different depreciation profiles that may have been used by different pipeline businesses.

For measuring the annual capital costs, the direct approach involves explicitly calculating the return of and return on capital to reflect depreciation and the opportunity cost of capital. The indirect approach is to allocate a residual or *ex post* cost to capital, being the difference between revenue and operating costs. This second method has been favoured by some regulatory agencies such as the US Federal Communications Commission (1997) and is the approach used in PEG (2006). Given that the implicit rates of return in the Economic Insights GDB database are relatively stable and broadly similar in magnitude, and the focus of this study is on productivity performance, this study uses the indirect approach here for simplicity. It is noted that this differs from the amortisation approach when the effect of sunk costs and financial capital maintenance are fully allowed for as in Economic Insights (2009b) but it will provide a close approximation in this case.

4.2.3 Normalisation for operating environment conditions

Operating environment conditions can have a significant impact on distribution costs and productivity and in many cases are beyond the control of managers. Consequently, to ensure reasonably like–with–like comparisons it is desirable to 'normalise' for at least the most important operating environment differences. Likely candidates for normalisation include energy density (energy delivered per customer), customer density (customers per kilometre of main), customer mix, the proportion of cast iron pipes and climatic and geographic conditions.

Energy density and customer density are generally found to be the two most important operating environment variables in energy distribution normalisation studies (see Lawrence 2003a). Being able to deliver more energy to each customer for the same investment in pipelines also means that the GDB would require less inputs to deliver a given volume of gas. A GDB with lower customer density will require more pipeline length to reach its customers than will a GDB with higher customer density, making the lower density distributor appear less efficient unless the differing densities are allowed for.

Most energy distribution studies incorporate density variables by ensuring that the three main output components – throughput, system capacity and customers – are all explicitly included. This means that distribution businesses that have low customer density, for instance, receive credit for their longer line lengths whereas this would not be the case if output was measured by only one output such as throughput.

4.3 Data used

The primary data source for the analysis in this Part B of the study is information supplied by ATCO, AGN, AusNet, Multinet and JGN in relation to each of their Western Australian, South Australian, Victorian and NSW gas distribution networks in response to common detailed data surveys, covering key output and input value, price and quantity information for the period 1999 to 2017, or 2018 in some cases. Similar data was provided in previous years by AGN in relation to its Queensland gas network for the period 1999 to 2014. No forecast data are used for any of the included GDBs.

4.3.1 Output quantities and weights

The outputs produced by GDBs are defined in this study as:

1) **Throughput**: The quantity of the GDB's throughput is measured by the number of terajoules of gas supplied. It is the sum of energy supplied to all customer segments: residential, commercial and large industrial customers.

2) **Customers**: Connection dependent and customer service activities are proxied by the GDB's number of customers.

3) **System capacity**: Gas distribution networks have three primary functions: delivery of gas from supply point to demand point; the interim storage of gas to make available sufficient gas during peak periods; and, the performance of these functions safely and efficiently. Included is a measure of system capacity to capture the GDB's functional responsibility of making capacity available to meet the needs of customers. This measure

we require is somewhat analogous to the MVA–kilometre system capacity measure used in electricity DB TFP studies (see, for example, Lawrence 2003a) but, in this case, it needs to also capture the interim storage function of pipelines.

The system capacity measure used in this study is that developed in Lawrence (2007) which is the volume of gas held within a gas network converted to standard cubic meters using a pressure correction factor based on the average operating pressure. The volume of the distribution network is calculated based on pipeline length data for high, medium and low distribution pipelines and estimates of the average diameter of each of these pipeline types, which differ between networks. The quantity of gas contained in the system is a function of operating pressure. Thus, a conversion to an equivalent measure using a pressure correction factor is necessary to allow for networks' different operating pressures. These conversion factors also differ between networks.

From historical observations GDB engineers have forecast the approximate load on the system per month during periods of peak flow and as a result have approximated the mean pressure in the network for the twelve month period. Average network pressure is a better representation of service to the majority of customers than is fringe pressure—the minimum pressure at the fringe of the network—because it needs to be sufficient to ensure periods of peak demand can be accommodated while still meeting the minimum pressure requirement.

The system capacity measure is the addition of the individual high, medium and low pressure network capacities. As noted above, pipelines owned by GDBs operating at very high pressures (above 1050 kPa) with characteristics normally associated with transmission or sub–transmission are excluded from the calculation.

To aggregate a diverse range of outputs into an aggregate output index using indexing procedures, weights need to allocated to each of the three outputs. This case uses the estimated output cost shares derived from the econometric cost function outlined in Appendix C, as used in Lawrence (2007) on data for the three Victorian GDBs for the period 1998 to 2006. The weights used in this study are the same as those used in previous Economic Insights studies, with the aim of ensuring the studies reflect actual changes in year–to–year operations. A weighted average of the output cost shares was formed using the share of each observation's estimated costs in the total estimated costs for all GDBs and all time periods following Lawrence (2003). This produced an output cost share for throughput of 13 per cent, for customers of 49 per cent and for system capacity of 38 per cent.

The total revenue of each GDB is the sum of revenue from all customer segments: residential, commercial and large industrial customers.

4.3.2 Input quantities and weights

The inputs used by GDBs are defined in this study as:

1) **Opex**: The quantity of the GDB's opex is derived by deflating the value of opex by the opex price deflator originally developed by PEG (2006). As noted above, the opex values supplied by the GDBs were consistent with the GDBs' Regulatory Accounts but the focus has been on ensuring data reflects actual year–to–year operations. A number of

accounting adjustments such as allowance for provisions have been excluded as they do not reflect the actual inputs used by the businesses in a particular year which is what is needed for TFP purposes. To ensure consistency in functional coverage throughout the period, for those years prior to the introduction of full retail contestability (FRC) each GDB's constant price opex is increased by the amount of expenses incurred in the early years of FRC. In these early years FRC was expected to have only affected opex (and not capital) requirements.

To ensure consistency with previous studies, including Economic Insights (2010, 2014), a number of adjustments have been made to the functional coverage of opex to ensure more like–with–like comparisons between GDBs. Government levies and unaccounted for gas are excluded from opex for all GDBs. Carbon costs are excluded where separately identified.[4]

The PEG (2006) opex price deflator was developed for electricity DBs. It is made up of a 62 per cent weighting on the Electricity, gas and water sector Wages price index with the balance of the weight being spread across five Producer price indexes covering business, computing, secretarial, legal and accounting, and advertising services. Since the functions of electricity and gas distribution are broadly analogous, the PEG (2006) deflator is considered the best currently available for GDB opex as well.[5]

2) **Transmission network**: The quantity of transmission network for each GDB is proxied by its transmission pipeline length (for JGN this is defined as the sum of its 'trunk' and 'primary' mains length).

3) **High pressure network**: The quantity of each GDB's high pressure network is proxied by its high pressure pipeline length.

4) **Medium pressure network**: The quantity of each GDB's medium pressure network is proxied by its medium pressure pipeline length.

5) **Low pressure network**: The quantity of each GDB's low pressure network is proxied by its low pressure pipeline length.

6) **Services network**: The quantity of each GDB's services network is proxied by its estimated services pipeline length.

7) **Meters**: The quantity of each GDB's meter stock is proxied by its total number of meters.

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[4] In the case of JGN, other items of opex have been excluded to put it on a comparable functional basis, including opex associated with trunk and primary mains, marketing and retail incentives, market operations expenses and meter reading. Network marketing expenses are also excluded for AGN Qld given its low penetration.

[5] The Australian Bureau of Statistics discontinued some of the Producer Price Indexes used in the PEG (2006) opex price deflator with its move to the latest industrial classification so it has been necessary to splice the series with the nearest proxies under the new classification.

8) **Other assets**: The quantity of other capital inputs is proxied by their deflated asset value. Other capital comprises city gate stations, cathodic protection, supply regulators and valve stations, SCADA and other remote control, other IT and other non–IT.

The starting point for asset values for each GDB is based on the regulatory asset base (RAB) valuation in an initial year (either 1997, 1998 to 1999) for 12 asset categories. Asset life and remaining asset life estimates were provided for each GDB for each of the asset categories, as well as estimated asset lives for capex using the same asset categories. Disaggregated constant price depreciated capital stock estimates are formed by rolling forward the opening asset values by taking away straight–line depreciation based on remaining asset life of the opening capital stock and adding in yearly constant price capital expenditure and subtracting yearly constant price depreciation on capital expenditure for each year calculated using straight line depreciation based on asset–specific asset lives.

Following PEG (2006) this study uses the endogenous rate of return method for forming estimates of the user cost of capital. Using this approach, the value of total costs equals total revenue by definition. As noted in Lawrence (2007), when implicit gross rate of return is relatively stable over time there should be little difference in TFP estimates formed using this approach and the exogenous user cost method. The input weight given to opex is simply the ratio of opex to total revenue. The aggregate capital input weight is simply given by one minus the opex share. It is then necessary to divide this overall capital share among the seven capital asset inputs. This is done using the share of each of the seven asset categories' asset values in the total asset value for that year.

4.4 Key characteristics of the included GDBs

The key characteristics of the seven GDBs included in this study are presented in Table 4.1 for 2018, or the latest year for which data are available in the database for each GDB. JGN is the largest of the GDBs in terms of throughput (89 petajoules (PJ)[6]), customer numbers (1.4 million), and distribution mains length (24,000 km). The Victorian GDBs are similar to each other in size and smaller than JGN. In terms of throughput they are on average about 70 per cent of the size of JGN, ranging from 56 PJ (Multinet) to 67 PJ (AusNet). In terms of the number of customers they are on average about half of the size of JGN, ranging from about 648,000 (AGN Vic) to 697,000 (Multinet). In terms of distribution network length they are on average about 40 per cent of the size of JGN, ranging from 10.0 (Multinet) to 11.3 thousand km (AusNet). ATCO is a little larger than the Victorian GDBs in terms of customer numbers (about 744,000) and network length (13.3 thousand km), and about half the size of JGN on these measures. However, ATCO's gas throughput (25 PJ) is just over 40 per cent of the average level of gas throughput of the Victorian GDBs and about 30 per cent of the gas throughput of JGN.

The remaining two GDBs are smaller. In terms of throughput, AGN SA's 23 PJ is almost as large as ATCO. Its customer base of approximately 442,000, and its mains length of 8.0 thousand km, are both approximately 40 per cent smaller than ATCO's. AGN Qld is much smaller than the other GDBs included in the study, being about one–quarter of the size of

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[6] One PJ = 1,000 TJ.

AGN SA on most of the measures discussed.

As noted previously, the two key operating environment characteristics that influence energy distribution productivity levels are energy density (throughput per customer) and customer density (customers per kilometre of mains). Together these determine the energy throughput per kilometre (km) of distribution mains. These measures are also shown in Table 4.1.

Energy densities shown in Table 4.1 are overall figures across domestic, commercial and industrial customers. JGN's energy density of 63.7 GJ per customer is reasonably close to the average for the sample as a whole. The three Victorian GDBs have relatively high energy density, ranging from 79 (Multinet) to 98 GJ per customer (AusNet). The energy densities of AGN Qld and AGN SA are 58 and 52 GJ/customer respectively. ATCO has relatively low energy density of 34 GJ per customer.

The customer density of JGN (57 customers per km) is broadly comparable to those of AGN SA (55 customers per km), ATCO (57 customers per km), AGN Vic and AusNet (both 60 customers per km). Multinet's customer density is somewhat higher (69 customers per km) and AGN Qld is somewhat lower (36 customers per km).

The combined effect of these two factors (energy density and customer density) is that JGN has energy throughput per km of mains (3.6 TJ per km) which is just below the average for the sample as a whole (3.9 TJ per km). The Victorian GDBs have relatively high energy throughput per km of mains of between 5.5 (AGN Vic and Multinet) and 5.9 TJ per km (AusNet). Other GDBs have lower energy throughput per km of mains than JGN. They include AGN SA (2.9 TJ/km) and ATCO (1.9 TJ per km).

Domestic energy density is a key cost driver for GDBs. GDBs operating in a temperate climate will be at an obvious disadvantage relative to GDBs operating in cold climates where there is a much higher demand for gas for space heating. The domestic demand for gas for GDBs operating in temperate climates is likely to be more focused on cooking and hot water heating. The domestic energy densities of the seven included GDBs are plotted in Figure 4.1. The significant differences in domestic energy densities highlight the different operating conditions faced by GDBs. The three Victorian GDBs have considerably higher domestic energy densities than the non–Victorian GDBs, due to relatively higher domestic space heating demand. Greater variability of the Victorian densities is also associated with heating use, as demand is less in milder winters. AGN Qld has the lowest domestic energy density of all the GDBs. JGN, AGN SA and ATCO have relatively low energy densities compared to the Victorian GDBs, and similar to each other reflecting broadly similar climatic conditions in the reticulated areas of NSW, South Australia and Western Australia.

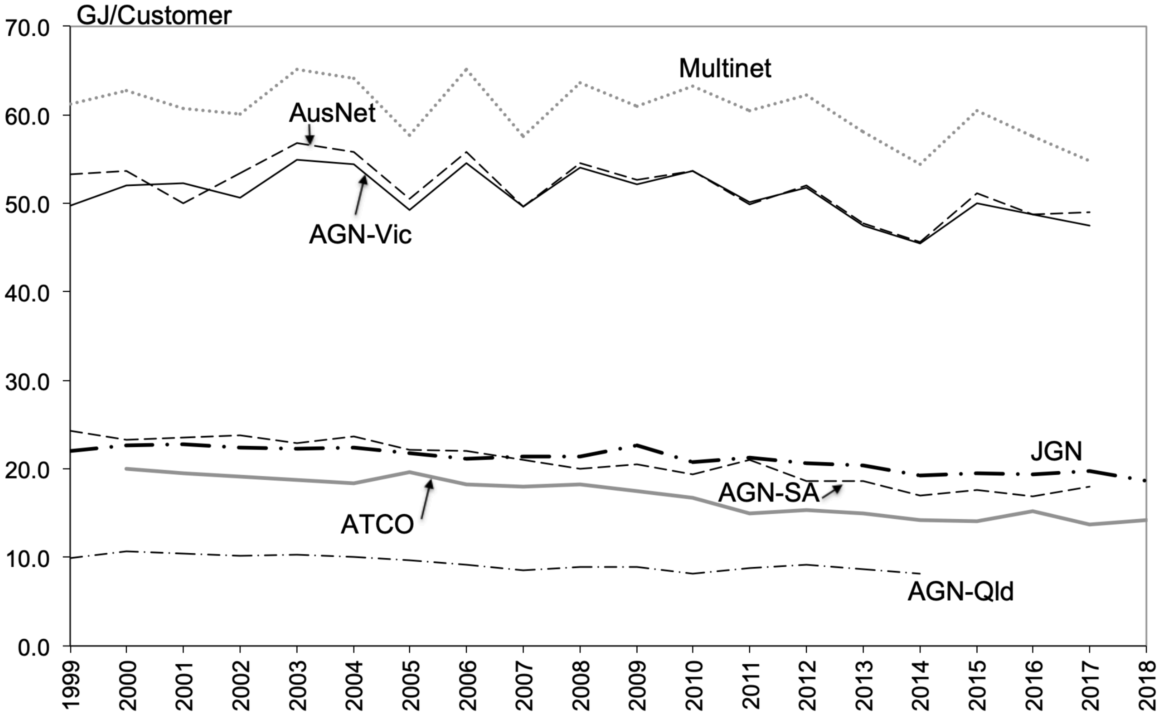
Table 4.1: Included GDBs' key characteristics, 2018 (or latest*)

GDB	Throughput *TJ*	Customers *No*	System capacity *Sm^3*	Distribution mains length *kms*	Energy density *GJ/cust.*	Customer density *Cust./km*	Energy per unit mains *TJ/km*
AGN–Vic	59,975	647,906	147,552	10,791	92.7	59.7	5.5
Multinet	56,395	696,973	125,636	10,041	78.8	69.3	5.5
AusNet	66,925	681,542	149,056	11,312	98.2	60.2	5.9
Jemena	88,547	1,390,296	302,196	24,368	63.7	57.1	3.6
AGN–SA	23,013	442,319	106,934	8,024	52.0	55.1	2.9
AGN–Qld	5,356	91,783	27,725	2,542	58.4	36.1	2.1
ATCO	25,395	743,800	108,412	13,303	34.1	56.8	1.9
Average	46,515	670,660	138,216	11,483	68.3	56.3	3.9

Notes: * AGN Vic, AusNet, Multinet and AGN SA (2017), AGN Qld (2014).

Source: Economic Insights GDB database

Figure 4.1: Included GDB domestic energy densities, 1999–2018



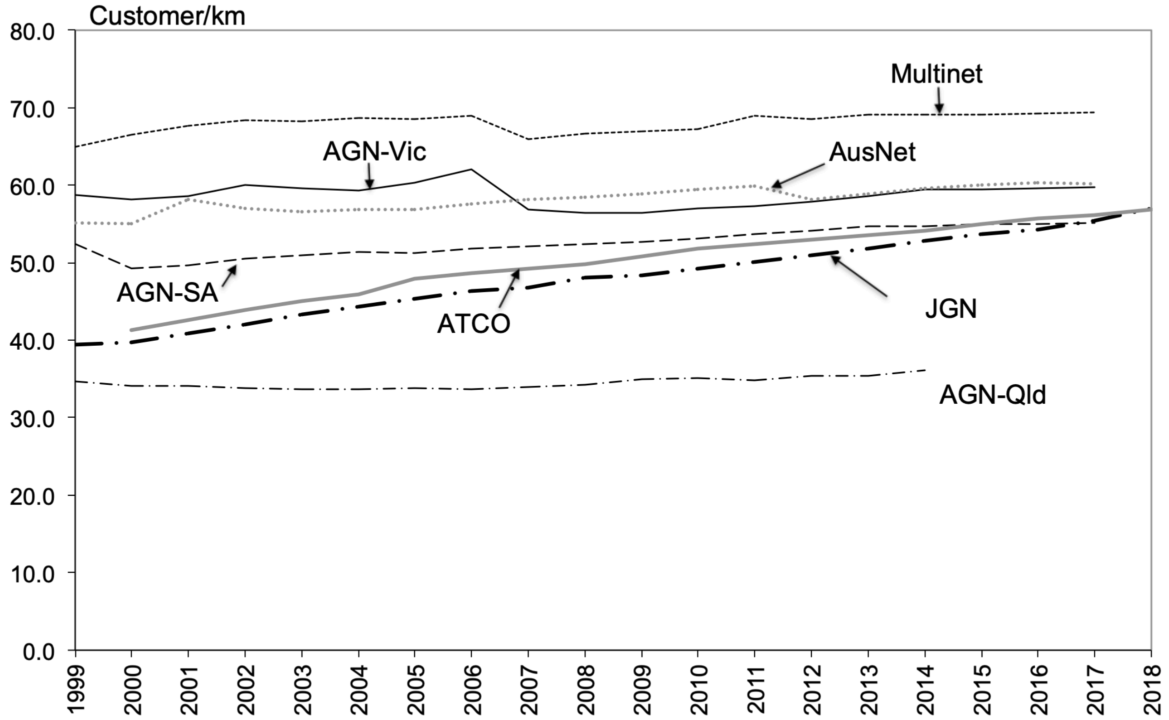
Source: Economic Insights GDB database

Such differences are further highlighted by differences in the share of domestic energy out of total energy throughput between GDBs. In 2018 (or latest year), domestic throughput accounted for 29 per cent of JGN's throughput; 34 per cent of AGN SA's throughput and 41 per cent of ATCO's throughput. By contrast domestic demand accounted for only 13 per cent of AGN Qld's throughput. In the case of both AGN Vic and AusNet, domestic demand accounted for 49 per cent of total throughput, and for Multinet it was as high as 69 per cent.

Climatic conditions also have a significant impact on a GDB's customer density, as do the geographic characteristics of the areas served. Domestic customer penetration rates are typically much lower for GDBs operating in warmer climates, meaning that those GDBs have to lay relatively more length of pipeline to reach each domestic customer. Customer densities will also be lower for those GDBs whose geography dictates a relatively 'dendritic' system rather than a more compact, meshed system. A dendritic system will arise where a number of spread out pockets of consumption have to be served.

Customer densities for the included GDBs are plotted in Figure 4.2. JGN's customer density is lower than the Victorian GDBs and similar to AGN SA and ATCO. Multinet has the highest customer density of the included GDBs reflecting its coverage of Melbourne's densely populated inner southeast. AGN Vic and AusNet have the next highest customer densities followed by ATCO, JGN and AGN SA. AGN Qld has a considerably lower customer density than the other GDBs.

Figure 4.2: Included GDB customer densities, 1999–2018



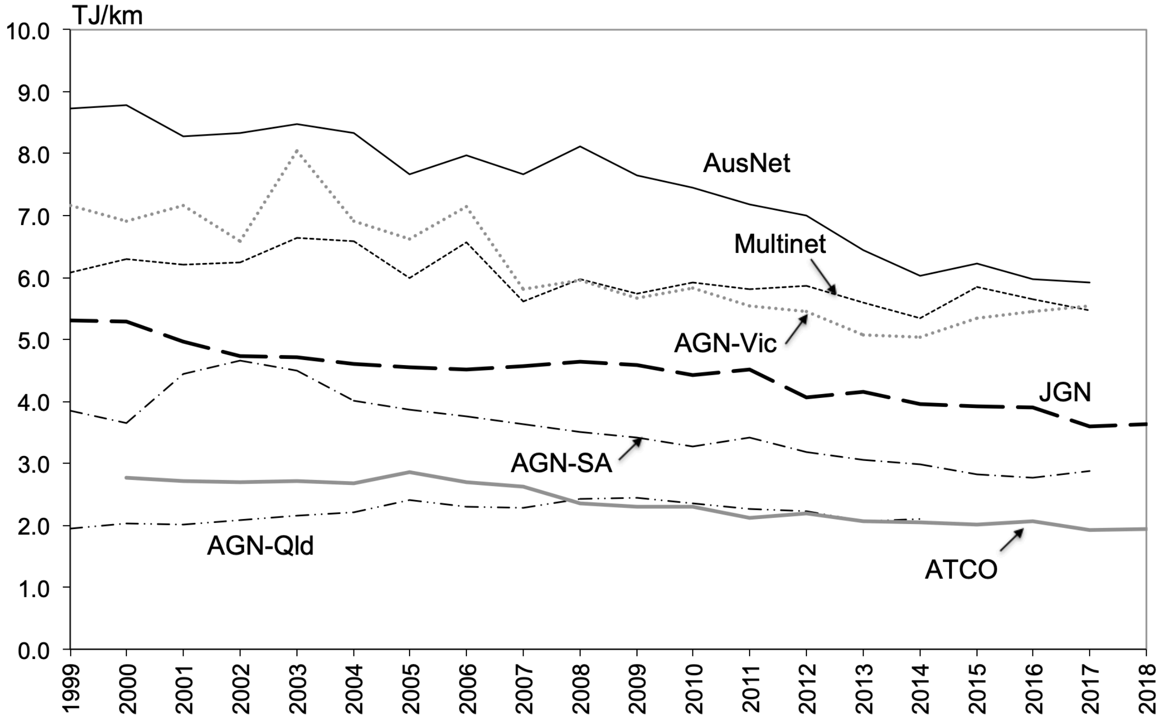
Source: Economic Insights GDB database

Figure 4.3 summarises the differences between the GDBs in terms of energy throughput per km of main. This is the product of energy density and customer density. JGN's of energy deliveries per km are significantly lower than the Victorian GDBs, and are most closely comparable to AGN SA. These GDBs have higher energy throughput per km of main than ATCO and AGN Qld. The comparatively high energy throughput per km of the Victorian GDBs reflects a combination of the high energy densities and high customer densities previously discussed. AGN SA and JGN have intermediate levels of energy throughput per km of main, which is consistent with their intermediate energy densities and customer densities.

