COMPETITION ECONOMISTS GROUP

Benchmarking and forecasting JGN opex

A report for Jemena Gas Networks

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COMPETITION ECONOMISTS GROUP

Table of contents

List of figures

List of tables

List of abbreviations

GDB	Gas Distribution Business
JGN	Jemena Gas Network
Opex	Operating expenditure
TFP	Total Factor Productivity
MTFP	Multilateral TFP

1 Executive Summary

1. Jemena Gas Network (JGN) has asked CEG to perform an analysis of relative efficiency of JGN's current level of operating expenditure (opex). JGN has also tasked CEG to provide trend inputs to its opex forecasts over the upcoming regulatory period (1 July 2025 to 30 June 2030), namely:

   a. the relative contribution of output growth to opex growth for Australian gas distribution businesses (GDBs);

   b. the annual change in opex productivity

1.1 Approach

2. We have adopted an approach that aligns with 2019 Economic Insights (EI)'s analysis for JGN's regulatory proposal for 2020 to 2025 regulatory period.[1] This approach was used as it was accepted by the AER in JGN's current regulatory determination and to ease data collection process in limited time frame which the Australian GDBs were familiar with as part of the 2019 EI analysis. Notwithstanding this, there were still some data gaps and delays in receiving information from all GDBs.

3. We conducted our analysis based on data from 8 Australian and 4 New Zealand GDBs.

4. We examine the relative opex efficiency of JGN compared to other GDBs using productivity indices, partial performance indicators and econometrics approach. A productivity index is a measure of how efficiently a firm uses opex and capital inputs to produce its outputs. We adopt two types of productivity indices, the Fisher index and the multilateral approach. The multilateral approach allows us to compare how a GDB uses its opex to produce its output over time and in comparison to other GDBs. Whereas the Fisher approach allows us to examine how the efficiency has change over time but not relative to other GDBs.

5. We also examine partial performance indicators such as opex per customer while controlling for other determining factors of cost. This allows us to make a comparison of opex per customer across GDB's with different characteristics. Additional factors that we control for include density, scale and environmental variables.

6. We adopt an econometric approach by regressing opex on a number of output variables, environmental variables and time. The econometric approach measures whether JGN is efficient in its use of opex inputs relative to that of a frontier. Regression is used to estimate the relationship between opex and its drivers to obtain an opex cost function. An efficiency score is calculated using the estimated opex cost function by comparing JGN's use of inputs to the frontier.

7. The estimated coefficients of the opex cost function help to examine the relative weight of outputs used to calculate the impact of output growth on opex and the trend in opex productivity in the long run.

8. The data for the eight Australian GDBs were sourced from a commercial in confidence survey of GDBs. The detailed data surveys was sent to the major Australian GDBs, covering key output and input values, price and quantity information over the period from 1998 or 1999 to the latest year where data is available.

9. In the case of missing data from the survey, we relied on publicly available data from the Regulatory Information Notices (RINs) published by AER. For the New Zealand GDBs, data has been sourced

[1] EI report (2019), Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), 24 April 2019

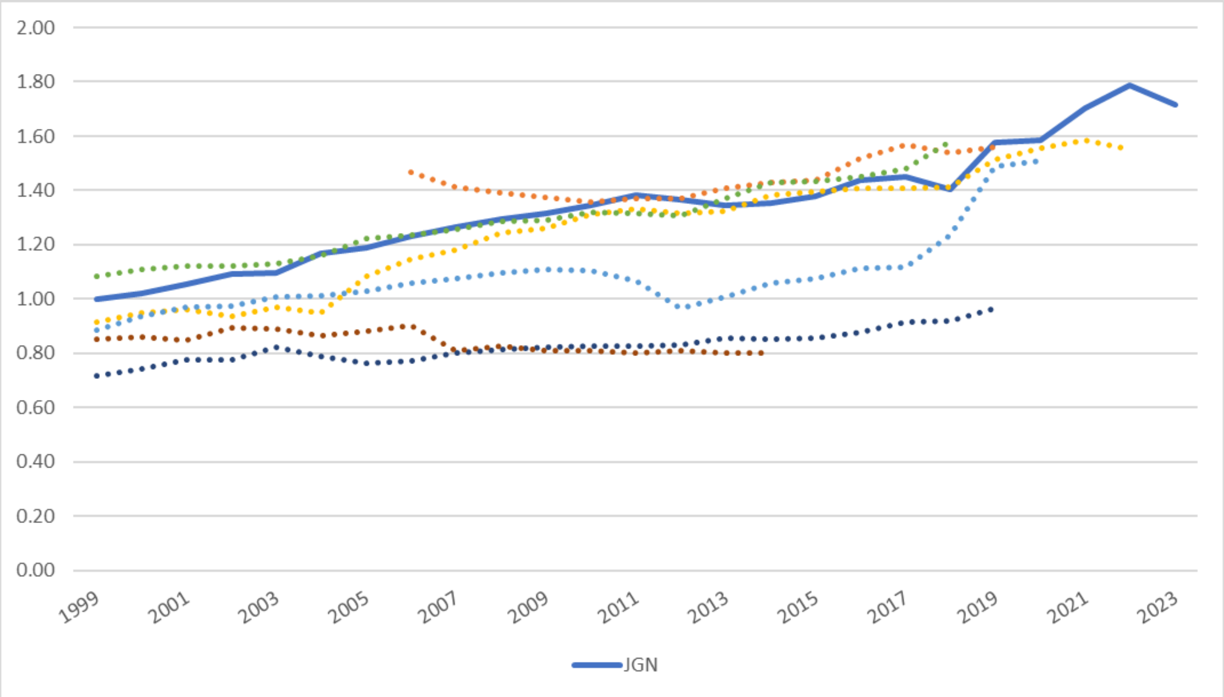
from publicly available data published by the New Zealand Commerce Commission (NZCC) and from annual reports.

1.2 Results

1.2.1 Efficiency of JGN base year opex

10. Figure 1-1 below presents a time series of the Australian and New Zealand GDB Multilateral Total Factor Productivity (MTFP) index. This metric allows for a comparison across firms and across time. The solid blue line shows JGN's productivity measure and the dotted lines show the productivity measure of other Australian and New Zealand GDBs.