There is a general trend, across all the GDBs (except AGN Qld), of declining energy throughput per km, which is quite a pronounced shift over the whole of the sample period. Over the period 1999 to 2018 (or latest year) the cumulative decline in energy throughput per km was: JGN, 32 per cent; AGN Vic, 23 per cent; Multinet, 10 per cent; AusNet, 32 per cent; AGN SA, 26 per cent; and ATCO, 30 per cent. An important factor in these declines has been reductions in demand by major industrial ('Tariff D' or 'contract') customers. For JGN, over the sample period, the total gas demand for this class of customers declined cumulatively by 33 per cent. For the other major GDBs, the decline in Tariff D demand was: 5 per cent for AGN Vic; 16 per cent for Multinet; 32 per cent for AusNet; 10 per cent for AGN SA; and 35 per cent for ATCO.

To summarise, JGN is the largest GDB among those included in the study. Its overall energy density (GJ per customer) is much lower than those of the Victorian GDBs and most similar to AGN SA and ATCO. These businesses have lower domestic energy densities, largely due to differences in climate. Their customer densities are also lower than the Victorian GDBs. For these reasons, energy density per km of main of JGN is much lower than for the Victorian GDBs, and most similar to AGN SA, while ATCO's and AGN Qld's energy densities per km of main are lower again. These differences can be expected to give lower energy density GDBs some disadvantage when comparing productivity levels.

Figure 4.3: Included GDB energy throughput per km main, 1999–2018



Source: Economic Insights GDB database

5 PRODUCTIVITY GROWTH RESULTS

5.1 TFP indexes

Index numbers are a quantitative method developed in economics for aggregating prices or quantities of products that may be measured in different units, and hence cannot be aggregated by summation or simple averages. Index numbers normally measure relativities, such as changes from one period to another or comparisons between other situations, such as comparisons between localities or groups of consumers.

To operationalise TFP measurement the method needs to combine changes in diverse outputs and inputs into measures of changes in total outputs and total inputs. That is, it is necessary to develop an index for all the outputs produced by a business and another for all the inputs used by the business. The four most popular index formulations are:

- the Laspeyres base period weight index;
- the Paasche current period weight index;
- the Fisher ideal index which is the square root of the product of the Paasche and Laspeyres index; and
- the Törnqvist index which has been used extensively in previous TFP studies.

Diewert (1993) reviewed alternate index number formulations to determine which index was best suited to TFP calculations. Indexing methods were tested for consistency with a number of axioms which an ideal index number should always satisfy.[7] Diewert found that only the Fisher ideal index passed all of the axiomatic tests.[8] On the basis of his analysis, Diewert recommended the Fisher ideal index be used for TFP work although he indicated that the Törnqvist index could also be used as it closely approximates Fisher's ideal index. For this study the Fisher ideal index was therefore chosen as the preferred index formulation for the TFP time series analysis. It is also increasingly the index of choice of leading national statistical agencies.

Mathematically, the Fisher ideal output index is given by:

$$(5.1) \quad Q_F^t = [(\sum_{i=1}^m P_i^B Y_i^t / \sum_{j=1}^m P_j^B Y_j^B)(\sum_{i=1}^m P_i^t Y_i^t / \sum_{j=1}^m P_j^t Y_j^B)]^{0.5}$$

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[7] These tests were: (a) the constant quantities test: if quantities are the same in two periods, then the output index should be the same in both periods irrespective of the price of the goods in both periods; (b) the constant basket test: this states that if prices are constant over two periods, then the level of output in period 1 compared to period 0 is equal to the value of output in period 1 divided by the value of output in period 0; (c) the proportional increase in outputs test: this states that if all outputs in period t are multiplied by a common factor, λ, then the output index in period t compared to period 0 should increase by λ also; and (d) the time reversal test: this states that if the prices and quantities in period 0 and t are interchanged, then the resulting output index should be the reciprocal of the original index.

[8] The Laspeyres and Paasche index fail the time reversal test while the Törnqvist index fails the constant basket test.

where: Q_F^t is the Fisher ideal output index for observation *t*;

P_i^B is the price of the *i*th output for the base observation;

Y_i^t is the quantity of the *i*th output for observation *t*;

P_i^t is the price of the *i*th output for observation *t*; and

Y_j^B is the quantity of the *j*th output for the base observation.

Similarly, the Fisher ideal input index is given by:

$$(5.2)\quad I_F^t = [(\textstyle\sum_{i=1}^n W_i^B X_i^t / \sum_{j=1}^n W_j^B X_j^B)(\sum_{i=1}^n W_i^t X_i^t / \sum_{j=1}^n W_j^t X_j^B)]^{0.5}$$

where: I_F^t is the Fisher ideal input index for observation *t*;

W_i^B is the price of the *i*th input for the base observation;

X_i^t is the quantity of the *i*th input for observation *t*;

W_i^t is the price of the *i*th input for observation *t*; and

X_j^B is the quantity of the *j*th input for the base observation.

The Fisher ideal TFP index is then given by:

$$(5.3)\quad TFP_F^t = Q_F^t / I_F^t\,.$$

The Fisher index can be used in either the unchained form denoted above or in the chained form used in this study where weights are more closely matched to pair–wise comparisons of observations. Denoting the Fisher output index between observations *i* and *j* by $Q_F^{i,j}$, the chained Fisher index between observations 1 and *t* is given by:

$$(5.4)\quad Q_F^{1,t} = 1 \times Q_F^{1,2} \times Q_F^{2,3} \times \ldots . \times Q_F^{t-1,t}\,.$$

In this section the chained Fisher ideal index number method is used to calculate output and input indexes, TFP and partial productivity measures.

5.2 JGN's productivity growth results, 1999 to 2018

This section presents the key productivity results for JGN's NSW gas distribution business for the 20–year period to 2018. Results are derived using the output index specification outlined in section 4.3 (throughput, customer numbers and system capacity) and with two broad inputs (real opex and capital). The capital index is based on seven components (lengths of transmission pipelines, high pressure pipelines, medium pressure pipelines, low pressure pipelines and services, number of meters, and the real value of other capital inputs), again as described in section 4.3. Table 5.1 shows the total factor and partial factor productivity index results for JGN.

JGN's rate of output growth in the period 1999 to 2007 was 1.9 per cent per year on average. Output grew at a similar rate in subsequent periods; 1.6 per cent per year from 2007 to 2014, and 1.9 per cent per year from 2014 to 2018. Inputs decreased slightly in the period from 2000 to 2007 (at an average annual rate of 0.1 per cent) and consequently the rate of TFP growth in that period was similar to the rate of output growth (2.0 per cent per year on average). During the period from 2007 to 2014 inputs increased at an average rate of 2.0 per cent, slightly exceeding output growth, which resulted in TFP declining at an average rate of 0.4 per cent per year. Over the last four years to 2018, inputs increased at the same rate as outputs (1.9 per cent per year), and hence TFP did not increase over this period. Over the whole period from 1999 to 2018, the average rate of increase in TFP was 0.7 per cent per year.

Table 5.1: JGN productivity indexes, 1999–2018

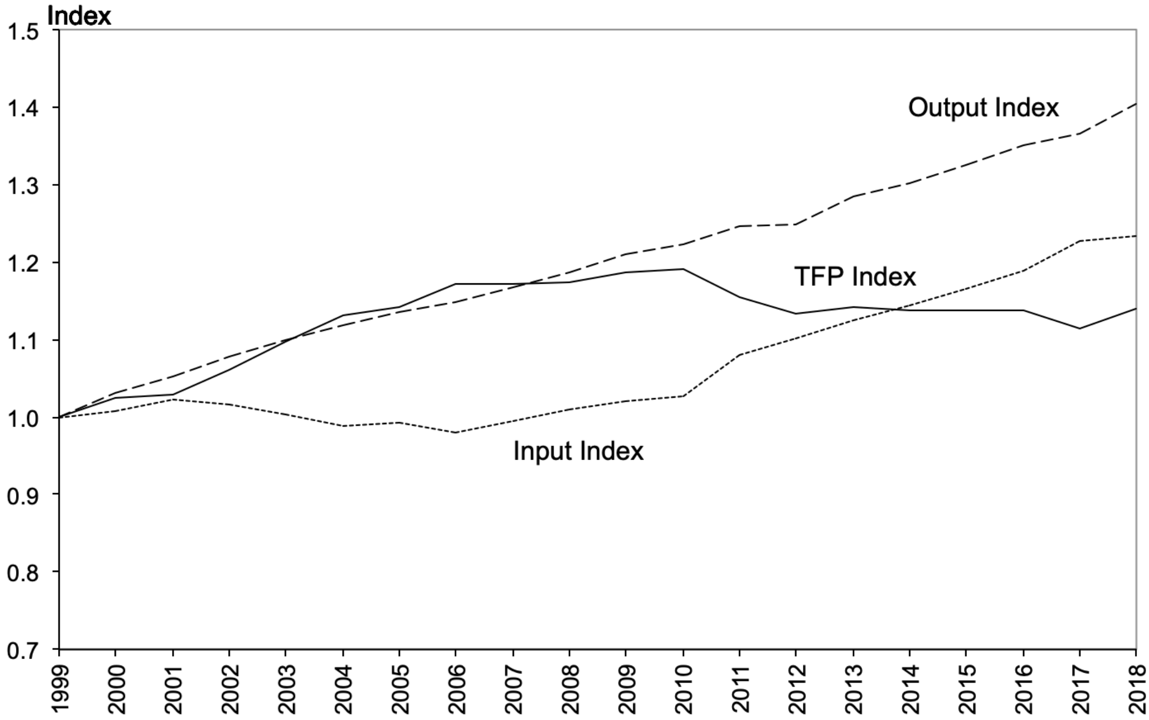
Year	Output	Input	Opex	Capital	PP Opex	PP Capital	TFP
1999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000	1.031	1.007	0.934	1.040	1.103	0.991	1.024
2001	1.052	1.022	0.930	1.067	1.132	0.986	1.029
2002	1.078	1.016	0.870	1.090	1.239	0.988	1.061
2003	1.100	1.003	0.802	1.110	1.371	0.991	1.097
2004	1.118	0.989	0.746	1.120	1.498	0.999	1.131
2005	1.135	0.994	0.725	1.140	1.565	0.995	1.142
2006	1.148	0.980	0.669	1.153	1.716	0.996	1.172
2007	1.167	0.995	0.677	1.173	1.723	0.995	1.172
2008	1.186	1.010	0.672	1.200	1.765	0.988	1.175
2009	1.210	1.019	0.665	1.221	1.820	0.991	1.187
2010	1.224	1.028	0.650	1.245	1.883	0.983	1.191
2011	1.247	1.079	0.713	1.286	1.748	0.969	1.155
2012	1.248	1.102	0.713	1.323	1.751	0.943	1.132
2013	1.285	1.125	0.728	1.351	1.765	0.952	1.142
2014	1.302	1.143	0.726	1.381	1.794	0.943	1.138
2015	1.326	1.166	0.716	1.421	1.853	0.933	1.137
2016	1.351	1.188	0.697	1.465	1.939	0.922	1.137
2017	1.366	1.227	0.758	1.489	1.802	0.917	1.113
2018	1.405	1.233	0.736	1.514	1.908	0.928	1.139
Average Annual Change							
1999–2007	1.9%	-0.1%	-4.8%	2.0%	7.0%	-0.1%	2.0%
2007–2014	1.6%	2.0%	1.0%	2.4%	0.6%	-0.8%	-0.4%
2014–2018	1.9%	1.9%	0.4%	2.3%	1.6%	-0.4%	0.0%
1999–2018	1.8%	1.1%	-1.6%	2.2%	3.5%	-0.4%	0.7%

Source: Calculations using Economic Insights GDB database

There were divergent trends in the use of real opex and capital inputs. On average, over the period from 1999 to 2018, opex inputs decreased at an average annual rate of 1.6 per cent. These reductions were concentrated in the period before 2007. In the period from 2007 to 2014, opex inputs increased at 1.0 per cent per year on average, and in the latest four–year period, opex inputs increased at an average rate of 0.4 per cent per year. In contrast, the capital inputs index increased over the whole period from 1999 to 2018, averaging an annual increase of 2.2 per cent. Consequently, opex partial productivity increased strongly, at an average annual rate of 3.5 per cent from 1999 to 2018, whereas capital partial productivity decreased over the same period at an average annual rate of 0.4 per cent. However, JGN's opex PFP grew at a very high rate of 7 per cent per year from 1999 to 2007 before reducing to only 0.6 per cent per year from 2007 to 2014 before showing a small increase to 1.6 per cent per year after 2014. Capital PFP growth, on the other hand, was more stable across the whole period.

Figure 5.1 plots JGN's TFP index, together with the output and input indexes. The latter assist to interpret movements in the TFP index, which is the ratio of the output and input indexes. JGN had a reasonably strong increase in TFP up to about 2006, and its TFP has been relatively flat since then. These trends were mirrored by movements in the input index which was relatively flat in the period up to 2006 but increased at a similar rate to the output index afterwards.

Figure 5.1: JGN output, input and TFP indexes, 1999–2018



Source: Economic Insights GDB database

Figure 5.2 shows the capital and opex input indexes for JGN. The capital input index grew at a reasonably steady rate over the whole period from 1999 to 2018,[9] although the growth rate of 2.4 per cent per year in the period 2007 to 2014 was slightly greater than in the preceding period (see Table 5.1). Opex inputs declined strongly in the period from 2000 to 2006, and have been comparatively flat since. In the period immediately after 2006, opex inputs were relatively constant up to 2010, but subsequently there were some small increases, so that by 2018 the opex inputs index was approximately 13 per cent higher than in 2010.

Figure 5.3 shows the partial factor productivity (PFP) indexes for JGN. The TFP index is effectively a weighted average of the two partial productivity indexes. The opex PFP index measures output produced per unit of non–capital inputs, and the capital PFP index measures

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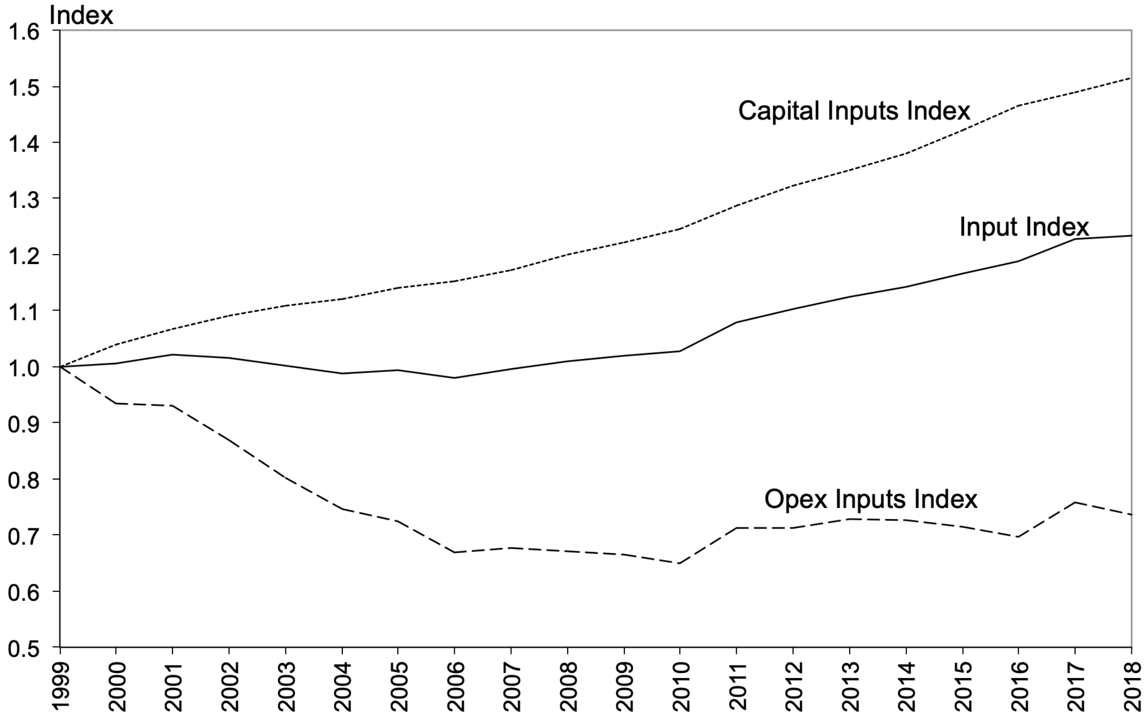
[9] The decline in 2018 is associated with a reduction in mains lengths due to changes in JGN's information systems. Corrections to earlier data have not been made at this stage, but will be carried out for the final report.

output per unit of capital inputs. JGN's capital PFP decreased slightly over the period 1999 to 2018 at an average annual rate of 0.4 per cent (see Table 5.1). Relatively flat capital PFP is common to most of the GDBs in the sample. JGN's opex PFP increased strongly from 1999 to 2006, and continued to increase up to 2010. Subsequent movements largely cancelled, and the opex PFP index in 2018 was similar to its level in 2010.

Figure 5.2: JGN inputs indexes, 1999–2018

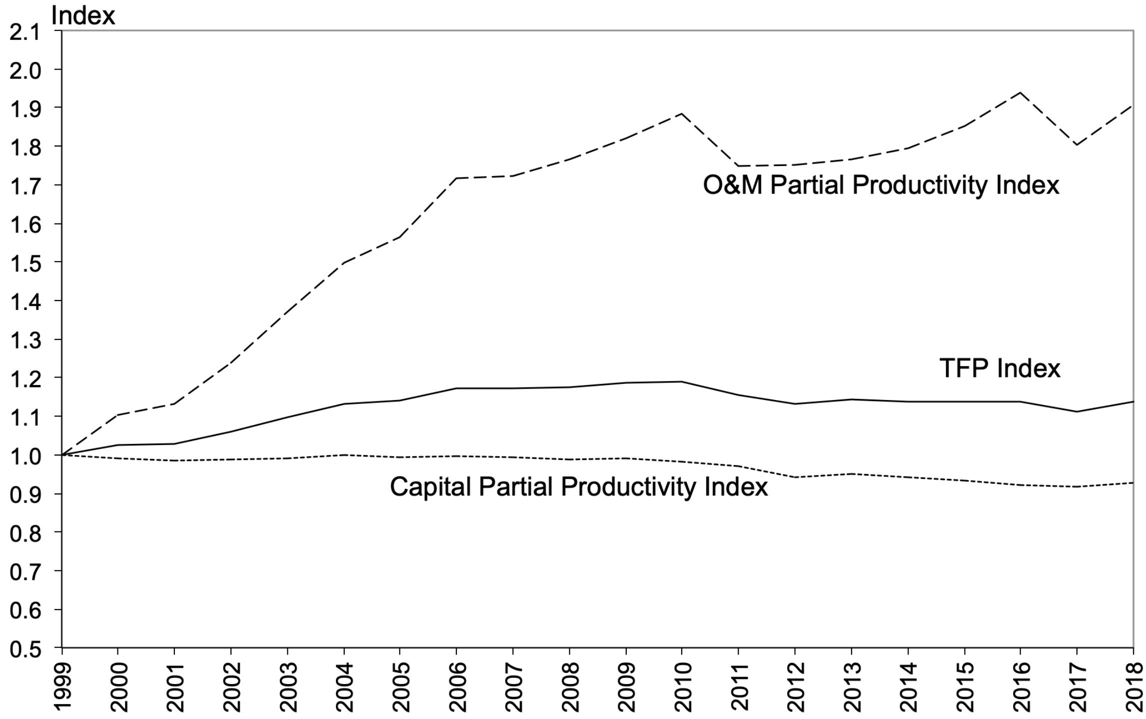


Source: Economic Insights GDB database

5.3 Comparison with Interstate GDB Productivity Growth

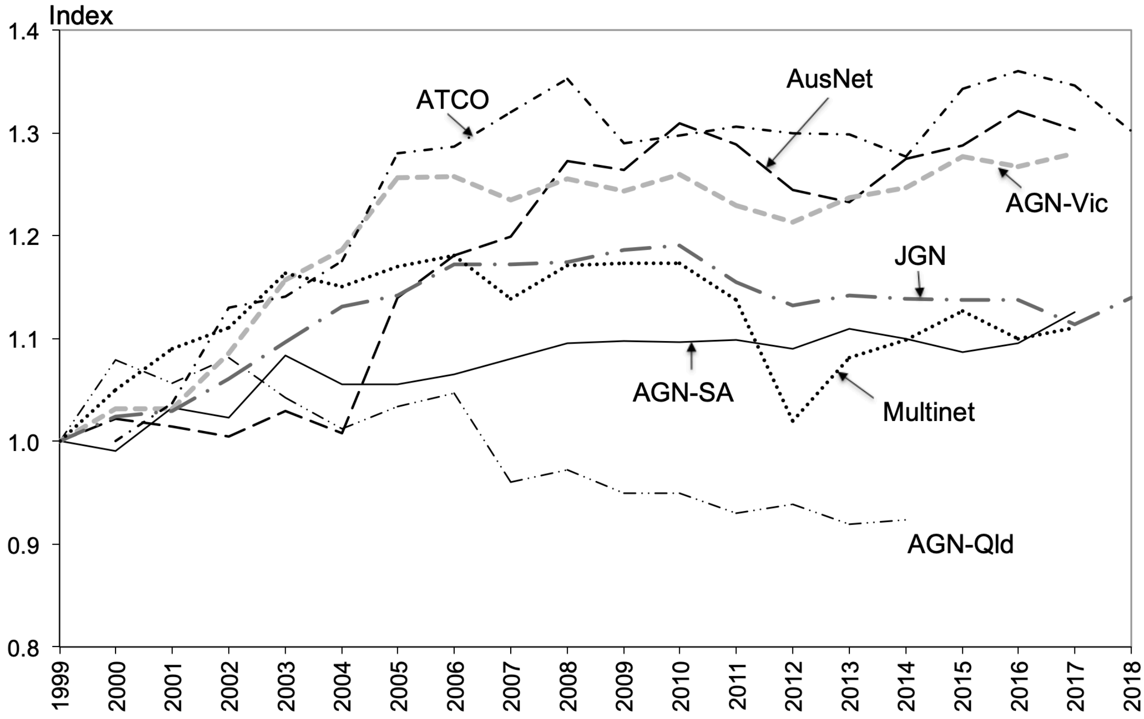
This section compares JGN's productivity growth with the interstate GDBs (ie AGN SA, AGN Qld, AGN Vic, Multinet, AusNet and ATCO). Comparative TFP, PFP, output and opex input indexes for these GDBs are presented in Figures 5.4 to 5.8. Comparative TFP, PFP, output and input indexes and growth rates are presented in Tables 5.2 to 5.8. The TFP performance of the GDBs in the sample is plotted in Figure 5.4. The GDBs with the strongest rates of total factor productivity growth were ATCO, AusNet and AGN–Vic. On average over the period 1999 to 2018 (or latest year available), the TFP of ATCO and AusNet both increased at average annual rates of 1.5 per cent, and AGN Vic's TFP increased at a rate of 1.4 per cent. JGN was among a group of GDBs with more moderate TFP growth. Its average annual TFP growth of 0.7 per cent over the period 1999 to 2018 compares to AGN SA (0.7 per cent) and Multinet (0.6 per cent). AGN Qld's TFP declined over most of the period since 1999. It is much smaller than the other GDBs and has a less favourable climate for gas consumption.

Figure 5.3: JGN partial productivity indexes, 1999–2018



Source: Economic Insights GDB database

Figure 5.4: Comparative TFP indexes, 1999–2018

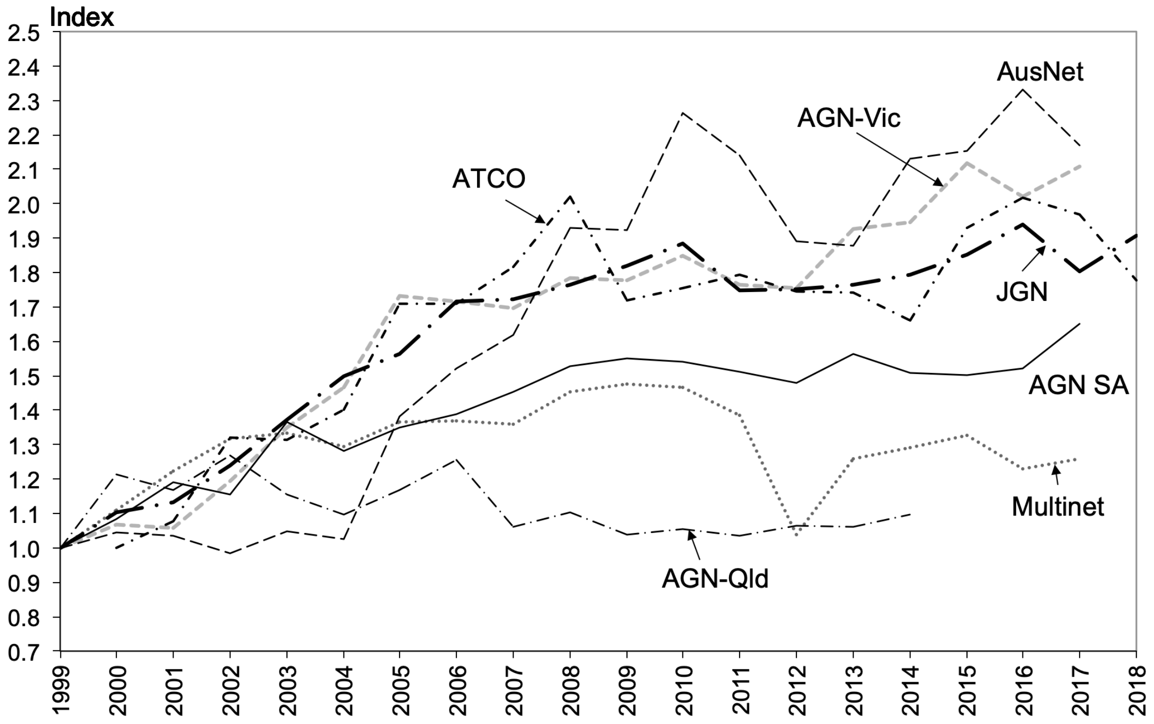


Source: Economic Insights GDB database

In most cases, productivity growth was strongest in the first part of the sample period from 1999 to 2007 (e.g. 2.7 per cent for AGN–Vic, 2.3 per cent for AusNet, 1.6 per cent for Multinet, and 4.1 per cent for ATCO). JGN also had a strong rate of TFP growth of 2.0 per cent per year over the same period. In most cases productivity growth was weak, and in some cases declining, in the period from 2007 to 2014 (e.g. 0.1 per cent for AGN–Vic, 0.9 per cent for AusNet, –0.5 per cent per annum for both Multinet and ATCO). Similarly, JGN's TFP growth over the same period was –0.4 per cent per year. The productivity growth of most of the GDBs improved somewhat over the period from 2014 to 2018 (e.g. 0.9 per cent for AGN–Vic, 0.7 per cent for AusNet, 0.3 per cent for Multinet and 0.5 per cent for ATCO). JGN's had zero TFP growth in this period.

Figures 5.5 and 5.6 plot the opex PFP indexes and the capital PFP indexes, respectively. JGN was among the GDBs with comparatively strong growth in opex PFP (including also AGN Vic, AusNet and ATCO). Generally, for these GDBs, opex PFP growth was particularly strong in the first half of the sample period, and comparatively weaker, or even negative, in the second half. Over the full sample period the opex PFP of these four GDBs increased at average annual rates of 3.3 per cent for ATCO, 4.2 per cent for AGN Vic, 4.4 per cent for AusNet and 3.5 per cent for JGN. Opex PFP growth rates were lower for the other GDBs. Over the full sample period, their opex PFP growth rates were 2.8 per cent for AGN SA, 1.3 per cent for Multinet and 0.6 per cent for AGN Qld.

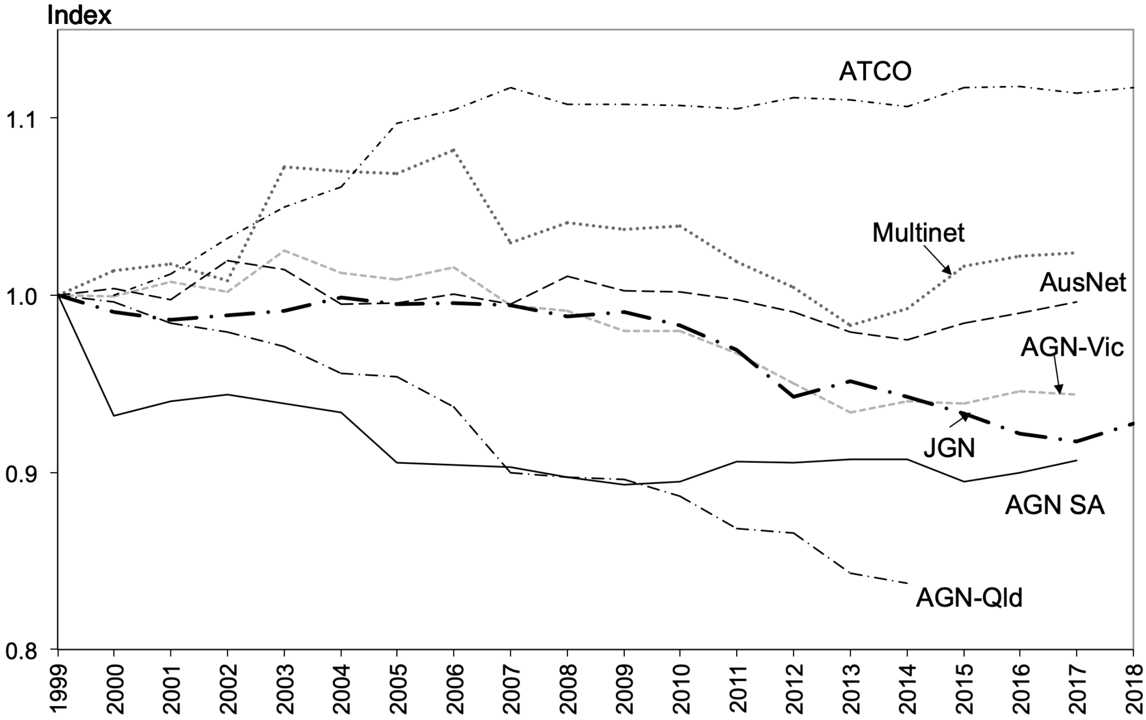
Figure 5.5: Comparative Opex PFP indexes, 1999 – 2018



Source: Economic Insights GDB database

For most GDBs, capital partial productivity indexes over the full period were either flat or else declining moderately. AusNet and Multinet are examples of GDBs with flat capital PFP over the period 1999 to 2018. JGN and AGN Vic had relatively moderate declines in capital PFP over the same period, averaging –0.4 per cent and –0.3 per cent per year respectively. AGN SA's capital PFP decreased at a similar average annual rate of –0.5 per cent over the same period. AGN Qld had more pronounced capital PFP decline averaging –1.2 per cent per year. ATCO's capital PFP increased at an average rate 0.6 per cent per year over the same period.

Figure 5.6: Comparative Capital PFP indexes, 1999–2018

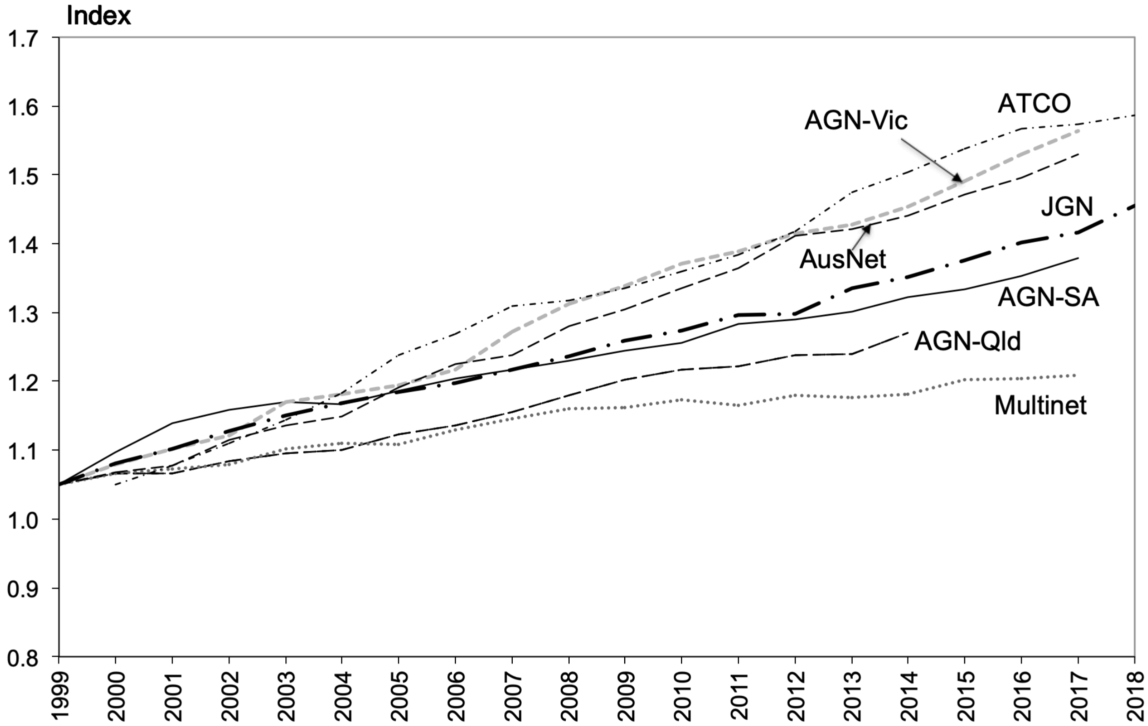


Source: Economic Insights GDB database

Figures 5.7 and 5.8 show the comparative output indexes and the opex indexes, respectively. In all cases, output growth was relatively steady over the 1999 to 2018 period, but the growth rates varied considerably between GDBs. JGN had average output growth over this period of 1.8 per cent per year, which was about average for the GDBs overall. GDBs with higher output growth over the full sample period include ATCO (averaging 2.4 per cent per annum), AusNet (2.2 per cent) and AGN Vic (2.3 per cent). Those with the lower output growth were AGN SA (1.6 per cent), AGN Qld (1.3 per cent) and Multinet Gas (0.8 per cent). The latter services a mature urban area which already has high rates of gas penetration, and does not include faster growing outer urban areas.

JGN was among the GDBs with the largest declines in real opex inputs over the 1999 to 2018 period. Its opex inputs index followed a broadly similar pattern to AusNet and AGN Vic. In each case, opex inputs decreased strongly in the period 1999 to 2007, with average annual rates of change of: –4.8 per cent for JGN; –4.0 per cent for AGN Vic; and –3.8 per cent for AusNet. Several other GDBs had substantial declines in opex inputs during the 1999 to 2007 period, including –5.1 per cent for ATCO; and –2.7 per cent for AGN SA; and –2.6 per cent for Multinet. Over the period from 2007 to 2018, JGN's opex inputs increased at an average annual rate of 0.8 per cent, which is close to the average across the GDBs. Some GDBs with low rates of growth in real opex between 2007 and 2018 include AGN Vic and AGN SA (both at 0.0 per cent) and AusNet (–0.7 per cent) over the same period. GDBs that had higher increases in opex inputs in the period from 2007 to 2018 include ATCO (2.0 per cent per year) and Multinet (1.3 per cent). However, in nearly all cases opex PFP growth was quite strong up to 2007 and much weaker after that.

Figure 5.7: Comparative Output indexes, 1999 – 2018



Source: Economic Insights GDB database

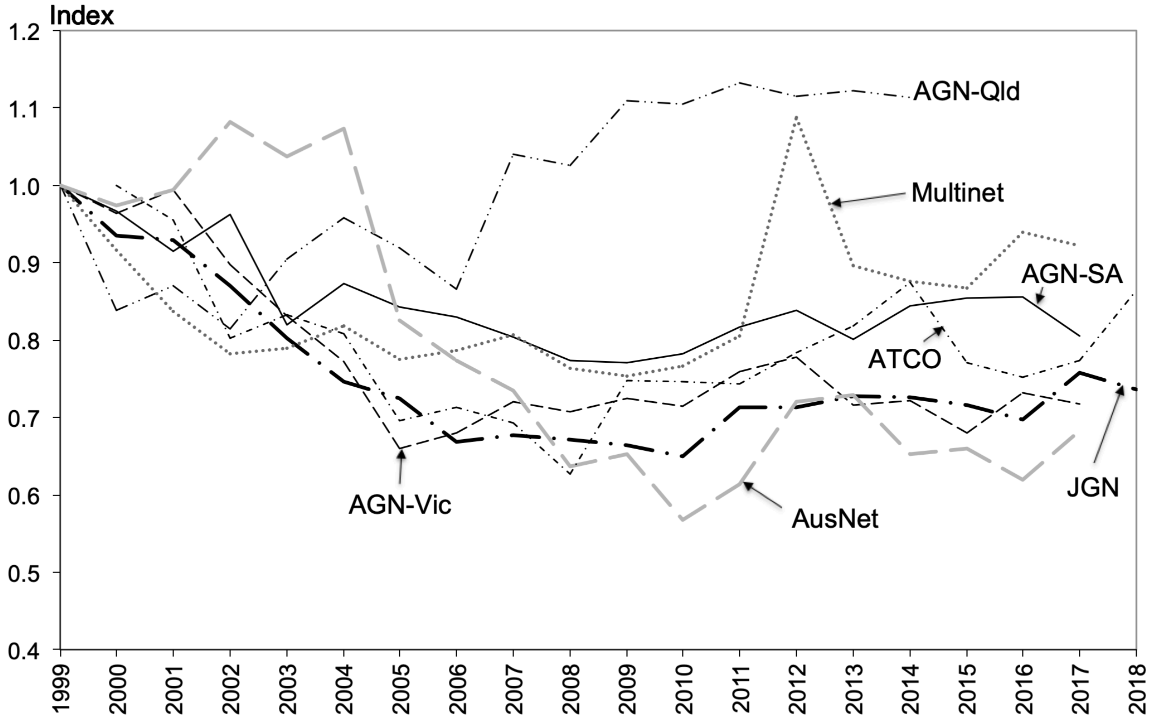
5.4 Summary Conclusions

Tine series productivity indexes are used to measure the *trends* in productivity. In summary, the TFP and opex PFP trend results for JGN are as follows:

- JGN's average rate of TFP growth over the whole period from 1999 to 2018 was 0.7 per cent per year. Most of the productivity growth occurred in the period 1999 to 2007, when there were large reductions in real opex and TFP growth averaged 2.0 per cent per year on average. From 2007 to 2014, TFP declined slightly, at an average rate of 0.4 per cent per year, and from 2014 to 2018, TFP growth was zero. The period since 2007 has seen some small gains in opex PFP offset by some small declines in capital PFP.
- Compared to the other GDBs in the sample, JGN's TFP growth rate over the whole sample period was close to the overall average for all GDBs. The GDBs with the strongest rates of total factor productivity growth were ATCO and AusNet (both with

average annual TFP growth rates of 1.5 per cent over the same period) and AGN–Vic (1.4 per cent). GDBs with similar TFP growth rates to JGN included AGN SA (0.7 per cent) and Multinet (0.6 per cent).

Figure 5.8: Comparative Opex indexes, 1999–2018



Source: Economic Insights GDB database

- There were divergent trends in JGN's use of real opex and capital input quantities. On average, over the period from 1999 to 2018, the quantity of opex inputs decreased at an annual rate of 1.6 per cent. These reductions were concentrated in the period before 2007. In the period from 2007 to 2014, opex inputs increased at 1.0 per cent per year on average, and in the latest four–year period opex inputs increased at an average rate of 0.4 per cent per year. Given JGN's output growth of 1.8 per cent per year on average from 1999 to 2018, opex partial factor productivity (PFP) increased at a rate of 3.5 per cent per year from 1999 to 2018, although this was heavily focussed in the period before 2007 when opex inputs were decreasing. Over the period 2007 to 2014, opex PFP growth averaged 0.6 per cent per year, and from 2014 to 2018 it averaged 1.6 per cent per year (or 0.9 per cent per year from 2007 to 2018). JGN was among those GDBs with relatively strong growth in Opex PFP (including also AGN Vic, AusNet and ATCO). Other GDBs had a similar pattern over time with high growth in the period 1999 to 2007 and more moderate opex PFP since then.
- Opex PFP changes depend not only on technical change (efficiency frontier shift) but also the effects of changes in the capital stock, scale economies, movements towards the frontier and the effects of operating environment characteristics. Hence the trends in opex PFP are not directly comparable to the rate of frontier shift estimated in Part C

of the report. That said, JGN's opex PFP growth rate over the period 2007 to 2018 is not very dissimilar to the estimated rate of frontier shift for GDBs in general over the whole sample period, which is presented in Part C.

- In contrast to opex inputs, the capital inputs quantity index increased over the whole period from 1999 to 2018, averaging an annual increase of 2.2 per cent. This is slightly higher than the average growth of the output index. Consequently the capital PFP decreased at an average rate of 0.4 per cent per year over the period over the same period. A similar trend applied in the latest period from 2014 to 2018. Overall, this is similar with the pattern among the other GDBs, for which capital PFP was either flat or declining moderately over the period 1999 to 2018.