Figure 1-1: MTFP index[2]



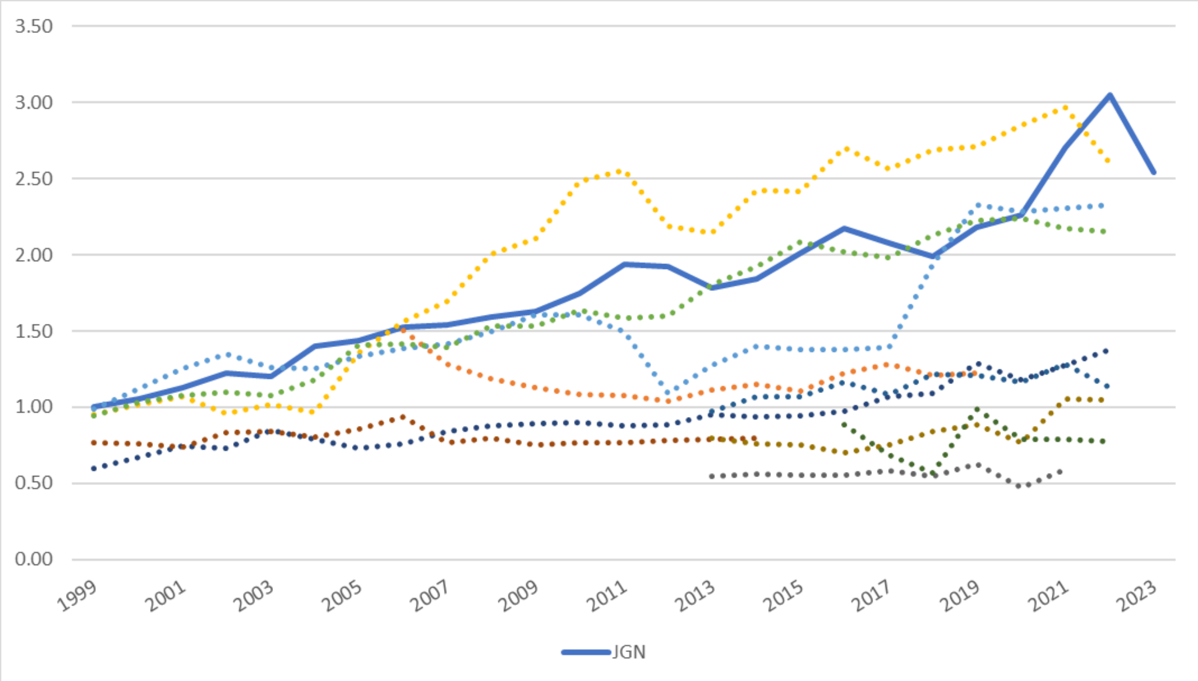
JGN data from 1999 to 2023. Comparison made against Australian and New Zealand GDBs.

11. This figure highlights that JGN consistently ranks in the top two or three amongst all the GDBs.

12. Figure 1-2 below presents a time series of the Australian and New Zealand GDB Multilateral Opex Partial Factor Productivity (PFP) index. Compared to the MTFP, the Multilateral Opex PFP compares the efficiency in the use of opex only, rather than all inputs, across firms and across time.

[2] ATCO is not included in the analysis due to lack of data on the breakdown of ATCO's pipes by pressure.

Figure 1-2: Multilateral Opex PFP index

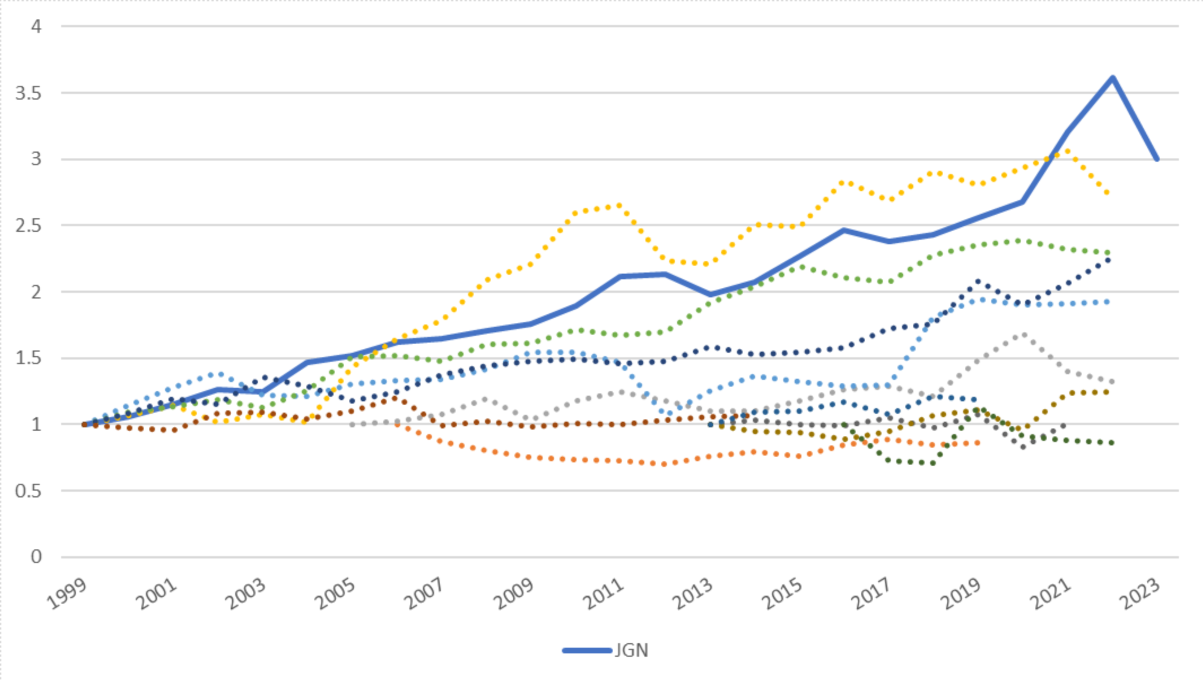


JGN data from 1999 to 2023. Comparison made against Australian and New Zealand GDBs.

13. This figure highlights that JGN consistently ranks in the top one or two amongst all the GDBs. In 2022, the most recent period we have data for the other Australian and New Zealand GDBs, JGN is ranked first across all the GDBs.

14. Figure 1-3 below shows the change in opex partial factor productivity (PFP) over time for each of the GDBs in Australia and New Zealand. The solid blue line shows JGN's productivity measure and the dotted lines show the productivity measure of other Australian and New Zealand GDBs. Figure 1-3 shows that JGN's opex productivity growth has been one of the fastest across Australian and New Zealand GDBs. This indicates that JGN's relative efficiency has improved at a faster rate than other GDBs. In other words, JGN is amongst the top performers on productivity improvements.

Figure 1-3: Opex partial factor productivity (PFP) index comparison



JGN data from 1999 to 2023. Comparison made against Australian and New Zealand GDBs.

15. In 2023, JGN's output per dollar of opex is approximately 3.0 times the base level measured in 1999. This has been achieved by JGN by:

    a. reducing real operating expenditure by 41% between 1999 and 2023; while

    b. delivering a 77% increase in outputs over the same period.

16. This is the fastest rate of increase in efficiency of any Australian and/or New Zealand GDB since 1999.

17. JGN's output per physical units of capital employed[3] has also increased and at a faster than average rate. In 2019, the latest date for which we have comprehensive data for other GDBs, JGN's output divided by its total assets (capital index) was 1.3 times higher than in 1999. This was higher than all but two other firms.

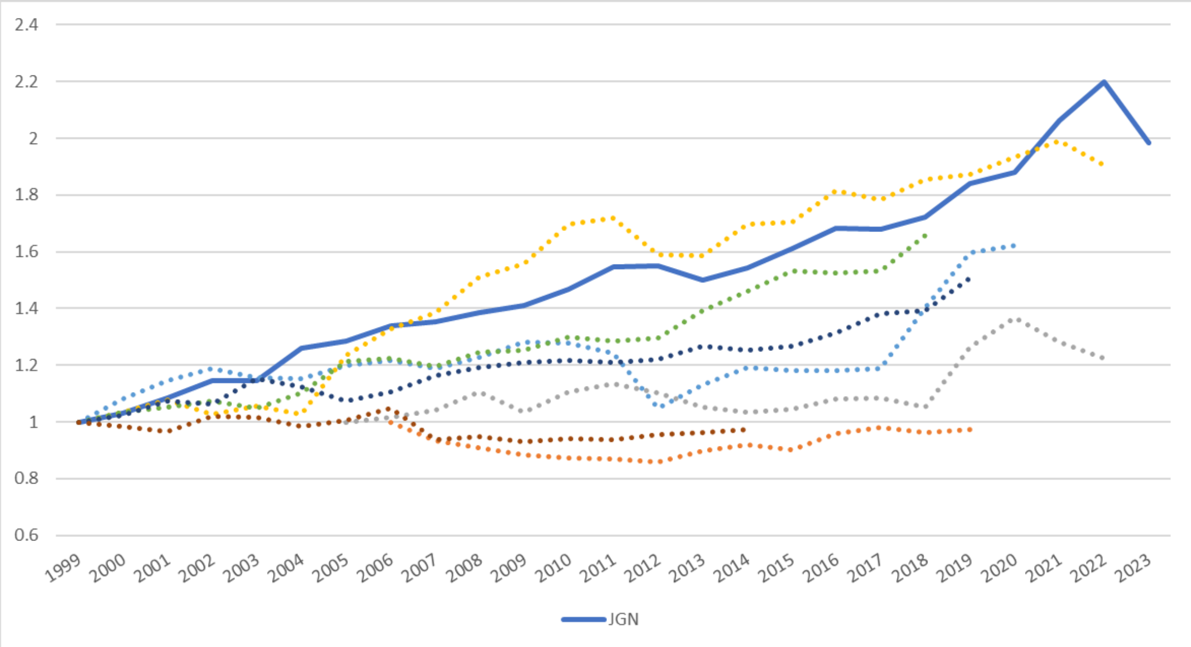
18. Consistent with the fastest growth in opex productivity and second fastest growth in efficiency using capital inputs, JGN has had the fastest growth of any GDB in total factor productivity between 1999 and 2023. JGN's total factor productivity (TFP) has almost more than doubled over that period. This is shown in Figure 1-4 below. By contrast, the average increase in total factor productivity for other firms was just 1.5 times[4] between 1999 and the most recent date that we have data for.

[3] The capital input index is constructed using a weighted average of 7 different quantity inputs (with the weights being their value in the RAB).

- Transmission network: The quantity of transmission network for each GDB is proxied by its transmission pipeline length.
- High pressure network km; medium pressure network km; low pressure network km; services network km; total number of meters: other assets – with each category weighted by its value in the RAB.

[4] This is measured between 1999 and the most recent date that we have data for, which varies by GDB. The average includes Evoenergy with data from 2006 to 2019; ATCO with data from 2005 to 2022; Ausnet and Multinet with data from 1999 to 2022; AGN Vic with data from 1999 to 2018; and AGN SA with data from 1999 to 2019. AGN QLD is not included because its data ends in 2014.

Figure 1-4: Total factor productivity (TFP) index comparison



JGN data from 1999 to 2023. Comparison made against Australian and New Zealand GDBs.

19. The Opex PFP and TFP results for JGN are consistent with the MTFP result (i.e., JGN has the fastest growth in productivity since 1999).

20. The evidence outlined above strongly supports a conclusion that JGN is operating efficiently.

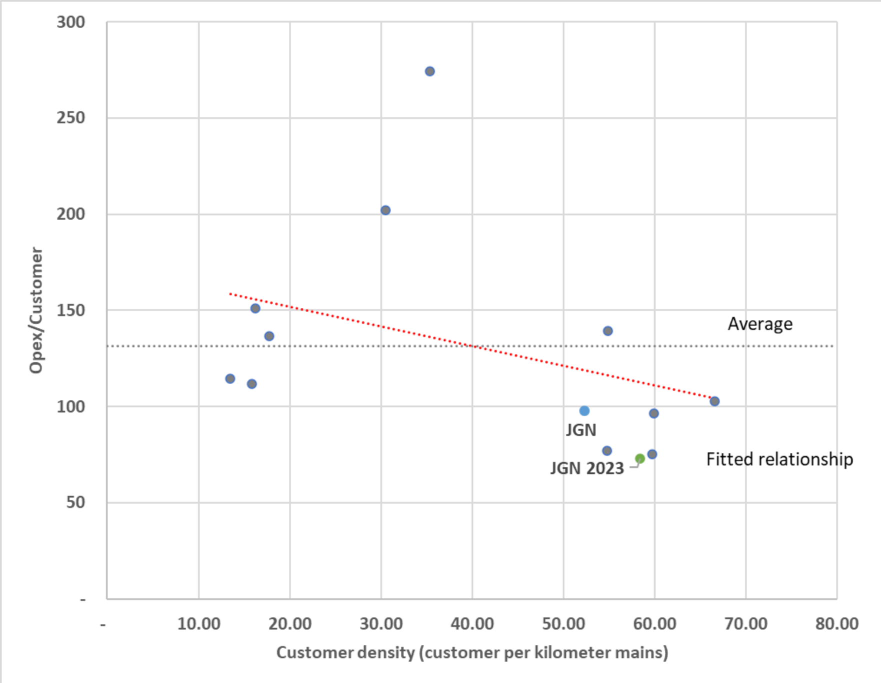
21. JGN has a lower than average opex per customer compared to the other Australian and New Zealand GDBs. This holds true whether the comparison is made over the period 2010 to 2022[5] or over the most recent five year period.