Annexure to Section 5: Detailed Tables

Table 5.2: TFP indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	.
2000	1.079	0.990	1.032	1.022	1.024	1.049	1.000
2001	1.056	1.032	1.032	1.014	1.029	1.090	1.037
2002	1.082	1.023	1.085	1.004	1.061	1.111	1.130
2003	1.042	1.084	1.157	1.029	1.097	1.163	1.141
2004	1.013	1.055	1.186	1.008	1.131	1.151	1.175
2005	1.034	1.055	1.256	1.140	1.142	1.169	1.280
2006	1.047	1.065	1.257	1.181	1.172	1.181	1.287
2007	0.960	1.080	1.235	1.199	1.172	1.139	1.321
2008	0.973	1.095	1.255	1.273	1.175	1.171	1.353
2009	0.950	1.097	1.244	1.264	1.187	1.173	1.290
2010	0.949	1.097	1.259	1.309	1.191	1.173	1.298
2011	0.930	1.099	1.229	1.289	1.155	1.137	1.306
2012	0.938	1.090	1.213	1.245	1.132	1.019	1.300
2013	0.919	1.109	1.237	1.232	1.142	1.082	1.298
2014	0.924	1.099	1.247	1.275	1.138	1.099	1.277
2015	.	1.087	1.276	1.288	1.137	1.127	1.343
2016	.	1.095	1.267	1.321	1.137	1.100	1.360
2017	.	1.125	1.280	1.303	1.113	1.111	1.346
2018	.	.	.	.	1.139	.	1.302
Average Annual Change							
1999–2007	–0.5%	1.0%	2.7%	2.3%	2.0%	1.6%	4.1%
2007–2014	–0.6%	0.3%	0.1%	0.9%	-0.4%	–0.5%	–0.5%
2014–2018*	.	0.8%	0.9%	0.7%	0.0%	0.3%	0.5%
1999–2018*	–0.5%	0.7%	1.4%	1.5%	0.7%	0.6%	1.5%

* Or latest year available. Source: Calculations using Economic Insights GDB database

Table 5.3: Opex PFP indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	.
2000	1.213	1.082	1.068	1.045	1.103	1.108	1.000
2001	1.169	1.190	1.058	1.035	1.132	1.222	1.077
2002	1.270	1.153	1.194	0.984	1.239	1.316	1.320
2003	1.156	1.367	1.348	1.047	1.371	1.333	1.313
2004	1.098	1.281	1.465	1.024	1.498	1.294	1.401
2005	1.168	1.350	1.733	1.382	1.565	1.365	1.708
2006	1.255	1.390	1.715	1.520	1.716	1.370	1.709
2007	1.062	1.452	1.696	1.617	1.723	1.359	1.816
2008	1.102	1.527	1.785	1.930	1.765	1.452	2.021
2009	1.039	1.550	1.777	1.923	1.820	1.476	1.720
2010	1.056	1.541	1.847	2.264	1.883	1.467	1.754
2011	1.035	1.511	1.763	2.140	1.748	1.385	1.793
2012	1.066	1.479	1.755	1.891	1.751	1.040	1.744
2013	1.060	1.562	1.925	1.879	1.765	1.257	1.741
2014	1.096	1.507	1.946	2.132	1.794	1.291	1.662
2015	.	1.502	2.117	2.153	1.853	1.328	1.931
2016	.	1.522	2.020	2.331	1.939	1.228	2.016
2017	.	1.651	2.108	2.169	1.802	1.259	1.967
2018	.	.	.	.	1.908	.	1.778
Average Annual Change							
2000–2007	0.7%	4.8%	6.8%	6.2%	7.0%	3.9%	8.9%
2007–2014	0.5%	0.5%	2.0%	4.0%	0.6%	–0.7%	–1.3%
2014–2018*	.	3.1%	2.7%	0.6%	1.6%	–0.8%	1.7%
1999–2018*	0.6%	2.8%	4.2%	4.4%	3.5%	1.3%	3.3%

* Or latest year available. Source: Calculations using Economic Insights GDB database

Table 5.4: Capital PFP indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	.
2000	0.996	0.932	0.999	1.004	0.991	1.014	1.000
2001	0.984	0.940	1.008	0.998	0.986	1.018	1.012
2002	0.979	0.944	1.002	1.020	0.988	1.008	1.032
2003	0.971	0.939	1.025	1.014	0.991	1.072	1.050
2004	0.956	0.934	1.013	0.995	0.999	1.070	1.061
2005	0.954	0.906	1.009	0.996	0.995	1.069	1.097
2006	0.937	0.905	1.016	1.001	0.996	1.082	1.105
2007	0.900	0.903	0.994	0.995	0.995	1.030	1.117
2008	0.897	0.897	0.991	1.011	0.988	1.041	1.108
2009	0.896	0.893	0.980	1.002	0.991	1.037	1.108
2010	0.886	0.895	0.980	1.002	0.983	1.039	1.107
2011	0.868	0.906	0.967	0.997	0.969	1.019	1.105
2012	0.866	0.905	0.950	0.991	0.943	1.004	1.112
2013	0.843	0.907	0.934	0.979	0.952	0.983	1.110
2014	0.837	0.907	0.940	0.975	0.943	0.992	1.106
2015	.	0.895	0.939	0.984	0.933	1.016	1.117
2016	.	0.900	0.946	0.990	0.922	1.022	1.118
2017	.	0.907	0.944	0.996	0.917	1.024	1.114
2018	.	.	.	.	0.928	.	1.117
Average Annual Change							
2000–2007	–1.3%	–1.3%	–0.1%	–0.1%	-0.1%	0.4%	1.6%
2007–2014	–1.0%	0.1%	–0.8%	–0.3%	-0.8%	–0.5%	–0.1%
2014–2018*	.	0.0%	0.1%	0.7%	-0.4%	1.0%	0.3%
1999–2018*	–1.2%	–0.5%	–0.3%	0.0%	-0.4%	0.1%	0.6%

* Or latest year available. Source: Calculations using Economic Insights GDB database

Table 5.5: Output indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	.
2000	1.016	1.047	1.029	1.018	1.031	1.016	1.000
2001	1.016	1.089	1.051	1.028	1.052	1.022	1.028
2002	1.034	1.109	1.072	1.064	1.078	1.029	1.060
2003	1.046	1.120	1.120	1.086	1.100	1.052	1.094
2004	1.051	1.118	1.132	1.098	1.118	1.059	1.132
2005	1.073	1.137	1.144	1.142	1.135	1.058	1.188
2006	1.086	1.153	1.167	1.175	1.148	1.079	1.219
2007	1.105	1.167	1.222	1.188	1.167	1.096	1.259
2008	1.130	1.181	1.262	1.230	1.186	1.110	1.267
2009	1.153	1.194	1.288	1.254	1.210	1.111	1.285
2010	1.167	1.206	1.320	1.285	1.224	1.124	1.310
2011	1.172	1.234	1.339	1.314	1.247	1.116	1.334
2012	1.188	1.240	1.366	1.361	1.248	1.130	1.368
2013	1.190	1.251	1.378	1.371	1.285	1.127	1.425
2014	1.220	1.273	1.403	1.390	1.302	1.131	1.453
2015	.	1.284	1.441	1.421	1.326	1.152	1.488
2016	.	1.303	1.479	1.446	1.351	1.154	1.517
2017	.	1.329	1.513	1.480	1.366	1.160	1.523
2018	.	.	.	.	1.405	.	1.536
Average Annual Change							
1999–2007	1.3%	1.9%	2.5%	2.2%	1.9%	1.2%	3.3%
2007–2014	1.4%	1.3%	2.0%	2.3%	1.6%	0.4%	2.1%
2014–2018*	.	1.5%	2.5%	2.1%	1.9%	0.8%	1.4%

1999–2018*	1.3%	1.6%	2.3%	2.2%	1.8%	0.8%	2.4%

* Or latest year available. Source: Calculations using Economic Insights GDB database

Table 5.6: Input indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	.
2000	0.942	1.057	0.997	0.996	1.007	0.968	1.000
2001	0.962	1.055	1.019	1.014	1.022	0.938	0.991
2002	0.956	1.084	0.987	1.060	1.016	0.926	0.937
2003	1.004	1.034	0.968	1.055	1.003	0.904	0.959
2004	1.038	1.059	0.954	1.090	0.989	0.921	0.964
2005	1.038	1.078	0.911	1.002	0.994	0.905	0.929
2006	1.038	1.083	0.928	0.996	0.980	0.914	0.948
2007	1.150	1.080	0.990	0.991	0.995	0.963	0.953
2008	1.162	1.078	1.005	0.966	1.010	0.948	0.937
2009	1.214	1.089	1.036	0.993	1.019	0.947	0.996
2010	1.229	1.100	1.049	0.982	1.028	0.958	1.009
2011	1.260	1.123	1.089	1.020	1.079	0.981	1.022
2012	1.266	1.137	1.126	1.093	1.102	1.108	1.053
2013	1.294	1.128	1.115	1.112	1.125	1.041	1.098
2014	1.321	1.158	1.126	1.090	1.143	1.029	1.138
2015	.	1.181	1.129	1.104	1.166	1.022	1.108
2016	.	1.190	1.167	1.094	1.188	1.049	1.116
2017	.	1.182	1.182	1.136	1.227	1.044	1.131
2018	.	.	.	.	1.233	.	1.180
Average Annual Change							
1999–2007	1.8%	1.0%	–0.1%	–0.1%	-0.1%	–0.5%	–0.7%
2007–2014	2.0%	1.0%	1.9%	1.4%	2.0%	1.0%	2.6%
2014–2018	.	0.7%	1.7%	1.4%	1.9%	0.5%	0.9%
1999–2018	1.9%	0.9%	0.9%	0.7%	1.1%	0.2%	0.9%

Source: Calculations using Economic Insights GDB database.

Table 5.7: Opex input indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	
2000	0.838	0.967	0.963	0.974	0.934	0.917	1.000
2001	0.870	0.915	0.994	0.994	0.930	0.837	0.955
2002	0.814	0.962	0.897	1.081	0.870	0.782	0.803
2003	0.905	0.819	0.831	1.037	0.802	0.789	0.833
2004	0.957	0.873	0.772	1.073	0.746	0.819	0.808
2005	0.919	0.842	0.660	0.826	0.725	0.775	0.696
2006	0.866	0.830	0.681	0.773	0.669	0.787	0.713
2007	1.041	0.803	0.721	0.735	0.677	0.807	0.693
2008	1.026	0.773	0.707	0.637	0.672	0.764	0.627
2009	1.110	0.771	0.725	0.652	0.665	0.753	0.747
2010	1.106	0.782	0.715	0.568	0.650	0.766	0.747
2011	1.132	0.816	0.759	0.614	0.713	0.806	0.744
2012	1.114	0.839	0.778	0.720	0.713	1.087	0.784
2013	1.122	0.801	0.716	0.729	0.728	0.896	0.819
2014	1.113	0.844	0.721	0.652	0.726	0.876	0.874
2015	.	0.855	0.681	0.660	0.716	0.868	0.771
2016	.	0.856	0.732	0.620	0.697	0.939	0.752
2017	.	0.805	0.718	0.682	0.758	0.921	0.774
2018	.	.	.	.	0.736	.	0.864
Average Annual Change							
2000–2007	0.5%	–2.7%	–4.0%	–3.8%	-4.8%	–2.6%	–5.1%
2007–2014	1.0%	0.7%	0.0%	–1.7%	1.0%	1.2%	3.4%

2014–2018	.	–1.6%	–0.2%	1.5%	0.4%	1.7%	–0.3%
1999–2018	0.7%	–1.2%	–1.8%	–2.1%	-1.6%	–0.5%	–0.8%

Source: Calculations using Economic Insights GDB database.

Table 5.8: Capital input indexes comparison, 1999–2018

Year	AGN–Qld	AGN–SA	AGN–Vic	AusNet	JGN	Multinet	ATCO
1999	1.000	1.000	1.000	1.000	1.000	1.000	.
2000	1.020	1.123	1.030	1.014	1.040	1.002	1.000
2001	1.032	1.158	1.043	1.031	1.067	1.005	1.016
2002	1.056	1.175	1.070	1.044	1.090	1.021	1.027
2003	1.077	1.193	1.092	1.071	1.110	0.981	1.042
2004	1.099	1.196	1.118	1.103	1.120	0.990	1.067
2005	1.125	1.255	1.134	1.147	1.140	0.990	1.083
2006	1.159	1.275	1.149	1.174	1.153	0.997	1.103
2007	1.228	1.292	1.230	1.194	1.173	1.065	1.127
2008	1.260	1.316	1.273	1.217	1.200	1.066	1.144
2009	1.287	1.337	1.315	1.251	1.221	1.071	1.160
2010	1.317	1.348	1.348	1.283	1.245	1.081	1.183
2011	1.350	1.361	1.385	1.318	1.286	1.095	1.207
2012	1.371	1.370	1.437	1.374	1.323	1.125	1.231
2013	1.412	1.379	1.476	1.400	1.351	1.146	1.284
2014	1.457	1.403	1.493	1.426	1.381	1.140	1.314
2015	.	1.435	1.535	1.444	1.421	1.134	1.332
2016	.	1.448	1.564	1.460	1.465	1.128	1.357
2017	.	1.466	1.603	1.486	1.489	1.132	1.367
2018	.	.	.	.	1.514	.	1.375
Average Annual Change							
2000–2007	2.6%	3.3%	2.6%	2.2%	2.0%	0.8%	1.7%
2007–2014	2.5%	1.2%	2.8%	2.6%	2.4%	1.0%	2.2%
2014–2018	.	1.5%	2.4%	1.4%	2.3%	–0.2%	1.1%
1999–2018	2.5%	2.1%	2.7%	2.2%	2.2%	0.7%	1.8%

Source: Calculations using Economic Insights GDB database.

6 PRODUCTIVITY GROWTH RESULTS

6.1 Multilateral TFP indexes

Traditional measures of TFP such as those discussed in chapter 5 have enabled comparisons to be made of rates of change of productivity between GDBs but have not enabled comparisons to be made of differences in the absolute levels of productivity in combined time series, cross section GDB data. This is due to the failure of conventional TFP measures to satisfy the important technical property of transitivity. This property states that direct comparisons between observations *m* and *n* should be the same as indirect comparisons of *m* and *n* via any intermediate observation *k*.

Caves, Christensen and Diewert (1982) developed the multilateral translog TFP (MTFP) index measure to allow comparisons of the absolute levels as well as growth rates of productivity. It satisfies the technical properties of transitivity and characteristicity which are required to accurately compare TFP levels within panel data. Lawrence, Swan and Zeitsch (1991) and the Bureau of Industry Economics (BIE 1996) have used this index to compare the productivity levels and growth rates of the five major Australian state electricity systems and the United States investor–owned system. Lawrence (2003) and Pacific Economics Group (PEG 2004) also used this index to compare electricity DB TFP levels and Lawrence (2007) used it to compare TFP levels across the three Victorian GDBs. Economic Insights (2009, 2010, 2012b,2014) have used this method in a number of GDB studies.

The multilateral translog index is given by:

$$\begin{aligned}(6.1)\qquad \log(TFP_m/TFP_n) = {} & \Sigma_i (R_{im}+R_i^*)(\log Y_{im} - \log Y_i^*)/2 - \\ & \Sigma_i (R_{in}+R_i^*)(\log Y_{in} - \log Y_i^*)/2 - \\ & \Sigma_j (S_{jm}+S_j^*)(\log X_{jm} - \log X_j^*)/2 + \\ & \Sigma_j (S_{jn}+S_j^*)(\log X_{jn} - \log X_j^*)/2\end{aligned}$$

Where R_i^* (S_j^*) is the revenue (cost) share averaged over all utilities and time periods and $\log Y_i^*$ ($\log X_j^*$) is the average of the log of output *i* (input *j*). In the main application reported in the following section we have three outputs (throughput, customers and system capacity) and, hence, *i* runs from 1 to 3. In the MTFP analysis, transmission assets are not included, and consequently there are 7 inputs (opex, high pressure pipelines, medium pressure pipelines, low pressure pipelines, services pipelines, meters, and other capital) and, hence, *j* runs from 1 to 7. The Y_i and X_j terms are the output and input quantities, respectively. The R_i and S_j terms are the output and input weights, respectively.

The formula in (6.1) gives the proportional change in MTFP between two adjacent observations (denoted *m* and *n*). An index is formed by setting some observation (usually the first in the database) equal to one and then multiplying through by the proportional changes between all subsequent observations in the database to form a full set of indexes. The index for any observation then expresses its productivity level relative to the observation that was set equal to one. However, this is merely an expositional convenience as, given the invariant nature of the comparisons, the result of a comparison between any two observations will be independent of which observation in the database was set equal to one.

This means that when using equation (6.1), comparisons between any two observations *m* and *n* will be both base–distributor and base–year independent. Transitivity is satisfied since comparisons between the two GDBs for 1999 will be the same regardless of whether they are compared directly or via, say, one of the GDBs in 2002. An alternative interpretation of this index is that it compares each observation to a hypothetical average distributor with output vector $log\ Y_i^*$, input vector $log\ X_j^*$, revenue shares R_i^* and cost shares S_j^*.

As noted, transmission assets are excluded in the MTFP analysis in order to facilitate like–for–like comparisons between GDBs, as they tend to have differing amounts of transmission mains depending on the characteristics of the territory they serve and on past decisions relating to vertical separation.

6.2 Productivity levels comparisons

The multilateral TFP indexes for seven GDBs are presented in Table 6.1 and Figure 6.1. For convenience, the indexes are calculated relative to AGN Vic in 1999 having a value of one. These indexes can, of course, be influenced by a number of factors, such as economies of scale, or climate differences (with their influence on demand patterns) which are mostly not controlled for in this comparison although key network density differences are allowed for via the output specification.

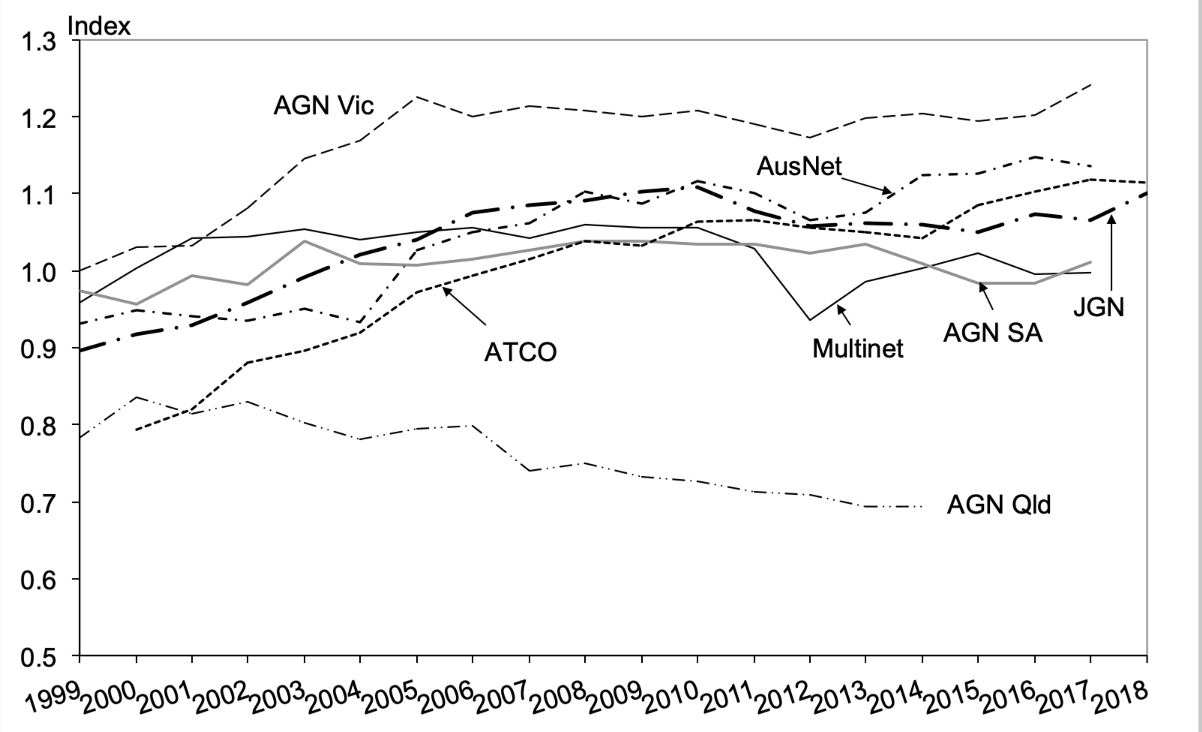
Table 6.1: GDB multilateral TFP indexes, 1999–2018

	AGN Vic	Multinet	AusNet	JGN	AGN SA	AGN Qld	ATCO
1999	1.000	0.959	0.931	0.895	0.973	0.782	.
2000	1.030	1.004	0.950	0.917	0.956	0.836	0.794
2001	1.033	1.043	0.940	0.928	0.994	0.814	0.820
2002	1.081	1.045	0.935	0.958	0.981	0.830	0.881
2003	1.146	1.054	0.950	0.992	1.039	0.803	0.897
2004	1.169	1.040	0.933	1.021	1.009	0.781	0.919
2005	1.225	1.050	1.027	1.041	1.008	0.795	0.972
2006	1.201	1.055	1.050	1.075	1.015	0.799	0.994
2007	1.213	1.043	1.061	1.085	1.027	0.740	1.016
2008	1.209	1.061	1.103	1.091	1.038	0.749	1.038
2009	1.200	1.056	1.088	1.103	1.038	0.731	1.032
2010	1.209	1.055	1.117	1.109	1.035	0.727	1.063
2011	1.191	1.029	1.100	1.078	1.035	0.713	1.065
2012	1.173	0.936	1.067	1.058	1.023	0.710	1.056
2013	1.198	0.986	1.075	1.063	1.035	0.694	1.050
2014	1.204	1.003	1.125	1.060	1.010	0.694	1.043
2015	1.194	1.022	1.127	1.050	0.985	.	1.084
2016	1.203	0.996	1.148	1.073	0.984	.	1.103
2017	1.241	0.998	1.136	1.065	1.011	.	1.118
2018	.	.	.	1.100	.	.	1.115

Source: Calculations using Economic Insights GDB database

The MTFP results indicate that in the latest years available, JGN is found to have a TFP level in the middle of those for the GDBs included, being similar to ATCO and exceeded by AGN Vic and AusNet. JGN's MTFP index in 2018 was 1.100, compared to AGN Vic (1.241 in 2017), AusNet (1.136), ATCO (1.116), Multinet (0.998), AGN SA (1.011), and AGN Qld (0.694 in 2014).

Figure 6.1: GDB multilateral TFP indexes, 1999–2018

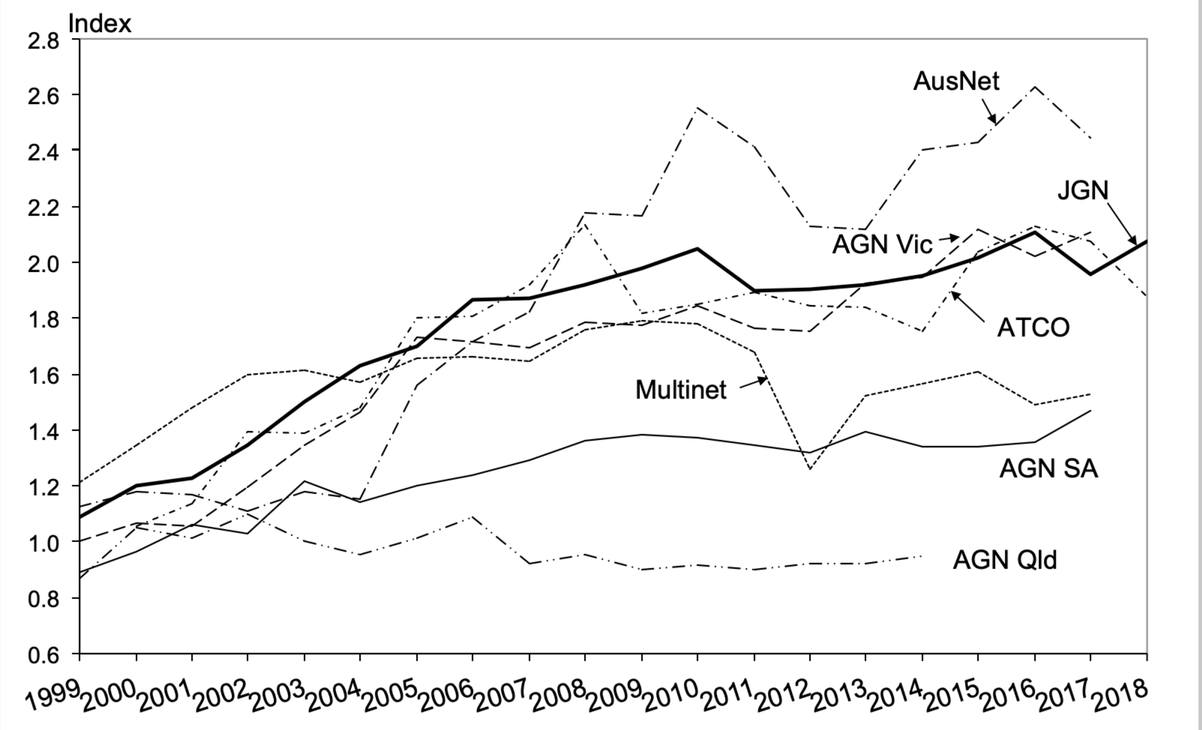


Source: Economic Insights GDB database

Figure 6.2 compares the levels of opex multilateral partial factor productivity (MPFP) for the seven GDBs, and Figure 6.3 compares capital MPFP levels. These indexes are also presented in Tables 6.2 and 6.3, respectively. Figure 6.2 shows that, at the end of the sample period, JGN had the third highest opex MPFP level among the GDBs, exceeded only by AusNet and AGN Vic. JGN's opex MPFP index in 2018 was 2.07, which was similar to AGN Vic opex PFP which was 2.11 in 2017, while AusNet's opex MPFP index was significantly higher at 2.45 in 2017. Those with lower levels of opex MPFP in the latest year include ATCO (1.88), Multinet (1.53), AGN SA (1.47) and AGN Qld (0.95).