22. Additionally, JGN has lower than predicted levels of opex per customer when we perform simple linear adjustments for differences in customer and/or energy density across GDBs. The adjustment takes into account the change in the level of opex per customer as the number of customers or energy density changes through the use of trendlines. This is illustrated in Figure 1-5. This figure plots opex per customer on the vertical axis and network density on the horizontal axis. In both cases, JGN's average opex per customer from 2010 and onwards and the opex per customer in 2023 are below the predicted level for a firm with JGN's network density.

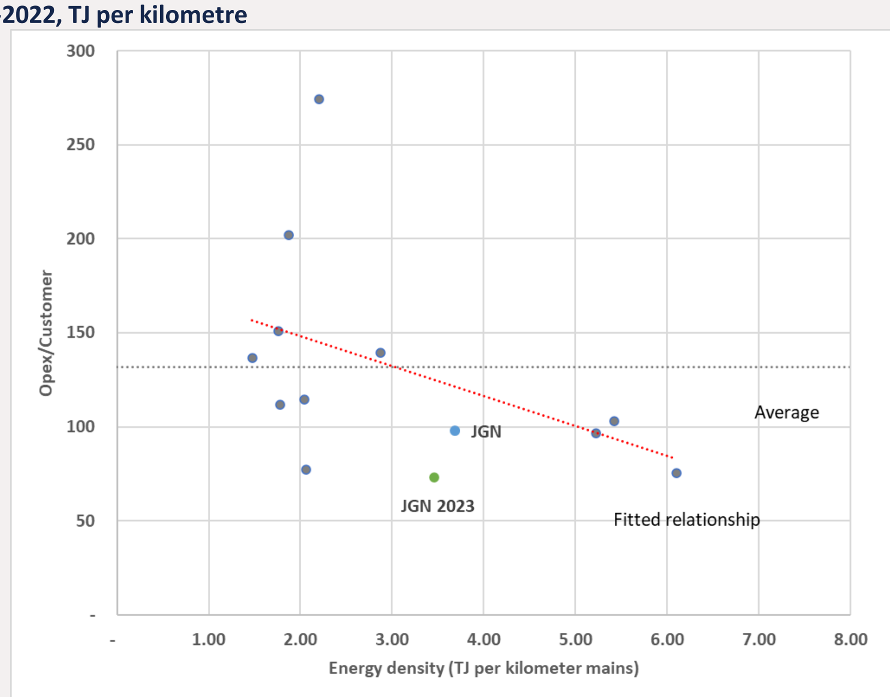
[5] 2022 is chosen as the last year sample to due to data availability across of Australian and New Zealand GDBs.

Figure 1-5: Opex per customer (2022 AUD)

a) 2010-2022, Customer per kilometre



b) 2010-2022, TJ per kilometre



23. This outcome provides evidence that JGN's level of operating costs is efficient relative to average industry level. This conclusion confirms evidence in the analysis of JGN's MTFP and TFP indices. This conclusion is further supported by econometric analysis outlined below.

24. In the econometric analysis, we have applied the same methodology that Economic Insights applied to JGN in its 2019 report[6] which the AER relied on when approving JGN's opex allowance over the current regulatory period.[7] We estimated an opex cost function, using regression techniques adopted by EI 2019[8], that explains the relationship between a GDB's opex and its drivers. Using the opex cost function, we compared JGN's opex to that of frontier. In the most recent year in which we have data for Australian and New Zealand GDBs, 2022, we calculate JGN to have the highest efficiency score compared to other GDBs.

25. JGN's efficiency score has increased from the long run average of 0.84 (from 2000 to 2022) to 0.92 in 2022. This indicates significant opex productivity growth over the sample period.

1.2.2 Output weight and productivity trend

26. We have calculated the relative weight of outputs contribution to changes in opex for Australian GDBs in addition to the trend of changes in opex productivity over time based on econometric analysis.

27. Table 1-1below presents our estimate of opex productivity over time, which we find reduces opex by 0.86% each year (when measured from 2000 to 2022), conditioning on all else equal.

Table 1-1: Coefficient on time trend

	Average of Econometric models (SFA and FGLS)*
Time trend	-0.86%

*Based on data from 2000 to 2022. *Stochastic Frontier Analysis (SFA) and Feasible Generalised Least Squared (FGLS)*

28. This productivity factor is more negative than JGN's current opex productivity factor of -0.74% for the current regulatory period.

29. The table below presents the weights to be applied to customer numbers and mains length to determine the weighted average output growth rate. The weights are determined by the relative value of the coefficients on each output in the regression model and are presented in Table 1-2 below.

Table 1-2: Estimated output weight

	SFA	FGLS	Average
Customer Weight	47.6%	49.5%	48.6%
Mains length Weight	52.4%	50.5%	51.4%

Based on data from 2000 to 2022.

[6] Economic Insights, Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), April 2019, Section 8 and Appendix D

[7] https://www.aer.gov.au/documents/aer-final-decision-jgn-access-arrangement-2020-25-alternative-estimate-opex-model-june-2020

[8] The regression techniques adopted from EI 2019 are Stochastic Frontier Analysis (SFA) and Feasible Generalised Least Squared (FGLS). See Appendix E for details.

2 Introduction

30. Jemena Gas Networks (JGN) has commissioned Competition Economists Group (CEG) to provide advice on the productivity and benchmarking of its gas distribution operations.

31. This report covers three areas of analysis

   a. Partial Performance Indicators (PPI): This report presents partial indicator comparisons between a set of 8 Australian and 4 New Zealand gas distribution businesses (GDBs). These partial performance indicators are analogous to those published by the Australian Energy Regulator for electricity distribution businesses (AER 2014).[9] The indicators compare the opex cost per customer across GDBs.

   b. Productivity Indices: This analysis examines JGN's total factor productivity (TFP) and partial factor productivity (PFP) trends, and compares against the productivity trends of other Australian 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 analysis similar to studies previously carried out for JGN by EI (2019)[10],

   c. Econometric Analysis: This report undertakes 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 by EI (2019)[11]. The outputs of the econometric analysis are used to:

      i. estimate the efficiency score of JGN relative to the frontier firm in the industry.

      ii. estimate the historical average rate of technical change; i.e. the rate of improvement in the efficient production frontier; and

      iii. estimate output index weights for use in projecting the opex rate of change over the next regulatory period.

32. This report has the following structure:

   a. Section 3 examines JGN's relative opex per customer, relative trend in productivity overtime and its relative efficiency compared to other Australian and New Zealand GDBs.

   b. Section 4 applies econometric approach to calculation JGN's base year opex efficiency and generate the inputs necessary to forecast JGN's opex growth over the 2026 to 2030 regulatory period.

   c. Appendix A provides a list of the GDBs included in the study.

   d. Appendix B provides a discussion on the data used in this study.

   e. Appendix C provides an expanded examination of JGN's opex productivity compared to other Australia New Zealand GDBs while controlling for multiple explaining variables that result in the differences in opex productivity across GDBs.

   f. Appendix D discusses the methodology adopted in calculating the trend in opex productivity and comparison using productivity indices.

[9] AER 2014, "Electricity Distribution network service providers, Annual benchmarking report, November 2014

[10] Economic Insights, Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), April 2019

[11] Economic Insights, Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), April 2019

g. Appendix E discusses the methodology adopted in generating the inputs necessary to forecast JGN's opex growth over the 2026 to 2030 regulatory period.

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3 Assessment of JGN efficiency of opex

3.1 Opex per customer comparisons

33. We begin by examining JGN's opex efficiency by comparing opex per customer across GDBs. Opex per customer is the most important criteria in evaluating the efficiency of GDBs. According to the AER:[12]

> *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.*

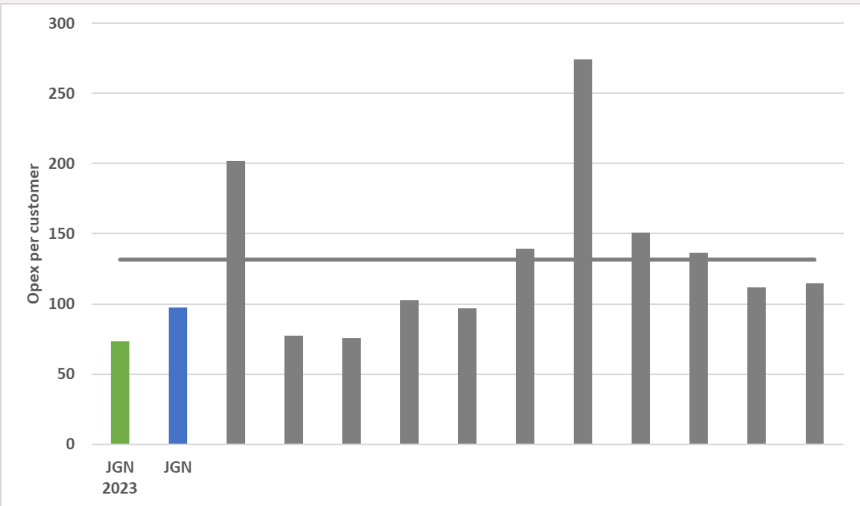
34. The measure of opex covers regulated distribution activities only and excludes all capital costs. It includes all operating costs allowed by the regulatory authorities, including directly employed labour costs, contracted services, materials and consumables, administration costs and overheads associated 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.[13]

35. The Australian GDBs opex cost data is first converted to nominal terms (where necessary) using the "All Groups Consumer Price Index" and the equivalent is done for New Zealand GDBs. The nominal series is then converted to real series in 2022 dollars using the same price index. The New Zealand GDBs opex data is converted to the 1999 base year and then converted to Australian dollars using the FY1999 average monthly exchange rate data published by the Reserve Bank of Australia (RBA). The Australian CPI index is used to express monetary values in 2022 Australian dollar.

36. The average opex per customer across Australian and New Zealand GDBs is illustrated by Figure 3-1 below – with JGN's average opex highlighted in blue (and green for 2023 opex). The result indicates that JGN's opex per customer is consistently below industry average (when compared between long run period (2010-2022)[14] and the shorter run period (2018-2022).

Figure 3-1: Actual opex per customer (2022 AUD)

a) 2010-2022

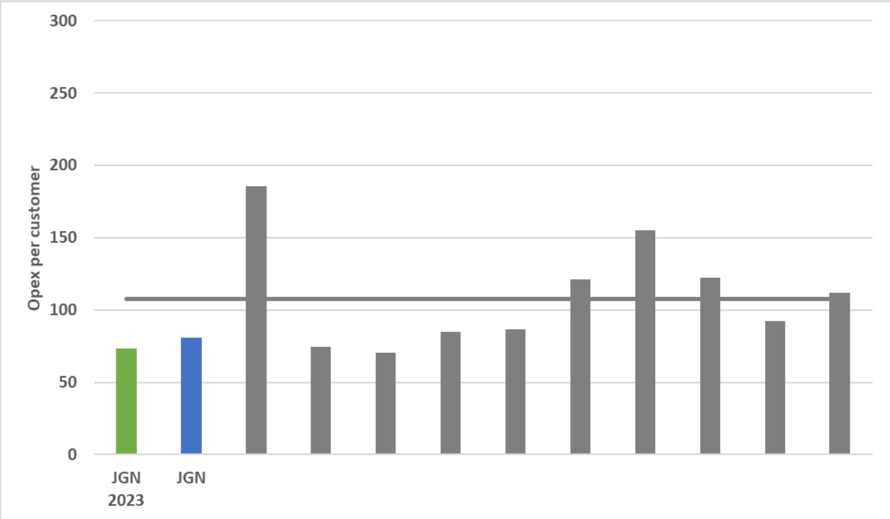


[12] AER 2014, "Electricity Distribution network service providers, Annual benchmarking report, November 2014 Page 23

[13] Similar adjustments are adopted in EI 2019 report where *"unaccounted for gas allowances for non-Victorian GDBs have been excluded to put those GDBs on a comparable basis with Victorian reporting"* (EI 2019 page 88)

[14] 2022 is chosen as the last year sample to due to data availability across of Australian and New Zealand GDBs.

b) 2018-2022



37. Opex per customer may vary with network characteristics such as the density of the network. Figure 3-2 below compares each GDB's opex per customer against their network density. Network density can be measured by either customer per kilometre or TJ per kilometre.