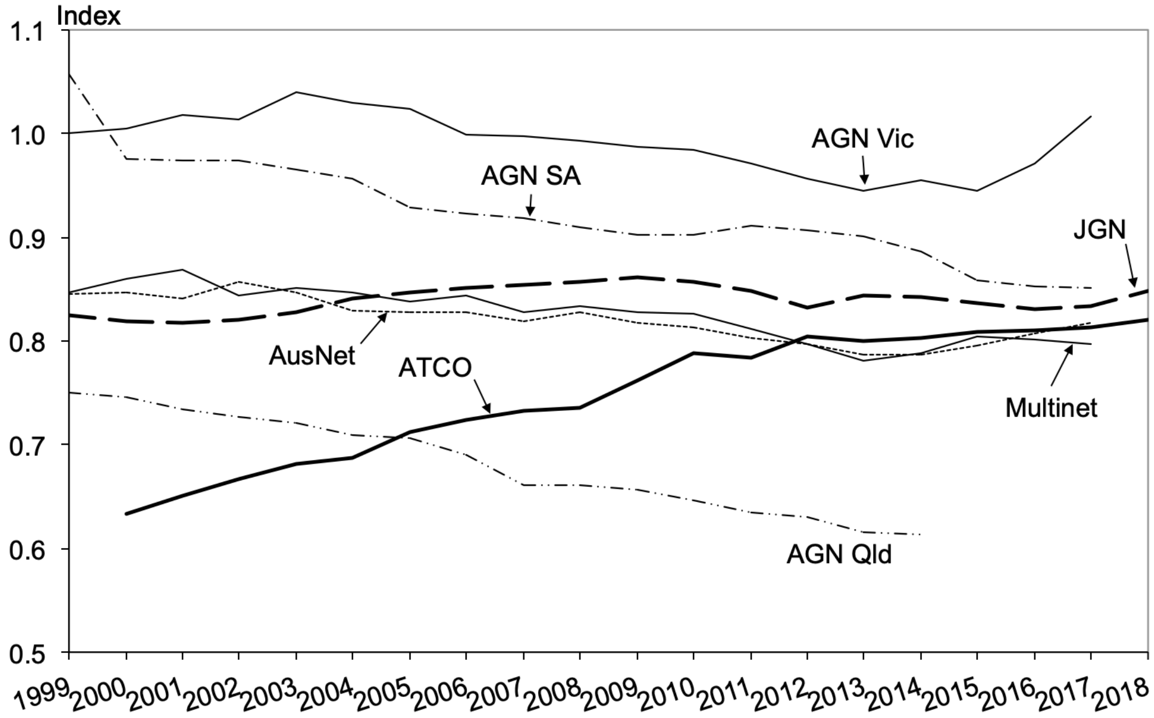
JGN's level of capital MPFP was equal second highest among the GDBs in the sample. JGN's capital MPFP index in 2018 of 0.85 was equal to AGN SA and exceeded only by that of AGN Vic (1.02 in 2017). The GDBs with lower levels of capital MPFP in the latest year available include AusNet and ATCO (both 0.82), Multinet (0.80), and AGN Qld (0.61).

Figure 6.2: GDB multilateral Opex PFP indexes, 1999–2018



Source: Economic Insights GDB database

Figure 6.3: GDB multilateral Capital PFP indexes, 1999–2018



Source: Economic Insights GDB database

Table 6.2: GDB multilateral Opex PFP indexes, 1999–2018

	AGN Vic	Multinet	AusNet	JGN	AGN SA	AGN Qld	ATCO
1999	1.00	1.21	1.13	1.09	0.89	0.87	.
2000	1.07	1.34	1.18	1.20	0.96	1.05	1.06
2001	1.06	1.48	1.17	1.23	1.06	1.01	1.14
2002	1.19	1.60	1.11	1.35	1.03	1.10	1.39
2003	1.35	1.62	1.18	1.50	1.22	1.00	1.39
2004	1.47	1.57	1.15	1.63	1.14	0.95	1.48
2005	1.73	1.66	1.56	1.70	1.20	1.01	1.80
2006	1.71	1.66	1.71	1.87	1.24	1.09	1.80
2007	1.70	1.65	1.82	1.87	1.29	0.92	1.92
2008	1.78	1.76	2.18	1.92	1.36	0.96	2.13
2009	1.78	1.79	2.17	1.98	1.38	0.90	1.82
2010	1.85	1.78	2.55	2.05	1.37	0.92	1.85
2011	1.76	1.68	2.41	1.90	1.35	0.90	1.89
2012	1.75	1.26	2.13	1.90	1.32	0.92	1.84
2013	1.93	1.53	2.12	1.92	1.39	0.92	1.84
2014	1.95	1.57	2.40	1.95	1.34	0.95	1.76
2015	2.12	1.61	2.43	2.01	1.34	.	2.04
2016	2.02	1.49	2.63	2.11	1.36	.	2.13
2017	2.11	1.53	2.45	1.96	1.47	.	2.08
2018	.	.	.	2.07	.	.	1.88

Source: Calculations using Economic Insights GDB database

Table 6.3: GDB multilateral Capital PFP indexes, 1999–2018

	AGN Vic	Multinet	AusNet	JGN	AGN SA	AGN Qld	ATCO
1999	1.00	0.85	0.84	0.83	1.06	0.75	.
2000	1.00	0.86	0.85	0.82	0.98	0.75	0.63
2001	1.02	0.87	0.84	0.82	0.97	0.73	0.65
2002	1.01	0.84	0.86	0.82	0.97	0.73	0.67
2003	1.04	0.85	0.85	0.83	0.97	0.72	0.68
2004	1.03	0.85	0.83	0.84	0.96	0.71	0.69
2005	1.02	0.84	0.83	0.85	0.93	0.71	0.71
2006	1.00	0.84	0.83	0.85	0.92	0.69	0.72
2007	1.00	0.83	0.82	0.85	0.92	0.66	0.73
2008	0.99	0.83	0.83	0.86	0.91	0.66	0.74
2009	0.99	0.83	0.82	0.86	0.90	0.66	0.76
2010	0.98	0.83	0.81	0.86	0.90	0.65	0.79
2011	0.97	0.81	0.80	0.85	0.91	0.63	0.78
2012	0.96	0.80	0.80	0.83	0.91	0.63	0.80
2013	0.94	0.78	0.79	0.84	0.90	0.62	0.80
2014	0.96	0.79	0.79	0.84	0.89	0.61	0.80
2015	0.95	0.80	0.80	0.84	0.86	.	0.81
2016	0.97	0.80	0.81	0.83	0.85	.	0.81
2017	1.02	0.80	0.82	0.83	0.85	.	0.81
2018	.	.	.	0.85	.	.	0.82

Source: Calculations using Economic Insights GDB database

6.3 Summary Conclusions

The MTFP index is used to measure comparative productivity *levels*. The MTFP results indicate that in the latest year available, JGN was among those GDBs with comparatively higher levels of TFP. JGN's MTFP index in 2018 was 1.100, which was less than AGN Vic (1.241 in 2017) and AusNet (1.136 in 2017), and similar to ATCO (1.116 in 2018); it was higher than those of Multinet (0.998), AGN SA (1.012), and AGN Qld (0.694).

JGN's level of opex MPFP in 2018 (2.07) was also among the highest for the latest available years of the GDBs included in the study. It was lower than that of AusNet (2.45) and AGN Vic (2.11); and higher than those of ATCO (1.88), Multinet (1.53), AGN SA (1.47) and AGN Qld (0.95). JGN's capital MPFP index in 2018 of 0.85 was equal second highest for the latest available years among the GDBs. It was equal to AGN SA (0.85) and exceeded only by that of AGN Vic (1.02 in 2017); and it was higher than those of AusNet and ATCO (both 0.82), Multinet (0.80), and AGN Qld (0.61).

The MTFP and MPFP analyses indicate that JGN is a relatively efficient performer in its use of both opex and capital inputs.

PART C: ECONOMETRIC COST FUNCTION ANALYSIS

In this part of the report, we estimate the opex cost function for gas distribution businesses. The principal aims of the analysis are to estimate trends in technical efficiency in the industry and estimate the opex efficiency of JGN relative to other GDBs. The econometric results are used to establish whether JGN is efficient in its use of opex inputs, and also to estimate parameters that can be used when forecasting JGN's opex rate of change (which is equal to the rate of opex price growth plus the rate of output growth minus the opex partial productivity growth rate) for the period 2020-21 to 2024-25. These parameters include the average historical rate of frontier shift (or technical change) and the appropriate weights for constructing the output index.

Cost function analysis of gas network businesses has a long history. In the United States, Barcella (1992) estimated the cost function of gas distribution businesses based on a sample of 50 companies over the period 1969-1988. In the context of Australia and New Zealand, Pacific Economics Group (2001a, 2001b, 2001c) evaluated the opex performance of the three Victorian GDBs relative to that of US gas distribution utilities by estimating an econometric cost function model that explained the effect on a company's gas distribution cost of some measurable 'business conditions'. The parameters of the model were estimated using data from a large sample of American investor–owned gas distribution utilities. The model was used to predict opex for the Australian utilities given the values for the (included) business conditions that the utilities faced. The business condition variables included input prices, the amount of outputs supplied and certain characteristics of the customer base and service territory. The model therefore controlled, among other things, for differences in realised scale economies. Cost performance was evaluated by comparing the Australian utilities' actual opex with those predicted by the model for an average US utility facing similar business conditions.

Economic Insights (2012a) used econometric analyses of the total and opex cost functions for gas distribution businesses to assess the comparative efficiency of SP AusNet. This analysis was based on a sample of 9 Australian GDBs and 2 New Zealand GDBs using data sourced from the public domain to the maximum extent possible. Total cost function analysis takes into account opex and capital input trade–offs, price effects and controls for certain operating environment factors in the analysis of comparative cost efficiency. The study also developed econometric estimates of the variable or operating cost function and the parameters of this function were combined with forecasts of output and capital input levels to forecast SP AusNet's future GDB opex partial productivity growth rates. Such forecasts are used in the 'rate of change' formula for rolling forward opex allowances often used in the application of building blocks regulation.

Economic Insights (2015a) estimated an econometric variable cost function for Australian and New Zealand gas networks on behalf of Jemena Gas Networks. The econometric analysis utilised both stochastic frontier and feasible generalized least squares methods, and the models were used for both efficiency benchmarking and forecasting opex partial productivity. The two outputs used in that study were customer numbers and gas throughput. Customer density was also an important explanatory variable, measured by customer numbers per kilometre (km) of mains. Real opex was found to be negatively related to customer density, which implies a positive relationship between network length and real opex.

In a subsequent econometric study for Multinet Gas, Economic Insights (2016c) estimated the relationship between gas network real operating costs ('opex') and outputs, fixed capital inputs and operating environment factors. The aim of that study was to ascertain the most significant output measures as determinants of opex and to quantify the elasticities of real opex with respect to each of the outputs. The study used a database that included 11 Australian and 3 New Zealand gas distribution businesses (GDBs). The study used stochastic frontier (SF) and random effects (RE) methods. The study concluded that gas throughput is not a statistically significant determinant of real opex; whereas customer numbers and network length were both found to be statistically significant determinants of real opex.

The analysis in this part of the report is similar to those previously undertaken by Economic Insights in 2015 and 2016. This study uses additional data available since the 2016 study was undertaken. It tests specifications developed in those previous studies and tests alternative specifications generally based on the translog variable cost function specification, and simplifications of it. Alternative stochastic specifications are also examined.

To ensure comparability with earlier studies and to ensure that the sample is as large and broad as possible, this econometric study uses a database that includes 11 Australian and 3 New Zealand gas distribution businesses (GDBs). The data has two main sources. For 5 Australian GDBs the data was provided by the businesses in response to surveys prepared by Economic Insights. These GDBs include Australian Gas Networks (AGN) South Australia (SA), AGN Victoria, Multinet, AusNet Services and JGN. Data for the other GDBs in the sample was sourced from documents in the public domain. The sample periods differ between utilities, but in most cases includes historical data for the period from 1999 to 2017. In a relatively small number of cases, forecast data from final regulatory determinations are also included, primarily because several of the smaller GDBs in the sample are no longer subject to price regulation, and up-to-date statistical information is no longer available for them. The data includes revenue, throughput, customer numbers, distribution pipeline length, opex, capex and regulatory asset value. In some cases missing observations were estimated based on growth rates for the variable or a related variable before and after the missing year. The database includes a total of 252 observations. This sample is larger than those available for previous econometric studies of the gas industry undertaken by Economic Insights.

7 CONTEXT, DATA & METHODOLOGY

Section 7.1 discusses the context relevant to the applications of the study. In section 7.2 the variable or opex cost function is introduced and the considerations relating to choosing the initial set of variables to be used in the analysis is discussed. The data used in the study is described in section 7.3. The approaches used to develop the functional form and the stochastic specifications are discussed in section 7.4, and section 7.5 discusses the method of employing the model in opex cost function analysis.

7.1 Regulatory Context

This study is directed to informing some of the requirements of JGN and the procedures of the Australian Energy Regulator (AER) under the gas industry regulatory framework. The AER has described its approach to forecasting opex in electricity network regulation in its *Expenditure Forecast Assessment Guideline 2013* and *Forecasting Productivity Growth 2019* (AER 2013b, 2019). The same principles are assumed to apply in gas distribution network regulation. The AER uses a 'base-step-trend' method for assessing businesses' opex proposals and forming its own view of the efficient future opex allowance for regulated energy distribution network service providers (DNSPs). This method involves estimating the efficient opex for a base year, at the end of the previous regulatory period, and projecting it forward for each year of the forthcoming regulatory period using forecasts for the rates of change in opex input prices, outputs and a relevant measure of opex productivity. Further adjustments, termed 'step changes', may be made to reflect any changes in DNSP responsibilities during the forthcoming regulatory period.

Productivity is taken into account in two different ways in the base-step-trend method. Firstly, the AER takes any *material inefficiency* of a DNSP into account when determining the base-year efficient opex. "When assessing a distributor's opex proposal we compare the distributor's productivity performance against that of the frontier to determine the distributor's efficiency in operating its network business" (AER 2018, 5). This adjustment reflects an allowance for 'catch up' to the efficiency frontier. It may only be a partial adjustment to remove inefficiency because the incentive features of the regulatory framework (including carry-over of efficiencies to later periods) may be relied on to ensure any remaining inefficiencies are removed over the prospective regulatory period.

Secondly, forecast *productivity growth* is one component of the calculation of the rate of change formula. In calculating the rate of change, productivity growth is measured as "the shift in the productivity frontier. It is not intended to include any 'catch up' to the frontier for a distributor that is materially inefficient." (AER 2018, 5) This productivity growth forecast is to be based on that which can be achieved by the best performing (ie, 'frontier') businesses. The AER's expectation is that "an efficient and prudent distributor should achieve the same level of productivity growth as the frontier distributors." (AER 2018, 5)

This study provides information directly relevant to both of these productivity-related questions. That is, whether JGN is estimated to have any material inefficiency in the latest periods for which data is available, and the historical rate of productivity growth associated with shift in the productivity frontier. The AER has noted that an estimate of the average rate of technological change over a past period need not be representative of future trends, and other information may need to be taken into account to reach an overall assessment.

The rate of change formula used for projecting opex forward over the next regulatory period also relies on estimates of the rates of change of an index of the relevant outputs and of an index of relevant input prices. Constructing an output index involves defining the relevant outputs and deriving appropriate weights for each output. Forecasts of the individual outputs are part of the set of forecasts developed by the DNSP for the purposes of its access arrangement (AA). From among these are chosen the most relevant output measures, and the weights are used to aggregate the relevant forecasts into an output index projected over the forthcoming regulatory period. The procedure for constructing the opex input price index relies heavily on estimating the split between labour and non-labour components of opex. These weights are used to construct the opex input price index from forecasts of labour and non-labour price movements. This study addresses three questions relating to the forecast of the rates of change of outputs and input prices:

- The choice of outputs to be used in the output index;
- The weights to be used in the output index; and
- The weights to be used in the input price index.

7.2 Variable Cost Function and Choice of Variables

The variable cost function is the variable cost part of the short-run cost function (i.e. excluding fixed costs), and the short run cost function is the minimum cost of producing a given set of outputs subject to the constraint that in the short-run some input or set of inputs is fixed. The variable cost function is a function in which a GDB's variable cost is dependent on the quantities of the outputs produced, the input prices of the variable inputs, and the quantities of the fixed inputs. The functional relationship between these explanatory variables and variable cost reflects the technology available and used in the industry. Differences in the operating environment characteristics of the distinct localities in which the utilities operate can influence the technology — i.e. the ability of an efficient firm to translate inputs into outputs.

Developing a model for a variable cost function involves:

- Deciding on the outputs and inputs, including those that are fixed and those that are variable, and identifying the operating environment variables, and determining how these quantities and input prices are to be measured.
- Specifying the functional form of the variable cost function and the stochastic specification of the model, which is essential to the inferences drawn from the model.

Our general approach to choosing the variables is to begin with those variables used in the econometric studies of gas DNSP opex costs that Economic Insights carried out in 2015 and 2016. The strategy is then to consider variations to those studies and determine those that improve the modelling, given the current dataset. The variables considered are generally consistent with other benchmarking studies of energy networks.

In the 2015 study there were two outputs; gas deliveries (TJ); and customer numbers (both in log form). A measure of capital inputs was included — the constant price asset value. Other explanatory variables included a measure of customer density based on customers per km mains (again in log form). Hence customer numbers entered into the model both directly, and as a ratio to network length. In the 2016 study we relaxed the specification to some extent, with (the logs of) customer numbers and network length entering the model as two separate variables (rather than as a ratio). In that analysis we found gas throughput was not statistically significant under that specification. That study also included a measure of the load factor (ie, average daily demand divided by the maximum daily demand (MDQ) for each network in each year), which was a statistically significant variable. Operating environment variables used or tested in these studies included: (i) the proportion of the network not made of cast iron or unprotected steel; (ii) the number of city gates; and (iii) tariff class customer share of total gas throughput (all in log form).

In this study the following variables are used or tested. The dependent variable used throughout the analysis is constant price opex (in 2010$). The annual rate of technological change is measured by the coefficient on a variable that measures time in years. The candidate outputs tested in the analysis are: customer numbers; gas deliveries (TJ); maximum daily quantity (MDQ); and network length (km). MDQ is a product of the load factor and the average daily deliveries (TJ), and therefore combines two of the variables previously used into an output measure that is alternative to gas deliveries.

The candidate measures of fixed capital inputs are: the constant price asset value (in 2010$); network length (km); and a geometric average of those two measures. Only the models using constant price asset value are reported here, although the models that include network length as an output and constant price asset value as a measure of capital inputs have a formal similarity to the models which use some form of average of two capital input measures (when the weights are endogenous).

The candidate operating environment factors were those used in one or both of the previous studies:

- Load factor (average TJ per day / MDQ)
- Proportion of total mains length not made of cast iron or unprotected steel (proxy for network age)
- Number of city gates (proxy for service area dispersion)
- Tariff customer-class gas volumes / total gas volumes.

Data for the outputs and inputs are reasonably complete in the dataset, although in some instances missing observations were estimated based on growth rates for the variable or a related variable before and after the missing year. In a number of cases adjustments were made to ensure the data related to comparable activities and measures (eg, unaccounted for gas allowances for non–Victorian GDBs have been excluded to put those GDBs on a comparable basis with Victorian reporting). Data coverage of some of the business environment variables is less complete — especially with regard to load factors for Victorian GDBs. Interpolation or extrapolation are used where necessary. While every effort has been made to make the publicly available data used in this study as consistent as possible, the limitations of currently available public domain data need to be recognised. For some of the small GDBs that are no longer regulated, the latest available regulatory forecasts are used due to lack of reported data in recent years. There may be somewhat different coverage of activities and definitions of variables reported between GDBs or over time where regulators have changed reporting requirements.

7.3 Data

The analysis makes use of the Economic Insights dataset for Australian and New Zealand gas distribution businesses, which includes the following gas distribution businesses (GDBs):

- in Australia: AGN Albury, AGN Vic, Multinet, AusNet, AGN SA, AGN Qld, Allgas, AGN Wagga, Jemena, Evoenergy, ATCO; and
- in New Zealand: Powerco, Vector and GasNet.

All of these GDBs are included in the sample in this part of the study.[10] Details of the sample are shown in Table B.1 in Appendix B. The data represents yearly observations, and GDBs differ in whether their reporting years end in June or December, or in one case, September. Some have changed their reporting years during the period studied. Overall, there are 252 observations, or approximately 18 observations per GDB on average. Data for most of the Australian GDBs in the study are available for the period from 1999 or 2000 to 2017 or 2018. However, there are fewer consistent observations available for the New Zealand GDBs, reflecting the impact of mergers, asset sales and industry restructuring. Some of the smallest Australian GDBs are no longer subject to price regulation, and the data for these GDBs are supplemented by regulator forecasts.

The data for AGN Vic, AusNet, AGN SA, Jemena and Multinet Gas are drawn from confidential survey data provided by those businesses for the purposes of productivity analysis. Two years of survey data is used for AGN Qld also. All of the remaining data has been sourced from public documents such as regulator final decisions, Assess Arrangement Information, asset management plans, statutory information disclosure and/or company Annual Reports. The public domain data source used for the New Zealand GDBs is the Information Disclosure Data filings required by the Gas (Information Disclosure) Regulations 1997. For Australian GDBs, we have used the final approval information, where possible, as we consider that it is the most consistent and objective source of information available. In some cases the data represents official forecasts made by regulators. As detailed in Table B.1 (Appendix B), they represent only a small proportion of the observations.

The data used for the Australian GDBs covers only their regulated activities. Data relating to large industrial users whose supply is not regulated are not included. Inclusion of this data would require access to information not generally in the public domain and has been beyond the scope and timeframe of this study.

All cost data were first converted to nominal terms (where necessary) using the All Groups Consumer Price Index in Australia and the equivalent in New Zealand. The nominal series were then converted to real series in (calendar year) 2010 dollars using the same price indexes. The New Zealand data were then converted to Australian dollars using the OECD (2014) purchasing power parity for 2010. Purchasing power parities are the rates of currency conversion that eliminate differences in international price levels and are commonly used to make comparisons of real variables between countries.

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[10] In Part A, GasNet was excluded due to its small size.

7.4 Model specification

The functional specifications of the models tested in this study are discussed in section 7.4.1. The stochastic specifications are discussed in section 7.4.2.

7.4.1 Functional specification

The functional specification used here is generally based on the translog variable cost function, in which the variables are in log form. The exogenous variables enter the model directly as well as through interaction and higher-order terms (together 'second-order effects'). The model includes variables that represent different operating environment characteristics of utilities. In most models (an exception is the study for JGN in 2015) they are only included as direct effects without higher-order effects. The reason is that these variables tend not to have a large enough impact to warrant the inclusion of higher-order effects. A linear approximation to their effect is sufficient.

It is assumed there are only two inputs: capital inputs, which are fixed in the short-run cost function; and noncapital inputs, which are variable. Hence there is only one variable input price. Since the short-run variable cost function is linearly homogenous in the variable input prices, when there is only one variable input, this implies that variable cost (*VC*) is proportionate to the noncapital input price (*W*). The translog variable cost (*VC*) function in this case has the following form:

$$\begin{aligned}(7.1)\qquad \ln VC &= a_0 + \ln W + c_1 \ln K + \sum_j \theta_j \ln Y_j + \sum_h a_h \ln Z_h + c_2 (\ln K)^2 \\ &+ \frac{1}{2}\sum_j \sum_k \theta_{jk} \ln Y_j \ln Y_k + \sum_j g_{Yj} \ln Y_j \ln K + a_t t + \varpi\end{aligned}$$

where:

- Y_j and Y_k are the quantities of outputs *j* and *k*; where *j,k* = 1, 2, … *J*;
- *K* is a service flow measure of fixed capital;[11]
- Z_h are operating environment factors *h*; where *h* = 1, 2, …*H*;
- *t* is a measure of time and reflects the principle that, all else unchanged, costs decrease marginally each year due to technical change; and
- ϖ is a stochastic term that reflects the combined influence of all other influences on variable cost, including inefficiency.

Regularity conditions derived from economic theory imply symmetry of certain parameters

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[11] This refers to the annual capital input quantity. Due to its durable nature, capital has two distinct economic characteristics, as a source of capital services in production and as a store of wealth. Measures of these characteristics will often be different, and the appropriate measure depends on the analytical context. Wealth measures of capital are more commonly available, and in some circumstances may be used as a proxy measure of capital services (as is the case in this study).

or interaction terms (specifically, $\theta_{jk} = \theta_{kj}$), which reduces the number of parameters to be estimated. The second-order terms can give rise to a large number of parameters to be estimated, which can give rise to multicollinearity, and affect the precision of the estimates of the coefficients. Hence, the precision of estimates of parameters of interest may be improved by reducing the model to a more parsimonious form. This can be carried out using a transparent set of criteria for iterative model simplification, but such procedures are not without shortcomings in the presence of multicollinearity. It is also common practice to impose *a priori* restrictions on functional specification to reduce the size of the model and to simplify the specification search. For example, the previously mentioned restriction on how the operating environment variables enter the model. A common approach in this context is to compare the translog specification against the simpler Cobb-Douglas specification, in which all of the second-order effects are removed.

The main model specifications tested in this study are variations on (1). Firstly, there is the specification used in the 2015 study for JGN, where:

(a) there were two outputs: customer numbers and gas deliveries (TJ), and higher-order effects for these outputs (i.e. the parameters θ_{jk} in equation (1)) were included for outputs;

(b) the measure of capital inputs was the real asset value and no higher-order effects were included for this variable (i.e. the restrictions, $c_2 = 0$ and $g_{Yj} = 0$ in equation (1));

(c) the operating environment variables included the proportion of total mains length not made of cast iron or unprotected steel; the number of city gates; and customer density (for which a quadratic term was also included).

Secondly, there is the specification used in the 2016 study for Multinet, which included three outputs: customer numbers, gas deliveries, and mains length. The same measure of capital inputs was used as before, and no higher-order effects were included for the outputs or for capital inputs ((i.e. the additional restriction that $\theta_{jk} = 0$ in equation (1)). The operating environment variables did not include customer density but included two additional variables: load factor and tariff customer-class gas volumes as a proportion of total gas volumes.

Third, we also test a specification used by ACIL-Allen, which has only one output (customer numbers), the same capital inputs measure, and one operating environment factor (customer density). Most of the remaining models we test are based on equation (1) with varying degrees of restriction on the higher-order terms, and where: there are two outputs: customer numbers and mains length (km); the measure of capital inputs is again the real asset value; and the operating environment variables include the proportion of total mains length not made of cast iron or unprotected steel; the number of city gates; and tariff customer-class gas volumes as a proportion of total gas volumes.

7.4.2 Stochastic specifications

The stochastic specification is another important aspect of the theoretical model underlying the econometric specification. Two of the issues to consider are the possibility that some businesses are not fully efficient, and also the possibility of 'unobserved heterogeneity' among the businesses in the sample.

Inefficiency: A cost function represents the minimum cost that a business can achieve with given technology, input prices and the levels of outputs. In theory the minimum cost is an ideal or frontier, which may not be realised by all businesses, and businesses may differ in the degree to which they minimise cost. That is, they may differ in their degrees of efficiency, and the measurement of their differing degrees of efficiency is one objective of the analysis.

Unobserved heterogeneity: Although the explanatory variables of the model ideally represent all of the important determinants of variable cost, there will always be a range of lesser determinants that affect technology (i.e. the ability of a best-practice GDB to transform inputs into outputs), some of which cannot be explicitly taken into account (eg, because they are not readily measurable or data is not available). Influences of this kind can give rise to "unobserved heterogeneity' between the businesses in the sample, and can affect measures of inefficiency.

The stochastic specifications discussed in this section differ in terms of which of these effects they seek to measure and how they do so. The approaches used in this study are stochastic frontier (SF) analysis and feasible generalized least squares (FGLS). Stochastic frontier models seek to identify an efficient frontier, based on best practice among the firms in the sample, and each firm may be closer or further from the frontier, hence there is a firm-specific inefficiency. The FGLS model does not separate firm-specific inefficiency from other sources of stochastic error, although it does permit standard errors to vary between GDBs. It is a useful comparator to the SF results. These two estimation methodologies were used in the study undertaken for JGN in 2015.

In what is perhaps the most standard stochastic frontier (SF) model, the stochastic specification is:

$$\begin{aligned} &\varpi_{it} = u_{it} + \varepsilon_{it} \\ &u_{it} = u_i G(t) \\ &u_i \sim N^+(\mu, \sigma_v^2) \\ &\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \end{aligned} \tag{7.2}$$

where: ε_{it} is a normally distributed random variable which has a unique value for each observation; u_{it} is interpreted as a measure of the inefficiency of GDB i relative to the efficient frontier (ie, best practice) in period t; u_i is a strictly positive random variable which, as shown, has a truncated normal distribution with mean μ, and has a unique value for each GDB; and $G(t)$ is some function of time, which represents a time pattern of inefficiency common to all GDBs. In the time invariant inefficiency model: $G(t) = 1$, and when the inefficiency effects are assumed to have a half-normal distribution: $\mu = 0$. Absent very large datasets, restrictions of this kind are often desirable to keep the models computationally tractable and to gain better precision on the effects of interest. The assumptions of time-invariant and half-normally distributed inefficiency are used throughout this analysis.

A number of more flexible and more complicated SF specifications are available, most of which involve either: (i) different distributions adopted for u_i; (ii) allowing the parameters μ, σ_v^2 and σ_ε^2 to be functions of the same or other exogenous factors; or (iii) various alternative functional forms for $G(t)$ (Kumbhakar, Wang, and Horncastle 2015). Beyond the simpler of these extensions, and absent large datasets, extensions of this kind can be difficult to implement satisfactorily. Hence, the reliance on a simple formulation of the SF model in this study.

The FGLS estimator allows for heteroscedastic panels, but does not provide estimates of the comparative efficiency of the GDBs. Here:

(7.3)
$$\varpi_{it} = \varepsilon_{it}$$
$$\varepsilon_{it} \sim N(0, \sigma_{\varepsilon i}^2)$$

The random error term has zero mean across the whole sample, and $\sigma_{\varepsilon i}^2$ is a different variance for each panel of the dataset, meaning the variance matrix of the disturbance terms has the form:

(7.4)
$$\mathrm{E}[\boldsymbol{\varepsilon} \cdot \boldsymbol{\varepsilon}'] = \begin{bmatrix} \sigma_1^2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_n^2 \end{bmatrix}$$

for panels 1 to *n*. This assumption is appropriate in this context because there is wide variation in the sizes of the GDBs in the sample, so the dependent variables, and some of the explanators, are of different orders of magnitude for some GDBs compared to others. So it is reasonable to expect the scale of the variances may also differ.

We report, and combine, the results from both the FGLS and SFA methods because each has different assumptions regarding the nature of the stochastic disturbance term assumed when estimating the model. Each has particular advantages that are appropriate to this application. The elasticities used from the models as simple averages of the elasticity estimates from each model. The SFA model is used to provide estimates of the technical efficiency of each GDB in the sample.

7.5 Using the econometric opex function

This section discusses how the econometric analysis can be applied within the 'base-step-trend' regulatory framework for projecting rates of change in productivity. In our 2015 report prepared for JGN, (Economic Insights 2015a, ch. 5) the short-run or opex cost function (combining equations (5.2) and (5.3) of that report) was expressed generically as:

(7.5)
$$C^{OM} = g(Y, W, K, Z, T).\eta$$

where: C^{OM} is real opex; *Y* represents the set of outputs; *W* is an index of the real opex input prices; *K* is fixed capital inputs; *Z* is a set of operating environment variables; *T* is time; and η is an inefficiency factor specific to each business ($\eta = 1$ for an efficient business, and $\eta > 1$ for an inefficient business). Efficiency benchmarking of the businesses in the sample, used to inform base-year efficiency adjustments, is based on the estimated values of the cost inefficiency, η, for each business.

The rate of change of opex requires a decomposition of the sources of changes in opex. The components of the rate of change in costs is shown in equation (5.6) of the 2015 report; reproduced below as equation (7.6) (except here only including a single capital input). This shows how the growth rate of real opex is related to the independent variables.

(7.6) $$\dot{C}^{OM} = \sum\nolimits_i \varepsilon_{Yi}\dot{Y}_i + \dot{W} + \varepsilon_K \dot{K} + \sum\nolimits_n \varepsilon_{Zn}\dot{Z}_n + \dot{g} + \dot{\eta}$$

where the dot over a variable represents the variable's growth rate, and the ε coefficients are elasticities of opex cost with respect to the variable. If equation (5) is estimated using a log-log form, then these elasticities are the partial derivatives of the dependent variable with respect to the relevant exogenous variable. In (7.6): $\dot{g}$ is the shift in the cost frontier over time (ie, technical change); and $\dot{\eta}$ is the growth rate of the inefficiency factor (ie, catch-up to the frontier). Equation (7.6) is a method for decomposing the sources of change in opex using the econometrically estimated parameters (the ε's, $\dot{g}$, and $\dot{\eta}$). For the purpose of forecasting technical change, $\dot{g}$ is the relevant measure of frontier shift over the sample period. The other main drivers of opex growth are: the growth rate of real input prices ($\dot{W}$); and the growth rates of outputs ($\dot{Y}_i$) and capital inputs ($\dot{K}$). The rate of change in opex is also influenced by the interaction between output growth and economies-of-scale,[12] and by the combined effect of changes in the operating environment variables. These effects are generally small.

Forecasting opex requires forecasts of the growth rates of outputs and fixed capital inputs, defined consistently with the model. These forecasts will, of course, be the same as the demand and customer forecasts, and the capital inputs forecasts, used by JGN in its proposed access arrangement. The definitions of outputs and capital inputs used for opex forecasting need to be the same as those used in the econometric model if the productivity forecast is to be consistent.(AER 2013b, 23)

Formula (7.6) can be related to the AER's rate of change formula:

(7.7) $$\delta_t = \dot{Y}_t + \dot{W}_t - \dot{\rho}_t$$

where δ_t is the rate of change applied to opex in year *t* of the regulatory period; $\dot{Y}_t$ is the growth rate of output in the same year; $\dot{W}_t$ is the rate of change in real input prices; and $\dot{\rho}_t$ is the rate of change in a relevant measure of productivity. The type of productivity measure used by the AER is discussed below.

In our 2015 report for JGN we rearranged (7.6) as:

(7.8) $$\dot{C}_t^{OM} = \dot{Y}_t + \dot{W}_t - P\dot{F}P_t^{OM}$$

where: $$\dot{Y} = \left(\sum\nolimits_i \varepsilon_{Yi}\dot{Y}_i\right) \Big/ \left(\sum\nolimits_i \varepsilon_{Yi}\right)$$

and: $$P\dot{F}P^{OM} = \left(1 - \sum\nolimits_i \varepsilon_{Yi}\right)\dot{Y} - \varepsilon_K \dot{K} - \sum\nolimits_n \varepsilon_{Zn}\dot{Z}_n - \dot{g} - \dot{\eta}$$

Hence the rate of change in opex PFP depends on the effects of: economies or diseconomies of scale; changes in the capital stock; changes in the business environment variables; frontier shift (ie, technical change); and catch-up to the frontier.

However, this is *not* the relevant measure of productivity used by the AER in calculating the rate of change in its recent guidance and decisions relevant to gas distribution access arrangements. Firstly, the AER expressly does not include any effect of catch-up to the

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[12] In equation (2), if $\sum_i \varepsilon_{Yi} < 1$, then there are economies of scale.

frontier ($\dot{\eta}$): "Since we consider the scope for catch-up productivity as part of our assessment of an individual distributor's base opex, the productivity growth factor that we use in trending forward base opex should only capture the productivity growth that would be achieved by a distributor on the efficiency frontier."(AER 2019, 8) In addition to addressing any material inefficiencies via an adjustment to the base year opex, there is a reliance on the incentive features of the regulatory framework to ensure any remaining inefficiencies are removed over the prospective regulatory period(s). Secondly, the AER has emphasised that its primary focus is on the shift in the cost frontier over time ($\dot{g}$): "Our forecast of productivity growth represents our best estimate of the shift in the industry 'efficiency frontier'" (AER 2017, 7–13). Consistent with this statement, the method used in the Multinet decision was to use the estimated rate of technical change over time as the relevant measure of productivity (AER 2017, 7–21). The AER has also said that "for opex, we rely on the efficiency incentives created by both revenue or price-cap regulation and the efficiency carryover mechanism" (AER 2017, 7–9).

The foregoing AER decisions and guidance statements tend to suggest that, for the purpose of making opex rate of change projections, the productivity component of those projections which the AER proposes to rely on are focused on the rate of technical change as the relevant measure of productivity in the rate of change calculations. Hence, for the purposes of this part of the study it has been assumed that this is the method that the AER will again adopt.

8 MODELLING AND RESULTS

The preliminary analysis for identifying the preferred specification is set out in Appendix D. This section presents the preferred model. A conclusion is that a simple model specification, which has no second-order effects, is preferred to the specifications that include second-order effects. This is consistent with the findings of our study for Multinet in 2016 and is likely to reflect the still relatively small size of the available GDB sample. In the Multinet study, gas throughput was found to be insignificant as an output. In this study, the preferred model is similar to that derived in the Multinet study, with the main difference being the removal of the gas throughput variable.

8.1 Econometric Results

The analysis presented in Appendix D compares alternative specifications and derives a preferred model which has the following variables:

(1) *Outputs*: Customer numbers and Mains length (km);

(2) *Fixed capital*: real value of the regulatory asset base

(3) *Time trend*

(4) *Operating environment variables*:

   a. proportion of mains not cast iron or unprotected steel;

   b. number of city gates; and

   c. tariff class customer share of total gas throughput.

The Cobb-Douglas functional specification (with no second-order effects) is considered to be the best of the functional specifications tested. The preferred model is shown in Table 8.1. In the table: *Cust* refers to the number of customers; *Mains* refers to the length of mains; *RAV* refers to real asset value (based on the RAB); *NCI* is the proportion of mains not cast iron or unprotected steel; *CG* is city gates; *VSHR* refers to the share of tariff V customers in total sales; and *t* is a time variable.

The preferred model satisfies the following requirements:

- in terms of goodness-of-fit, indicated by the Bayesian Information Criterion (BIC), is at least as good as the other models tested (within tolerance);
- the elasticities of variable cost with respect to each of the outputs (*Cust* and *Mains*) are positive and significant;
- the elasticity of variable cost with respect to the capital stock (*RAV*) is positive and significant;
- the elasticities of variable cost with respect to the operating environment factors (*NCI*, *CG* and *VSHR*) have the expected sign and are significant in at least one of the SF or FGLS models.

Table 8.1: **Model with Mains as 2nd Output (Cobb-Douglas form)**

	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-5.7293	(-12.30)	-5.1458	(-28.79)
ln*Cust*	0.2385	(2.79)	0.3146	(10.38)
ln*Mains*	0.4240	(3.27)	0.1856	(3.55)
ln*RAV*	0.3368	(3.72)	0.4483	(10.44)
ln*NCI*	-0.2483	(-1.31)	-0.4502	(-4.45)
ln*CG*	0.0122	(0.38)	0.0581	(5.14)
ln*VSHR*	-0.2465	(-2.68)	0.0065	(0.19)
t	-0.0072	(-3.24)	-0.0075	(-4.52)
D-H test (p-value)(1)	0.5035		0.0002	
BIC(2)	-158.6801		-108.3392	
RMSE(3)	0.1447		0.2007	
N (sample size)	252		252	

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

(1) Bayesian Information Criterion (BIC) — a goodness-of-fit measure in lower values indicate a better fit.

(2) Root-mean-square error of stochastic disturbance (not including estimated inefficiency effects).

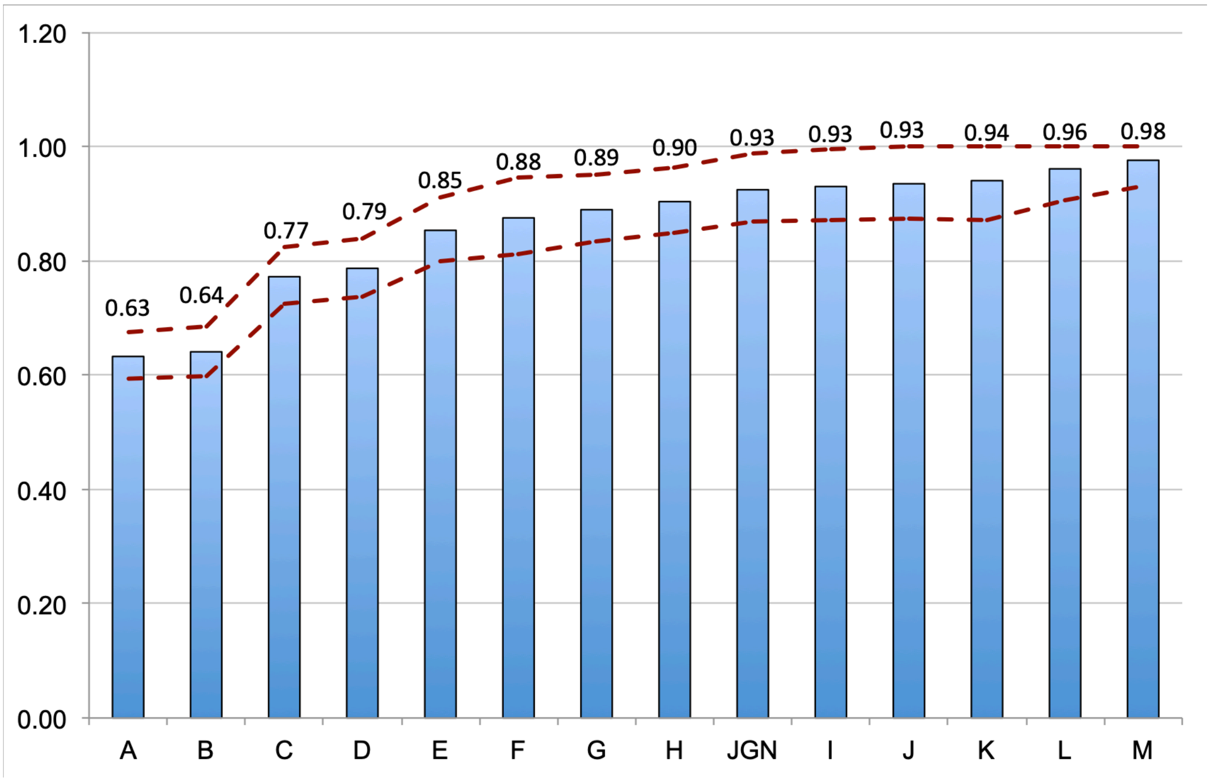
The elasticity of variable cost with respect to the proportion of mains *not* made of cast iron or unprotected steel (*NCI*) should be negative because older mains require higher maintenance. The elasticity with respect to the number of city gates should be positive because more inputs may be needed to maintain a more geographically dispersed network. A negative coefficient on the share of tariff V customers in total throughput suggests, broadly, that the average variable cost per tariff V customer is lower than for the average variable cost per tariff D customer.

8.2 Inference

8.2.1 JGN's Technical Efficiency

A chart showing the pattern of efficiency scores across the GDBs in the sample is presented in Figure 8.1. JGN's efficiency score in this model is 0.93, with a confidence interval of between 0.87 and 0.99. The average efficiency score of all GDBs in the sample is 0.86 and the highest efficiency score of 0.98. Hence, the highest efficiency score is within the confidence interval of JGN's efficiency score. This result indicates that JGN's efficiency score is not significantly different from the highest efficiency score in the sample. This in turn implies that JGN is an efficient GDB. It is one of several firms clustered on or close to the efficient frontier.

Figure 8.1: Comparative Technical Efficiency Scores (with confidence interval)*



* Value labels relate to the central estimates of the efficiency scores indicated by the height of the bars.

8.2.2 Industry Rate of Frontier Shift

A second key finding of the model relates to the estimated coefficient on the time variable, which measures the estimated average rate of technical change or 'frontier shift'. The estimates obtained are -0.72 per cent and -0.75 per cent per annum (with an average of -0.74 per cent). This represents the average reduction in real opex requirements per year associated from frontier shift. This estimate is close to estimates we obtained in previous studies for JGN in 2015 (-0.7 per cent) and for Multinet in 2016 (-0.6 per cent). When expressed as a rate of opex productivity growth, the estimated average rate is 0.74 per cent.

8.2.3 Output Index Weights

The output index weights are derived as shown in equation (7.8) and presented in Table 8.2. Each estimated output elasticity is divided by the sum of the output elasticities to obtain weights which sum to one.