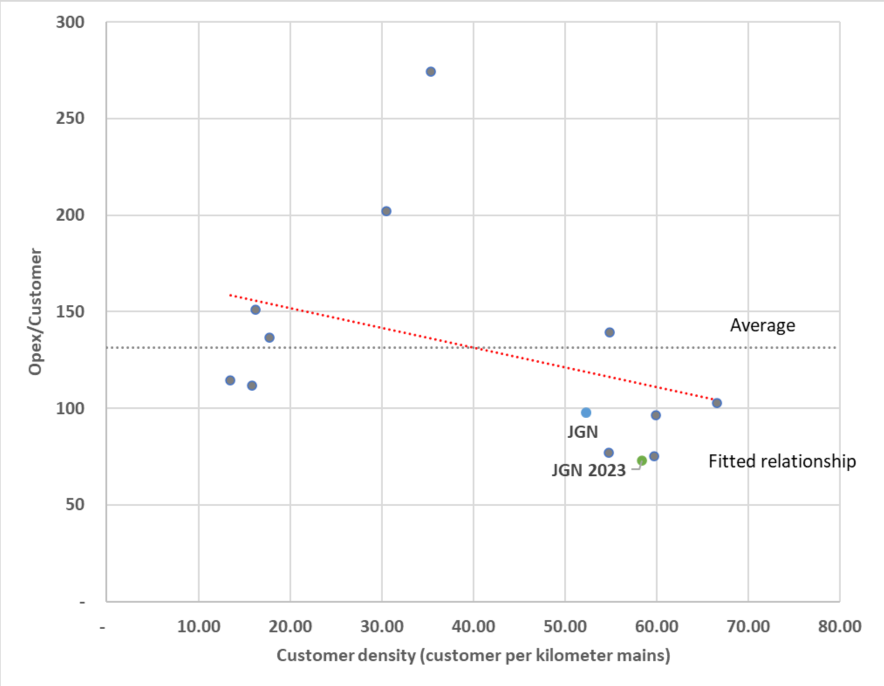
38. The grey line in Figure 3-2 shows the average opex per customer (this is the same horizontal line as is shown in Figure 3-1) and the red line shows the fitted relationship between opex per customer and network density (the horizontal axis). There is a decreasing relationship between opex per customer and density – with the GDB's that have the highest density tending to have the lowest opex per customer.

39. In Figure 3-2-a and Figure 3-2-b the blue dot is JGN's opex per customer and network density over the 2010 to 2022 period and is directly comparable to the blue dots for other GDBs. We also show a green dot for JGN which is the most recent year estimate.

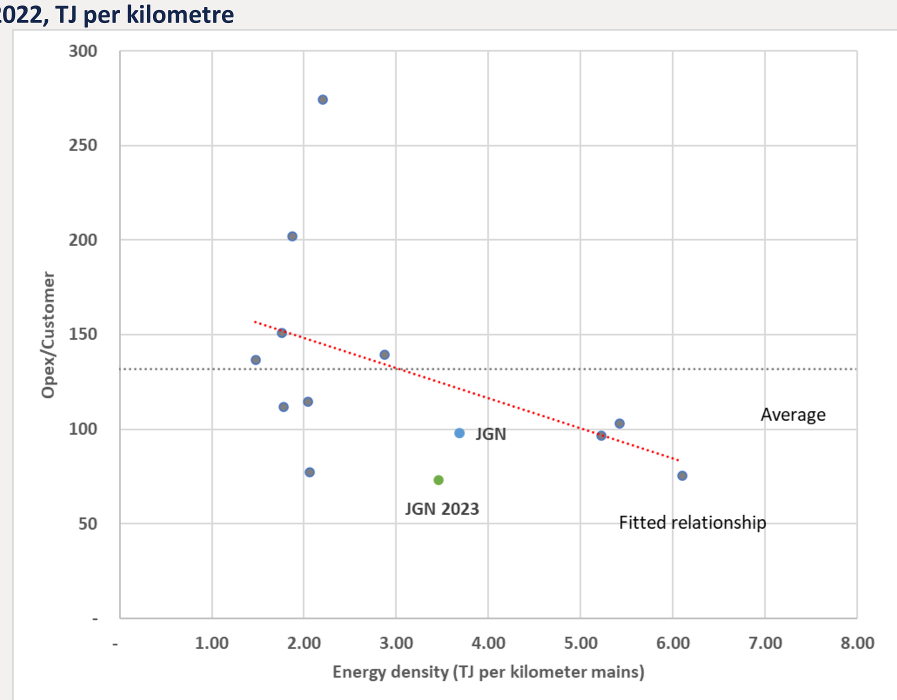
40. JGN's opex per customer is below the average GDBs' opex per customer (grey line) and also below the average opex per customer conditional on network density (red line). This indicates that even controlling for density, JGN has a below average opex per customer.

Figure 3-2: Opex per customer (2022 AUD)

a) 2010-2022, Customer per kilometre



b) 2010-2022, TJ per kilometre



41. In the most recent year (2023), JGN's opex per customer (green dot) has been below its average over 2010-22. JGN's lower opex per customer in 2023 is in line with what would be expected due to higher customer density per kilometre in 2023 (see Figure 3-2 a). However, if network density is measured in terms of TJ per kilometre, then this result flips and JGN's 2023 opex is lower despite being associated with lower network density (see Figure 3-2 b). The reduction in energy density may have

occurred due to a reduction in consumption per customer. This may be due to gas appliances becoming more energy efficient or reduction in the number of home appliances that use gas.

3.2 Productivity indices

42. This part of our report focuses on the total and partial factor productivity performance of JGN's NSW gas distribution business for the period from 1999 to 2023. Measures of productivity indices are calculated using time series and multilateral indices. These are used to compare JGN's productivity growth rates and productivity levels, respectively, with those of other GDBs in Australia and New Zealand.

43. The index analysis (Section 3.2.1) involves forming indices of outputs and inputs using the Fisher index method. This index provides the best measures of the relative changes over time of inputs and outputs for each GDB. 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).

44. This specification is consistent with the analogous electricity distribution output and input specification presented in AER (2013)[15]. It is also consistent with the specification presented by Economic Insights (EI) in 2019[16]. The time series productivity indices use the first year of data as the base–year for each individual GDB, and the analysis provides estimates of productivity growth over the period 1999 to 2023.

45. There are two types of indices, total factor productivity (TFP) and partial factor productivity (PFP). PFP is a partial measure of productivity in which the measure of output is compared against a subset of inputs. TFP measures the productivity of outputs against all inputs used in the production. While these measures are useful for understanding trends across time, they cannot simultaneously be used to compare productivity levels across time and between GDBs due to the violation of the statistical property of transitivity (see Appendix D.4 for a technical description).

46. We then extend this analysis by introducing the Multilateral TFP (or MTFP) index (in Section 3.2.2). 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.