Table 8.2 Output index weights (%)

Output	*SF model*	*FGLS model*	*Avg*
Customer numbers	36.0	62.9	49.4
Mains length	64.0	37.1	50.6
Total	100.0	100.0	100.0

8.3 Summary Conclusions

The main findings of the econometric analysis are as follows:

- JGN's estimated efficiency score is the sixth highest among the 14 GDBs in the sample (and the 5th highest among the Australian GDBs), but, most importantly, it is not significantly different from the highest efficiency score in the sample. JGN's efficiency score is 0.93, with a confidence interval of between 0.87 and 0.99. The average efficiency score of all GDBs in the sample is 0.86 and the highest efficiency score of 0.98. Hence, the highest efficiency score is within the confidence interval of JGN's efficiency score. JGN is one of several firms clustered on or about the efficient frontier. Only 5 percentage points separates the efficiency scores of the top six GDBs, indicating that several of the GDBs are very close to the efficiency frontier These findings suggests that JGN does not have any material inefficiency and does not require an adjustment to its base year opex.
- The estimated average rate of technical change or 'frontier shift' is 0.74 per cent per annum[13]. This estimate is close to estimates we obtained in previous studies for JGN in 2015 (0.7 per cent) and for Multinet in 2016 (0.6 per cent), and is slightly higher than the figure of 0.5 per cent per year recently put forward by AER (2019) for electricity distribution.
- The estimated output index weights for the two outputs used in the preferred econometric model are: (i) customer numbers, 49.4 per cent; and (ii) mains length, 50.6 per cent.

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[13] Frontier shift is expressed here as a rate of productivity growth and is hence a positive number.

APPENDIX A: GAS DISTRIBUTION BUSINESSES INCLUDED IN THE STUDY

The database formed for the study includes 11 Australian GDBs and three New Zealand GDBs (although GasNet is not used in Part A. It is only used in Part C). Part B uses a subset of Australian GDBs which have completed detailed survey questionnaires. A brief summary of the operations of the included GDBs follows.

Australian GDBs

Evoenergy, Australian Capital Territory

Evoenergy (the energy networks part of Evoenergy[14]) is the distribution business supplying gas and electricity in the Australian Capital Territory (ACT). The total population of the ACT in 2017 was 413,000. Gas is distributed to a predominantly residential customer base with Canberra the largest market. Outside the ACT, Evoenergy supplies gas to Queanbeyan, Bungendore and Nowra in NSW. There are relatively few major industrial users in its supply area. Canberra covers a large geographical area and the majority of urban development is low density. Moreover, gas distribution in residential areas utilises a dual mains configuration with mains on both sides of a street, rather than a single sided system with longer across-road service connection. For these reasons, it is a low-density distribution network when measured in terms of customers per kilometre of main. In 2017 Evoenergy supplied 140,200 customers with 7,600 TJ of gas from a distribution network of around 4,700 kilometres of mains.

Allgas Energy Pty Ltd (Allgas), Queensland

Allgas is owned by Marubeni Corporation, SAS Trustee Corporation and the APA Group. It supplies gas to consumers in several areas in and around Brisbane and to several Queensland regional areas. The Allgas distribution system is separated into three operating regions. About 59 per cent of the network is located in Brisbane (south of the Brisbane river to the Albert River), 19 per cent in the Western region (including Toowoomba and Oakey) and the remaining 22 per cent on the South Coast (including the Gold Coast, and Tweed Heads in NSW).

Queensland's mild to hot climate means that residential and commercial heating demand is low. Residential demand for gas is mainly for hot water systems and cooking. In 2016 southeast Queensland's population was around 3.3 million. Approximately 70 per cent of Allgas' gas demand is from around 100 large demand class customers. In 2016 Allgas supplied approximately 99,600 customers with 10,300 TJ of gas from a distribution network of 3,200 kilometres of mains. From 2015-16, Allgas is no longer required to have an approved access arrangement, and instead the AER arbitrates any access disputes.

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[14] Evoenergy includes an energy retailing partnership and an energy distribution partnership. The latter is called Evoenergy, and is owned jointly by Icon Water and Jemena Networks (ACT) Pty Ltd.

AGN Albury, NSW

Australian Gas Networks Limited (AGN) is, since 2017, part of the Australian Gas Infrastructure Group, owned by a consortium led by CK Infrastructure Holdings.

AGN Albury operates in the large regional centre on the border of NSW and Victoria often referred to as Albury–Wodonga. It operates on the North side of the Murray River in Albury and Ettamogah which in 2016 had a population of approximately 51,000. There is a small number of large industrial customers which represent over half of its gas deliveries. In 2017 AGN Albury supplied its 22,100 customers with around 2,200 TJ of gas from a distribution network of 400 kilometres of mains. Prior to 2017, AGN had separate approved access arrangements for AGN Albury and AGN Victoria, but these are now consolidated into a single approved access arrangement.

AGN Queensland, Queensland

AGN Queensland is an operating division of AGN, with a distribution network that supplies a Brisbane region (including Ipswich and suburbs north of the Brisbane river); and a Northern region (serving Rockhampton, Gladstone and Bundaberg). The network comprises approximately 2,600 kilometres of low, medium, high and transmission pressure mains. Assets used to service the Brisbane region comprise 88 per cent of the network with the balance of 12 per cent attributable to the Northern region.

AGN Queensland is subject to similar climatic influences on residential gas demand as Allgas. Customer numbers are similar to those for Allgas but gas volumes for customers included in this study are smaller. However, AGN has a number of industrial customers with very large volumes that are not reflected in the data used in this study. In 2016 there were approximately 96,600 customers consuming 6,100 TJ of gas. From 2015, AGN Queensland is no longer required to have an approved access arrangement, and instead the AER arbitrates any access disputes.

AGN SA, South Australia

AGN SA's distribution network services: greater Adelaide; to the north-east of Adelaide, the Barossa Valley, Riverland and Mildura in Victoria; to the north, Peterborough, Port Pirie and Whyalla; and in the east and south-east regions, Murray Bridge and Mt Gambier. Adelaide's population in 2016 was approximately 1.3 million. As with Melbourne, Adelaide's winter climate is conducive to relatively high residential gas demand for heating.

In 2017, AGN SA supplied 442,300 customers with 23,000 TJ of gas from a distribution network of 8,200 kilometres of mains. The Adelaide network makes up 93 per cent of the total network length.

AGN Victoria, Victoria

AGN Victoria serves parts of the greater Melbourne metropolitan area (population of 4.85 million in 2016) including the northern suburbs, the Mornington Peninsula and Pakenham/Cranbourne. AGN Victoria also supplies the north central Victorian area (including Seymour, Wodonga, Wangaratta, Shepparton-Mooropna and Echuca among others). It also supplies rural townships and cities in the Gippsland region (including Bunyip, Drouin, Warragul, Traralgon, Morwell and Sale among others), and a number of outlying towns in East Gippsland such as Bairnsdale and Paynesville (which are in the new Eastern Zone). The Distribution System is divided into four Zones – North, Central, Murray Valley and Eastern.

Melbourne's gas market is well established and cool to mild climatic conditions result in high residential gas consumption for heating, cooking and hot water systems. A relatively high concentration of industry also supports industrial gas demand provided that prices are competitive with other sources of energy supply. In 2017 there were 640,900 customers using 54,100 TJ of gas, supplied from a distribution network of 10,800 kilometres of mains.

AGN Wagga Wagga, NSW

AGN (formerly Envestra) took over gas supply from the NSW Government's Country Energy from October 2010. It supplies gas to the city of Wagga Wagga (estimated population of 48,300 in 2016) in southern regional NSW.

In 2015 there were approximately 20,100 customers. AGN supplied these customers with 1,600 TJ of gas from a distribution network of 750 kilometres of mains. In April 2014 the NSW Energy Minister, the Honourable Anthony Roberts, determined that coverage of the Wagga Wagga gas distribution network be revoked, and economic regulation of the network by the AER ceased at that time.

ATCO Gas Australia, Western Australia

ATCO acquired the network previously operated by WA Gas Networks (WAGN) in July 2011. ATCO Gas Australia is the principal GDB for Western Australian businesses and households. It operates the gas distribution system in the mid-west and south-west of Western Australia, including the greater Perth Metropolitan region (with a population of approximately 1.9 million in 2016), Busselton and Bunbury (together a population of 96,000), Geraldton, Kalgoorlie and the Albany region (each with a population of approximately 30,000). Each of these urban areas has a separate gas distribution network (Albany is supplied with reticulated LPG). In 2017, ATCO supplied approximately 738,100 customers with 25,300 TJ of gas from a distribution network of 13,800 kilometres of mains.

AusNet Services, Victoria

AusNet's Victorian gas distribution business was formerly TXU networks, which was formerly Westar (Assets) Pty Ltd, and is now part of AusNet Services, an ASX-listed business. The AusNet gas distribution business delivers gas to a number of urban centres across a geographically diverse region spanning the western half of Victoria, including the Western part of Melbourne, from the Hume highway in metropolitan Melbourne west to the South Australian border and from the southern coast to Horsham and just north of Bendigo. Its supply area includes the major Victorian regional centres of Geelong, Ballarat and Bendigo, and many other cities and towns in western Victoria. In 2017, AusNet supplied its 677,800 customers with 71,800 TJ of gas from a distribution network of 11,300 kilometres of mains.

Jemena Gas Network, NSW

JGN was formed from the sale of Alinta Ltd in 2007, Alinta itself having acquired the gas assets of AGL Gas Networks (AGLGN) in 2006. It is now co-owned by State Grid

Corporation of China and Singapore Power. The JGN network provides gas to customers in Sydney, Newcastle, Wollongong and the Central Coast, and over 20 country centres including those within the Central Tablelands, Central West, Southern Tablelands and Riverina regions of NSW. JGN has the largest distribution network and customer base of the Australian GDBs. In 2017 it supplied 1,330,800 customers with 86,200 TJ of gas from a distribution network of 26,800 kilometres of mains.

Multinet Gas, Victoria

Multinet Gas is, since 2017, part of the Australian Gas Infrastructure Group, owned by a consortium led by CK Infrastructure Holdings, following that consortium's acquisition of the DUET Group. The Multinet gas distribution system covers the eastern and south–eastern suburbs of Melbourne extending over an area of approximately 1,600 square kilometres as well as comparatively recent extensions of supply to townships in the Yarra Valley and South Gippsland. In 2017, Multinet supplied 697,300 customers with 54,800 TJ of gas from a distribution network of 10,100 kilometres of mains.

New Zealand GDBs

The New Zealand gas distribution industry is generally less mature than Victoria's with penetration rates still increasing relatively quickly, but comparatively low customer density at present.

Powerco Limited

Powerco is based in New Plymouth (population 56,000 in 2015) and distributes gas in the central and lower North Island regions. It is a dual gas and electricity network business. Powerco's gas networks in the central North Island region include the Taranaki (including New Plymouth), Manawatu and Horowhenua (including Palmerston North, population 83,500 in 2015), and Hawkes Bay networks (including Napier-Hastings, population 130,000 in 2015). In the lower North Island it supplies Wellington City (population of 203,000 in 2015), Hutt Valley (estimated population 141,000 in 2015) and Porirua (district population of 54,000 in 2015). Powerco acquired part of UnitedNetworks' gas operations in 2002 comprising the Hawkes Bay, Wellington, Horowhenua and Manawatu networks. In 2017, Powerco supplied 106,000 customers with 8,700 TJ of gas from a distribution network of 3,900 kilometres of mains.

Vector Ltd

Vector Ltd operates the gas distribution network in Auckland (estimated population of 1,418,000 including North Shore City, and the urban parts of Waitakere and Manukau cities). It is listed on the NZ Stock Exchange and is about 75 per cent owned by the Auckland Energy Consumer Trust. Vector acquired the remaining part of UnitedNetworks' gas operations in 2002 comprising its Auckland gas network and the National Gas Corporation's gas distribution business in 2004 and 2005. The Vector data from 2006 represent the combined operations of Vector and the former NGC Distribution. In November 2015 it sold its regional gas pipelines business via which it supplied a number of regional towns and cities in the North Island. In 2015, Vector supplied 105,900 gas distribution customers with 14,100 TJ of gas from a distribution network of 6,500 kilometres of mains.

GasNet

GasNet is a New Zealand GDB which is owned by the Whanganui District Council and operates five gas networks in the Whanganui, Rangitikei and South Taranaki regions in the North Island of New Zealand. It was formed 2008 after amalgamating with Whanganui Gas Limited. In 2017, GasNet had 9,900 customers and supplied 1,250 TJ, and its networks were approximately 400 km in length. In terms of customer numbers it is approximately half the size of AGN Albury and AGN Wagga. In terms of mains length it is smaller than AGN Wagga, but similar is size of AGN Albury.

APPENDIX B: DATABASES USED IN THE STUDY

The analysis in Parts A and C of this report uses a dataset that includes 13 GDBs, including 11 Australian and two New Zealand GDBs. The analysis in Part B uses data for six major Australian GDBs (AusNet, AGN Vic, Multinet, AGN SA, ATCO and JGN). Data for these six GDBs used in Part B was sourced from survey data obtained for this study. In most cases this survey data extends from 1999 to 2017, and for JGN and ATCO it extends to 2018. In Parts A and C of the report, the survey data is supplemented by data for another seven GDBs, which has been sourced from documents in the public domain and relates to the period 1999 to 2018, or a shorter period.

Table B.1: Summary of data sample

GDB	*Data period*	*Years ending*	*# obs*
Evoenergy	1999–2018	Jun	20
AGN Albury	1999–2017	Dec	19
AGN Qld#	1999–2016(1)	Jun	18
AGN SA	1999–2017	Jun	19
AGN Vic	1998–2017	Dec	20
AGN Wagga	1999–2015(2)	Jun	17
Allgas	2000–2016(1)	Jun	17
ATCO	2000–2017	Dec	18
AusNet	1998–2017	Dec	20
Jemena	1999–2018	Jun	20
Multinet	1998–2017	Dec	20
Powerco (NZ)	2004–2018(3)	Sep	14
Vector (NZ)	2005–2017(4)	Jun	11
GasNet (NZ)*	1999–2018	Jun	19
Total			254

Notes: # For AGN Qld, public domain data is used in Parts A and C; and survey data is used in Part B which is available for the period 1999-2014.

* GasNet is included in Part C but not included in Part A analysis.

(1) Regulatory forecasts used for the period 2012 to 2016

(2) Regulatory forecasts used for the period 2011 to 2015.

(3) Capex available only for 2011–2017.

(4) Capex available only for 2007–2017. Vector divested some major networks in November 2015. In Part C, the two periods after 2015 were excluded.

The detailed data surveys carried out for the major Australian GDBs followed a common format, covering key output and input value, price and quantity information over the period from 1998 or 1999 to the latest year available (either 2017 or 2018). The GDBs for which data from public sources data is used in Parts A and C include: (i) in Australia, Evoenergy, AGN Albury, AGN Qld, AGN Wagga, and Allgas; and (ii) in New Zealand, Powerco, Vector and GasNet (the last in part C only).

The public domain data sources used for Australian GDBs include:

- Access Arrangement Information (AAI) filings as proposed and as amended by a regulator's decision
- Regulators' final decisions, sometimes with amendment following appeal, and
- Annual Reports from the GDB or its parent firm.

The public domain data source used for the NZ GDBs is the Information Disclosure Data filings required by the Gas (Information Disclosure) Regulations 1997. There are fewer consistent observations publicly available for the New Zealand GDBs, reflecting the impact of mergers, asset sales and industry restructuring.

Data used includes throughput, customer numbers, distribution pipeline length, opex, capex and regulatory asset value. While every effort has been made to make the publicly available data used in this study as consistent as possible, the limitations of currently available public domain data need to be recognised. In a few cases missing observations were estimated based on growth rates for the variable or a related variable before and after the missing year. In a number of cases adjustments were made to ensure the data related to comparable activities and measures (eg unaccounted for gas allowances for non-Victorian GDBs have been excluded to put those GDBs on a comparable basis with Victorian reporting). The data used for the Australian GDBs cover only the regulated (or previously regulated) activities. Data relating to large industrial users whose supply is not regulated are not included. Inclusion of this data would require access to information not generally in the public domain and has been beyond the scope and timeframe of this study.

The data derived from public sources relate to the time periods normally reported by each GDB, and some GDBs use calendar year reporting while others use financial year reporting, and sources varied in reporting data in nominal and real terms. All cost data were first converted to nominal terms (where necessary) using the All Groups Consumer Price Index in Australia and the equivalent in New Zealand. The nominal series were then converted to real series in 2010 dollars using the same price indexes. The New Zealand data were then converted to Australian dollars using the OECD (2014) purchasing power parity for 2010. Purchasing power parities are the rates of currency conversion that eliminate differences in international price levels and are commonly used to make comparisons of real variables between countries.

The measure of opex covers regulated distribution activities only and excludes all capital costs. It includes all non–capital costs allowed by the regulatory authorities, including directly employed labour costs, contracted services, materials and consumables, administration costs and overheads associated with operating and maintaining the distribution service. It excludes unaccounted for gas for all the GDBs as this is treated differently in Victoria compared to the other Australian States and excluding this item provides the best basis for like–with–like comparisons. In line with earlier studies, full retail contestability (FRC) costs are included as reported. All of the cost data are expressed in \$A 2010 prices. The estimates of capital assets are based on depreciated asset values for regulatory purposes or those calculated using the same approach as used in regulatory accounts in \$A 2010.

APPENDIX C: DERIVING OUTPUT COST SHARE WEIGHTS

The index analysis in Part B of this study uses output cost share weights derived by estimating a multi–output Leontief cost function using method applied in Lawrence (2007). These weights are then used as the revenue shares in forming the multilateral output index outlined in appendix A. This multi–output Leontief functional form essentially assumes that GDBs use inputs in fixed proportions for each output and is given by:

$$C(y^t, w^t, t) = \sum_{i=1}^{M} w_i^t \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^t (1 + b_i t)\right] \tag{C1}$$

where there are M inputs and N outputs, w_i is an input price, y_j is an output and t is a time trend representing technological change. The input/output coefficients a_{ij} are squared to ensure the non–negativity requirement is satisfied, ie increasing the quantity of any output cannot be achieved by reducing an input quantity. This requires the use of non–linear regression methods. To conserve degrees of freedom a common rate of technological change for each input across the three outputs was imposed but this can be either positive or negative.

The estimating equations were the M input demand equations:

$$x_i^t = \sum_{j=1}^{N} (a_{ij})^2 y_j^t (1 + b_i t) \tag{C2}$$

where the i's represent the M inputs, the j's the N outputs and t is a time trend representing the nine years, 1998 to 2006.

The input demand equations were estimated separately for each of the three GDBs using the non–linear regression facility in Shazam (White 1997) and data for the years 1998 to 2006. Given the limited number of observations and the absence of cross equation restrictions, each input demand equation is estimated separately.

Lawrence (2007) then derived the output cost shares for each output and each observation as follows:

$$h_j^t = \left\{\sum_{i=1}^{M} w_i^t [(a_{ij})^2 y_j^t (1 + b_i t)]\right\} / \left\{\sum_{i=1}^{M} w_i^t \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^t (1 + b_i t)\right]\right\}. \tag{C3}$$

Lawrence (2007) then formed a weighted average of the estimated output cost shares for each observation to form an overall estimated output cost share where the weight for each observation, b, is given by:

$$s_b^t = C(b, y_b^t, w_b^t, t) / \sum_{b,t} C(b, y_b^t, w_b^t, t). \tag{C4}$$

APPENDIX D: MODEL SELECTION

This appendix provides a summary of the results of estimating models of GDB real opex cost functions, using several different functional specifications. Six different model specifications are shown. The first two specifications include specifications used in studies by Economic Insights (2015a) and (2016c), and Model 3 is a variation on Model 2. The fourth specification is that used by ACIL Allen (2016). The following three specifications (Models 5 to 7) are based on progressive simplification beginning with a translog variable cost function which has the following variables:

- two outputs, Customer numbers and Mains length (km);
- Fixed capital measured be the real value of the regulatory asset base;
- a time trend variable; and
- three operating environment variables: the proportion of mains not cast iron or unprotected steel; the number of city gates; and the share of tariff class customers of total gas throughput.

Model 7 uses the same variables in a Cobb-Douglas formula and Model 6 has an intermediate functional form. For each of the model specifications, the SF and FGLS estimation methods are used, as discussed in section 2.

In the tables below: *Cust* refers to the number of customers; *TJ* refers to total gas throughput; *RAV* refers to real asset value (based on the RAB); *Mains* refers to the length of mains; *CDens* refers to customer density; *NCI* is the proportion of mains not cast iron or unprotected steel; *CG* is city gates; *t* is a time variable; *VSHR* refers to the share of tariff V customers in total sales; and *LF* is load factor.

D.1 Specification used in JGN 2015

The models shown in Table D.1 are similar to those used in the study we carried out for JGN in 2015. This specification has two outputs, customer numbers and gas deliveries (TJ); and includes customer density as an operating environment variable, defined as customer numbers divided by mains length. The main concerns with this model, when applied to the current data sample, are that:

(a) The elasticity of real opex with respect to *customer density* is not statistically significant in either the SF or the FGLS models; and

(b) the elasticity of real opex with respect to *gas throughput* is not significantly different from zero in the SF model and is negative in the FGLS model (which is the incorrect sign for an output).

These observations provide good grounds to search for a specification that better fits the current data for gas DNSPs.

Table D.1: Specification similar to study for JGN 2014

	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-20.8840	(-5.34)	-14.2062	(-6.42)
ln*Cust*	2.3873	(3.23)	3.7878	(13.59)
ln*TJ*	-0.4914	(-0.96)	-2.9938	(-11.61)
$(\ln Cust)^2$	0.5735	(3.48)	0.1373	(1.36)
$(\ln TJ)^2$	1.2373	(6.27)	0.9469	(6.98)
$\ln Cust \times \ln TJ$	-0.9369	(-5.62)	-0.5205	(-4.52)
ln*RAV*	0.4860	(4.52)	0.6336	(14.68)
ln*CDens*	3.7800	(2.11)	1.8036	(2.04)
$(\ln CDens)^2$	-1.1029	(-2.14)	-0.4925	(-2.03)
ln*NCI*	-0.0730	(-0.37)	0.0523	(0.51)
ln*CG*	0.0313	(0.87)	-0.0105	(-1.02)
t	-0.0009	(-0.28)	-0.0109	(-5.91)
D-H test (p-value)#	0.0163		0.0000	
BIC	-196.0477		-160.8660	
RMSE	0.1250		0.1996	
N	252		252	
Elasticities:				
Cust	0.2902	(1.87)	0.4633	(12.17)
TJ	0.1399	(1.59)	-0.1694	(-4.76)
CDens	-0.2851	(-1.60)	-0.0117	(-0.22)

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

Table D.1 also shows that the SF model satisfies the D-H test for normality of the residuals whereas the FGLS model does not. This is a general finding relevant to all of the models in this appendix, and suggests an advantage of the SF model over the FGLS model. That said, none of the models presented here have any severe outliers.

D.2 Specification used in Multinet 2016

Table D.2 shows the results obtained using the specification developed in the study we carried out for Multinet in 2016. In this model there are no higher order effects (i.e. quadratic terms such as squared variables and cross products) — hence the coefficients are equivalent to elasticities.

This model has three outputs: customer numbers, gas deliveries (TJ) and the length of mains; and one measure of capital inputs: real asset value.[15] An important limitation of this model is

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[15] However, note that this model, and all of the subsequent models that use mains length as an output, can be given an alternative interpretation in which mains length represents part of a combined measure of capital inputs, which is a weighted-average of mains length and real RAB. If using this alternative interpretation with Model 2, the coefficient on the combined measure of fixed capital would be: $\beta_K = \beta_{Mains} + \beta_{RAV} = 0.4207 +$

that the elasticity of real opex with respect to gas deliveries (TJ) is not significantly different from zero in the SF model and is negative in the FGLS model. This tends to suggest that the quantity of gas delivered cannot be regarded as a significant output in the variable cost model for gas DNSPs. The LF variable is discussed below. The other three operating environment variables are statistically significant in at least one of the SF and FGLS models, and have the correct signs. For this reason, these three variables are retained in the subsequent models.

Table D.2: Specification used in study for Multinet 2016

	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-5.8441	(-11.86)	-5.6061	(-21.62)
ln*Cust*	0.2184	(2.26)	0.3291	(6.30)
ln*TJ*	0.0359	(0.48)	-0.0157	(-0.49)
ln*Mains*	0.4206	(3.59)	0.2064	(3.72)
ln*RAV*	0.3359	(3.80)	0.4440	(10.01)
ln*LF*	-0.0931	(-0.54)	-0.3147	(-3.36)
ln*NCI*	-0.2764	(-1.43)	-0.4923	(-4.62)
ln*CG*	0.0095	(0.29)	0.0528	(4.52)
ln*VSHR*	-0.2485	(-2.45)	-0.1567	(-2.72)
t	-0.0064	(-2.53)	-0.0068	(-3.76)
D-H test (p-value)#	0.6377		0.0080	
BIC	-148.0333		-100.9676	
RMSE	0.1451		0.1896	
N	252		252	

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

D.3 Variation using MDQ

In Model 2, the load factor variable (*LF*) is closely related to the gas throughput variable (*TJ*), and the rationale for including *LF* may be diminished if *TJ* is excluded from the model. As an alternative, we tested the inclusion of ln*MDQ* instead of ln*TJ* and ln*LF*. Since $MDQ \equiv Gas\ Throughput\ \div 365 \div LF$, it follows that: $\ln MDQ = -5.9 + \ln TJ - \ln LF$. Hence, including ln*MDQ* instead, is equivalent to including ln*TJ* and ln*LF* with the restriction on their coefficients: $\beta_{TJ} = -\beta_{LF}$.

Table D.3 shows this variation of the model using ln*MDQ*. Unsurprisingly, ln*MDQ* is not a significant output in either the SF or FGLS models, indicating that *TJ* and *LF* need to be excluded from the model altogether.

$0.3359 = 0.7566$; and the fixed capital measure would be:
$\ln K = (\beta_{Mains}/\beta_K) \ln Mains + (\beta_{RAV}/\beta_K) \ln RAV = 0.556 \ln Mains + 0.444 \ln RAV$.

Table D.3: Variation using MDQ instead of TJ & LF

	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-5.5266	(-9.56)	-5.0467	(-23.23)
ln*Cust*	0.2111	(2.24)	0.2964	(7.24)
ln*Mains*	0.4212	(3.56)	0.1882	(3.53)
ln*MDQ*	0.0430	(0.59)	0.0164	(0.65)
ln*RAV*	0.3347	(3.78)	0.4514	(10.45)
ln*NCI*	-0.2611	(-1.39)	-0.4522	(-4.38)
ln*CG*	0.0078	(0.24)	0.0577	(5.03)
ln*VSHR*	-0.2327	(-2.56)	-0.0079	(-0.22)
t	-0.0065	(-2.59)	-0.0077	(-4.22)
D-H test (p-value)#	0.5992		0.0002	
BIC	-153.4653		-102.9621	
RMSE	0.1443		0.2085	
N	252		252	

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

D.4 Specification used by ACIL Allen

Table D.4 shows a specification used by ACIL Allen (2016). This model is quite simple, with only four explanatory variables including the time trend. While this is a parsimonious model, there is a risk of omitted variable bias. This specification has much higher coefficients on the time trend variable than the foregoing models, and compared to the other models considered here. This may be due to the exclusion of other relevant influences on variable cost. This model is considered too simplified.

Table D.4: Specification used by ACIL Allen

	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-4.7806	(-15.33)	-4.9829	(-32.07)
ln*Cust*	0.5002	(6.48)	0.4647	(12.50)
ln*RAV*	0.5299	(6.80)	0.5533	(15.85)
ln*CDens*	-0.3921	(-3.05)	-0.2203	(-5.61)
t	-0.0109	(-5.91)	-0.0122	(-8.65)
D-H test (p-value)#	0.5355		0.0017	
BIC	-163.1397		-101.6379	
RMSE	0.1480		0.1980	
N	252		252	

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

D.5 Model with Mains as 2nd Output (Cobb-Douglas form)

In the model shown in Table D.5 there are two outputs (customer numbers and mains length) and one measure of fixed capital (real RAB).[16] Unlike model 2, this model does not include either gas deliveries (*TJ*) or load factor (*LF*); but includes the additional output. There are no second-order terms in this model — it is a Cobb-Douglas functional form.

Model 5 works particularly because all of the explanatory variables are

- statistically significant in either the SF or FGLS models, or in both;
- have the correct signs when they are statistically significant; and
- overall, in the great majority of cases the coefficients are significant.

The estimated rate of technical change is 0.72 per cent in the SF model and 0.75 per cent in the FGLS model. The average 95 per cent confidence intervals around these estimates are from 0.36 per cent to 1.12 per cent.

Table D.5: Model with Mains as 2nd Output (Cobb-Douglas form)

	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-5.7293	(-12.30)	-5.1458	(-28.79)
ln*Cust*	0.2385	(2.79)	0.3146	(10.38)
ln*Mains*	0.4240	(3.27)	0.1856	(3.55)
ln*RAV*	0.3368	(3.72)	0.4483	(10.44)
ln*NCI*	-0.2483	(-1.31)	-0.4502	(-4.45)
ln*CG*	0.0122	(0.38)	0.0581	(5.14)
ln*VSHR*	-0.2465	(-2.68)	0.0065	(0.19)
t	-0.0072	(-3.24)	-0.0075	(-4.52)
D-H test (p-value)#	0.5035		0.0002	
BIC	-158.6801		-108.3392	
RMSE	0.1447		0.2007	
N	252		252	

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

D.6 Model with Mains as 2nd Output (Partial Translog form)

The model in Table D.6 has the same explanatory variables as that in Table 5, except that it includes higher-order terms for the logs of customer numbers and mains length — i.e. the outputs.

The model does not add a great deal to Model 5. A Wald test of the hypothesis that the higher-order effects are jointly equal to zero rejects that hypothesis at a 0.05 level of significance. However, any improvement is marginal. The Bayesian Information Criterion

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[16] As mentioned in relation to Model 2, models which include both the length of mains and the real RAB value have an alternative interpretation in which those two variables can form a combined measure of capital inputs.

(BIC) measures the goodness of fit, with lower values implying better goodness-of-fit. In the SF model the BIC is -169 in Model 6, compared to -159 in Model 5. However, differences in the BIC of less than 10 points are usually considered to be immaterial. This suggests that the when the loss of simplicity (or degrees of freedom) is taken into account, these variables do not materially add to the model.

It is also likely that multicollinearity is a problem in Model 6 given the particularly large variation in the elasticity estimates between the SF and FGLS models. This view is supported by high average variance inflation factors (not shown). These reasons suggest that Model 6 does not offer an improvement over Model 5.

Table D.6: **Model with Mains as 2nd Output (Partial Translog form)**

	*Stochastic frontier model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-32.2536	(-5.16)	-17.9075	(-6.34)
$\ln Cust$	8.1833	(3.23)	4.3899	(4.22)
$(\ln Cust)^2$	-1.3385	(-2.33)	-0.6097	(-2.83)
$\ln AvgK$	-5.0518	(-1.86)	-2.5833	(-2.64)
$(\ln AvgK)^2$	-1.1536	(-1.73)	-0.2099	(-0.86)
$\ln Cust \times \ln AvgK$	1.1538	(1.86)	0.4203	(1.89)
$\ln NCI$	-0.0873	(-0.44)	-0.484	(-4.61)
$\ln CG$	-0.0005	(-0.02)	0.0053	(0.43)
$\ln VSHR$	-0.2164	(-2.61)	0.1315	(3.10)
t	-0.0055	(-2.52)	-0.0066	(-4.24)
D-H test (p-value)[#]	0.1469		0.0141	
BIC	-169.6833		-115.3665	
RMSE	0.1380		0.1867	
N	252		252	
Elasticities:				
Cust	0.3762	(3.04)	0.0912	(1.94)
AvgK	0.5557	(3.61)	0.9438	(15.93)

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; p > 0.05 suggests residuals are normally distributed.

D.7 Model with Mains as 2nd Output (Translog form)

The model in Table D.7 has the same explanatory variables as the two preceding models, but it includes higher-order terms for the log RAV in addition to those for the outputs. The additional variables are jointly significantly different from zero. However, again the model does not appear add much to Model 5. This is indicated by the BIC in the SF model, which is -158 in Model 7 and -159 in Model 5. Hence the goodness-of-fit is no better than Model 5. Again, multicollinearity is likely to be a problem in this models, which may lead to lower precision in the estimation of the parameters of interest. These reasons suggest that Model 5 is to be preferred over Model 7.

D.8 Conclusions

These comparisons indicate that Model 5 is considered to be the best of the models.

Table D.7: **Model with Mains as 2nd Output (Translog form)**

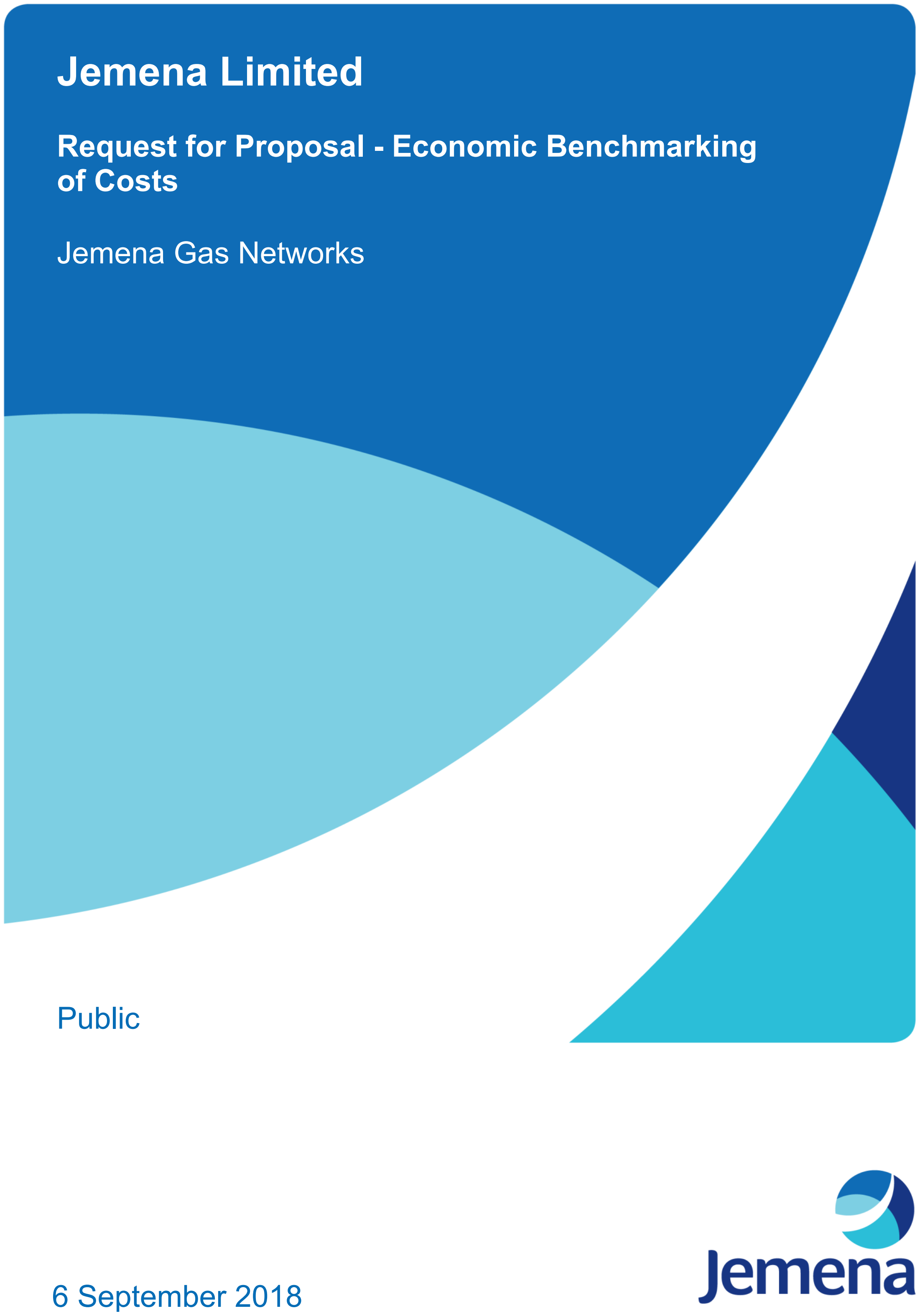
	*SF model**		*FGLS model***	
	coeff	*t-stat*	*coeff*	*t-stat*
Const	-37.2157	(-5.94)	-18.7690	(-4.99)
ln*Cust*	8.4289	(3.71)	0.8542	(0.66)
ln*Mains*	0.0935	(0.04)	4.6217	(3.58)
$(\ln Cust)^2$	-1.5909	(-2.95)	0.1337	(0.45)
$(\ln Mains)^2$	-1.7386	(-2.18)	-0.8639	(-1.87)
ln*Cust* × ln*Mains*	0.9790	(2.01)	-0.0796	(-0.30)
ln*RAV*	-4.9672	(-2.60)	-2.2068	(-2.05)
$(\ln RAV)^2$	-0.7518	(-1.47)	0.0698	(0.24)
ln*Cust* × ln*RAV*	0.4834	(1.74)	-0.2609	(-1.70)
ln*Mains* × ln*RAV*	0.4780	(0.89)	0.6466	(2.23)
ln*NCI*	0.1600	(0.78)	0.1642	(1.11)
ln*CG*	-0.0099	(-0.31)	0.0025	(0.18)
ln*VSHR*	-0.2518	(-2.91)	0.0186	(0.33)
t	-0.0078	(-3.30)	-0.0187	(-11.30)
D-H test (p-value)#	0.4076		0.0000	
BIC	-157.5676		-136.9860	
RMSE	0.1369		0.1987	
N	252		252	
Elasticities:				
Cust	0.3741	(3.13)	0.2581	(5.96)
Mains	0.2633	(1.72)	0.3679	(6.76)
RAV	0.3041	(3.06)	0.4150	(8.47)

* Inefficiencies are time invariant and with a half-normal stochastic distribution.

** Feasible generalised least squares with allowance for heteroscedastic errors between panel groups.

Doornik-Hansen test for normality of residuals; $p > 0.05$ suggests residuals are normally distributed.

APPENDIX E: TERMS OF REFERENCE



Jemena Limited

Request for Proposal - Economic Benchmarking of Costs

Jemena Gas Networks

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1. BACKGROUND

Jemena Gas Networks (Ltd) (**JGN**) is a gas distribution network service provider. JGN's gas network is comprised of over 25,000km of pipeline, and delivers gas to more than 1.3 million homes, businesses and industrial customers in New South Wales (**NSW**). JGN is currently preparing its 2025 Access Arrangement (**AA**) submission, covering the period 1 July 2020 to 30 June 202. The AA submission is due to be submitted to the Australian Energy Regulator (**AER**) on 30 June 2019.

A summary of the regulatory periods is outlined in the table below.

Table 1–1: Timetable

Business	Current regulatory period	Future regulatory period
JGN	1 Jul 2016 – 30 Jun 2020	1 Jul 2020 – 30 Jun 2025

JGN submission will include an assessment of efficiency of its base year costs. This terms of reference requires a consultant to undertake techniques to compare JGN's historical and base year costs over time and against other businesses, in order to ensure the AER and our customers that our forecast costs that are based on efficient historical costs for JGN's respective regulatory proposals.

1.1 RELEVANT NATIONAL GAS RULE REQUIREMENTS

When considering approval of JGN's AA submission, the AER must have regard to the National Gas Objective, which is:

> *"to promote efficient investment in, and efficient operation and use of, natural gas services for the long term interests of consumers of natural gas with respect to price, quality, safety, reliability and security of supply of natural gas."*

The AER may also take into account the pricing principles in section 24(2) of the National Gas Law, and must do so when considering whether to approve a reference tariff:

A service provider should be provided with a reasonable opportunity to recover at least the efficient costs the service provider incurs in—

1. providing reference services; and
2. complying with a regulatory obligation or requirement or making a regulatory payment.

JGN is developing its forecast of operating expenditure for Access Arrangement for RY21-25 using base-step-trend method and is adopting RY2019 as its base year. In this regard, rule 72 provides that, amongst other things, the supporting information to be submitted with a full AA proposal (AA Information) must include forecasts of both conforming capital and operating expenditure over the AA period and the basis for these forecasts. Economic benchmarking of costs is a useful tool to compare efficiency of historical costs of businesses against each other and over time although care is required in interpreting the results. This tool provides a lens to our customers and the AER around the efficiency of our base costs used for development of forecasts.

Some of the key rules that JGN must comply with in submitting its AA submission are set out below.

Rule 74 of the National Gas Rules:

BACKGROUND — 1

1. Information in the nature of a forecast or estimate must be supported by a statement of the basis of the forecast or estimate.
2. A forecast or estimate:
   a) must be arrived at on a reasonable basis; and
   b) must represent the best forecast or estimate possible in the circumstances.

Rule 91(1) of the National Gas Rules:

Operating expenditure must be such as would be incurred by a prudent service provider acting efficiently, in accordance with accepted good industry practice, to achieve the lowest sustainable cost of delivering pipeline services.

Rule 79 of the National Gas Rules:

Conforming capital expenditure is capital expenditure that conforms with the following criteria:

1. the capital expenditure must be such as would be incurred by a prudent service provider acting efficiently, in accordance with accepted good industry practice, to achieve the lowest sustainable cost of providing services.

2. SCOPE OF WORK

The consultant will provide one report, consisting of partial performance indicators (**PPI**), Total Factor Productivity (**TFP**) and econometric analysis. We expect the consultant will conduct an economic benchmarking review of the operating and capital costs of JGN against other gas distribution networks, incorporating data up to and including the 2017-18 financial year.

The review is to be conducted within the context of the regulatory submission process, and is required to include -

1. Preparation of data templates and collecting data from all comparable businesses to collect latest information
2. Benchmarking of JGN’s productivity performance through analysis of JGN’s total factor productivity (TFP) and partial factor productivity (**PFP**) trends over time, including a comparative analysis of JGN’s relative productivity levels and growth rates using multilateral TFP against major Australian, New Zealand and/or Canadian gas distribution businesses.
3. Benchmarking of JGN’s operating and capital efficiency through partial indicator comparisons against Australian, New Zealand and/or Canadian gas distribution businesses.
4. Benchmarking of JGN’s base year opex using econometric analysis and recommend output measures, output weights and productivity adjustment to be applied to the rate of change component of opex forecast.

We expect this review to leverage off the work done for similar businesses in which JGN participated in 2018 to lower the cost for our customers. The review is to be conducted with regard to Rule 74(2), 79(1)(a) and 91(1) of the National Gas Rules.

In preparing the analysis and report, the consultant should use reliable and robust data and have regard to environmental or operational factors that may be relevant in explaining the observed differences in productivity levels of businesses.

3. DELIVERABLES

At the completion of its review the consultant will provide an independent report which:

- are of a professional standard capable of being submitted to the AER;
- clearly set out all findings and the reasons for those findings, justify the methodology applied, separate facts from opinions, and explain all the assumptions made to provide the real cost escalation forecasts;
- explain how and why the base year costs are fit for submission to the AER as part of JGN's regulatory proposals;
- contain a section summarising the consultants experience and qualifications, and attaches the consultant's curriculum vitae (preferably in a schedule or annexure);
- identifies any person and their qualifications, who assists the consultant in preparing the report or in carrying out any research or test for the purposes of the report;
- includes an executive summary which highlights key aspects of the consultant's work and conclusions; and
- (without limiting the points above) carefully sets out the facts that the consultant has assumed in putting together his or her report, as well as identifying any other assumptions made, and the basis for those assumptions.

The consultant is to provide an electronic (Excel) version of its model(s) where working arrangements with other businesses allow this and one consolidated report on TFP/PFP, PPI and econometric analysis that can be provided to the AER.

Use of the report

It is intended that the consultant's report will form part of JGN's AA submission for the AA period from 1 July 20 to 30 June 25.

The report may be provided by the AER to its own advisers, and released publicly on the AER's and/or Jemena's websites. The report must be expressed so that it may be relied upon by JGN and the AER.

The AER may ask queries in respect of the report and the consultant will be required to assist JGN in answering these queries. In addition, the AER may choose to interview the consultant and, if so, the consultant will be required to participate in any such interview.

4. RESPONSE TO THESE TERMS OF REFERENCE

The consultant is to prepare a short form proposal, responding to these terms of reference, which sets out:

- The timeframes that it will required;
- The staff who will provide the modelling and advice; and
- Lump sum fees to deliver the scope of work set out in these terms of reference and basis for the fees, and hourly rates should additional work be required;
- The consultant is to identify and disclose any current or future realised or potential conflicts of interest.

The short form proposal should be submitted to Jemena no later than close of business on 12 September 2018. The proposal should be submitted electronically to syed.karim@jemena.com.au. Any questions on this terms of reference should be directed to Syed Karim, at the above email address, or an (02) 98677528.

This engagement will be undertaken under the terms and conditions of the Regulatory Services Panel arrangements.

5. TIMETABLE

The consultant will deliver its required output as follows:

	Timeline
Draft version of report	12 Apr 2019
Final version of report	17 May 2019

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