47. The MTFP yields less precise measures of the change in productivity over time compared to the Fisher index method and is therefore only used for comparing TFP levels of GDBs in this report.

3.2.1 PFP and TFP trends

48. The purpose of a productivity index is to measure the relative ratio of an index of outputs compared to an index of inputs. Indices are constructed by aggregating prices or quantities of products that may be measured in different units and therefore cannot be aggregated based on a simple average.

49. 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 outputs relative a subset of inputs (e.g. labour productivity is the ratio of output to labour input).

[15] AER. 2013. "Better Regulation Explanatory Statement: Expenditure Forecast Assessment Guideline"

[16] EI report (2019), Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), 24 April 2019

50. PFP and TFP indices have a number of advantages including:

   a. indexing procedures are simple and robust;

   b. they can be implemented when there are only a small number of observations;

   c. the results are readily reproducible;

   d. they have a rigorous grounding in economic theory;

   e. the procedure imposes good disciplines regarding data consistency; and

   f. 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.

51. The output and input indices are constructed using a formulation known as the Fisher ideal index. Similar to calculating the weighted average of outputs and inputs, one of the key benefits of the Fisher index is its ability to deal with changing weights over time. A detailed discussion of the Fisher index is contained in Appendix D.3.

52. The outputs produced by GDBs are defined in this study as:[17]

   a. Customers: Connection dependent and customer service activities are proxied by the GDB's number of customers, and

   b. System capacity: The system capacity measure 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.

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

53. We've adopted the same output weights as EI report (2019) (49% customers and 38% system capacity, 13% throughput).[18] Adoption of this weight is appropriate given the consistency in the use of this weight in the benchmarking of GDBs. The same weight is used 2012 by Economic Insights in its report for Envestra Victoria, Multinet and SP Ausnet.[19] Economic Insights continued to use the same weights in its 2020 report for AGN SA.[20] The weights are constructed based on the share of each output's estimated costs in the total estimated costs for all GDBs over a period. In the case of fixed weights, where weights don't change over time, the Fisher formulation is equivalent to weighted average.

54. Figure 3-3 shows the trends in JGN's outputs over time and its output index, it shows the number of customers (dashed grey) and system capacity (dashed yellow) has increased for JGN, but a reduction in the amount of gas (dashed red) delivered over time. Note that the temporary dip in system capacity in 2018 is a statistical artefact.[21] The weighted average of the outputs is summarised by the output index shown in solid blue.

[17] Details on the outputs are in Appendix D.1.4.3Appendix D.1

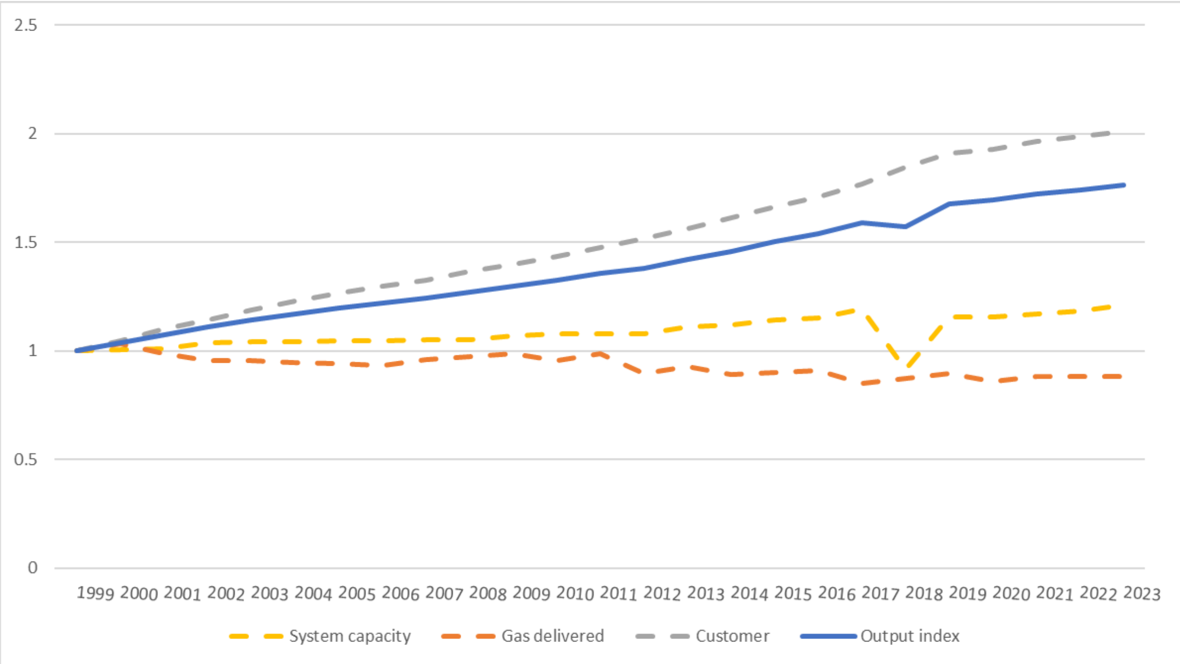
[18] See page 38 in EI report (2019), Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), 24 April 2019

[19] EI Report (2012), The total Factor Productivity Performance of Victoria's Gas Distribution Industry, 26 March 2012

[20] EI Report (2020), The Productivity Performance of Australian Gas Networks' South Australian Gas Distribution System, 15 June 2020

[21] The dip in system capacity in 2018 is the due to the change in JGN system where the diameter of the pipes where reduced and the pressure increased to offset the reduction in the diameter. However, the system recorded a delay in the increase in the pressure resulting in a dip in system capacity.

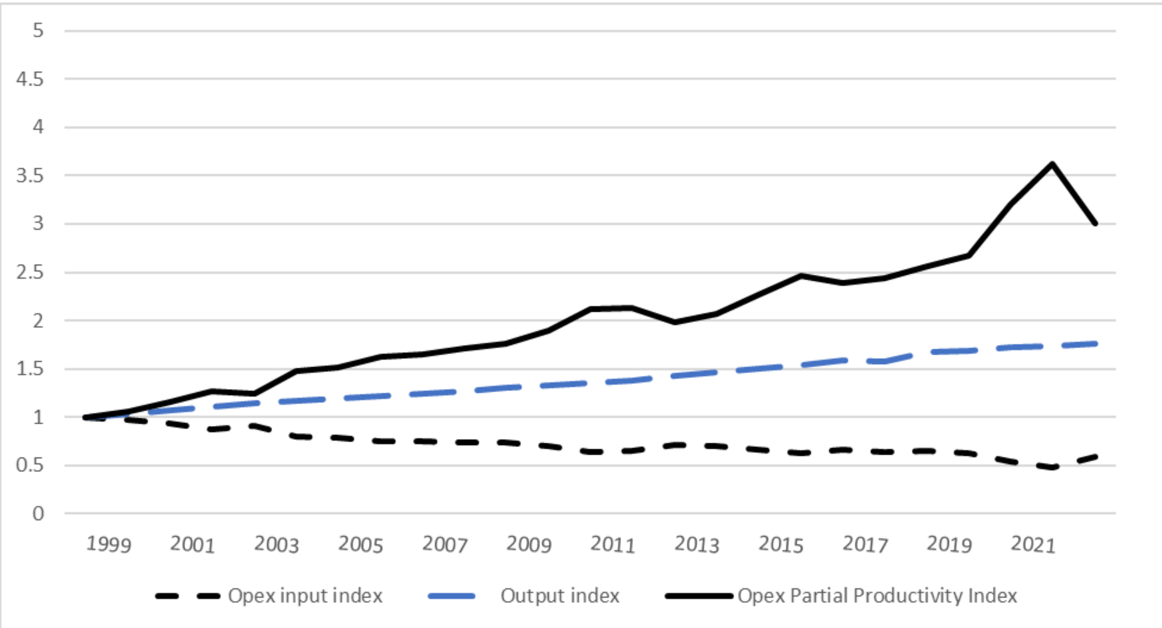
Figure 3-3: Trend in JGN outputs



JGN data from 1999 to 2023.

55. Figure 3-4 shows the growth in real opex and real outputs. When the output index is divided by the opex input index, it shows the trend of opex partial productivity over time. Opex PFP has increased materially over time due to the increase in output and decrease in opex over time.

Figure 3-4: JGN opex productivity index



JGN data from 1999 to 2023.

56. JGN's 2023 output per dollar of opex is approximately 3.0 times the base level measured in 1999. This is due to JGN:

a. reducing real operating expenditure by 41% between 1999 and 2023; while

b. delivering a 77% increase in outputs over the same period

57. The result also indicates a temporary increase in opex productivity in 2021 and 2022 before returning to the long run trend in 2023. The temporary increase in opex productivity in 2021 and 2022 is likely due to the impact of the Covid pandemic.

58. We now turn our analysis to TFP calculations that take account of both opex and capital inputs used by GDBs. The relevant inputs that we consider in our analysis include:[22]

a. Opex: The quantity of the GDB's opex is derived by deflating the value of opex by the opex price deflator.

Australian opex cost data are converted to real values using 62% weight on Electricity, water and gas wage price index and 38% weight evenly divided between Domestic Materials; Data processing, web hosting and electronic information storage services; Legal and accounting services; Market research and statistical services; and Other administrative services.[23]

Similar New Zealand indices are used for New Zealand GDBs' opex. The costs are converted to the FY1999 base year so that the New Zealand data are then converted to Australian dollars using the FY1999 average monthly exchange rate data published by the RBA. Then the Australian index is used to express monetary values in 2022 Australian dollar.

b. Capital:

i. Transmission network: The quantity of transmission network for each GDB is proxied by its transmission pipeline length.

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

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

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

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

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

vii. Other assets: The quantity of other capital inputs is proxied by their deflated asset value. The assets are deflated using the CPI.

59. Each capital input is weighted based on the relative contribution of their asset value in the aggregate value of the regulatory asset base (RAB).

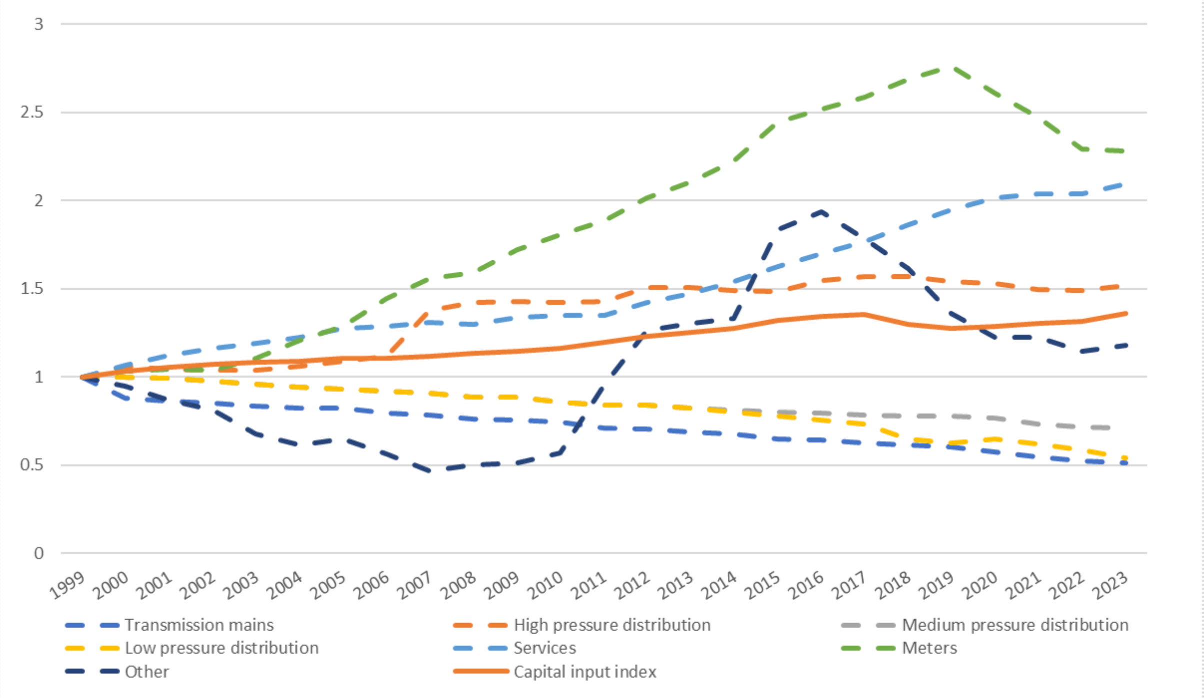
60. The trend of each capital input is shown in Figure 3-5 as the dashed lines. The weighted average, calculated using the Fisher index, is shown in the solid orange line.[24]

[22] Details on the inputs are in Appendix D.2.

[23] The weights are consistent with EI report (2019). See page 39 in EI report (2019), Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), 24 April 2019

[24] Due to change in weights over time, the Fisher index differ from a simple weighted average.

Figure 3-5: JGN capital inputs

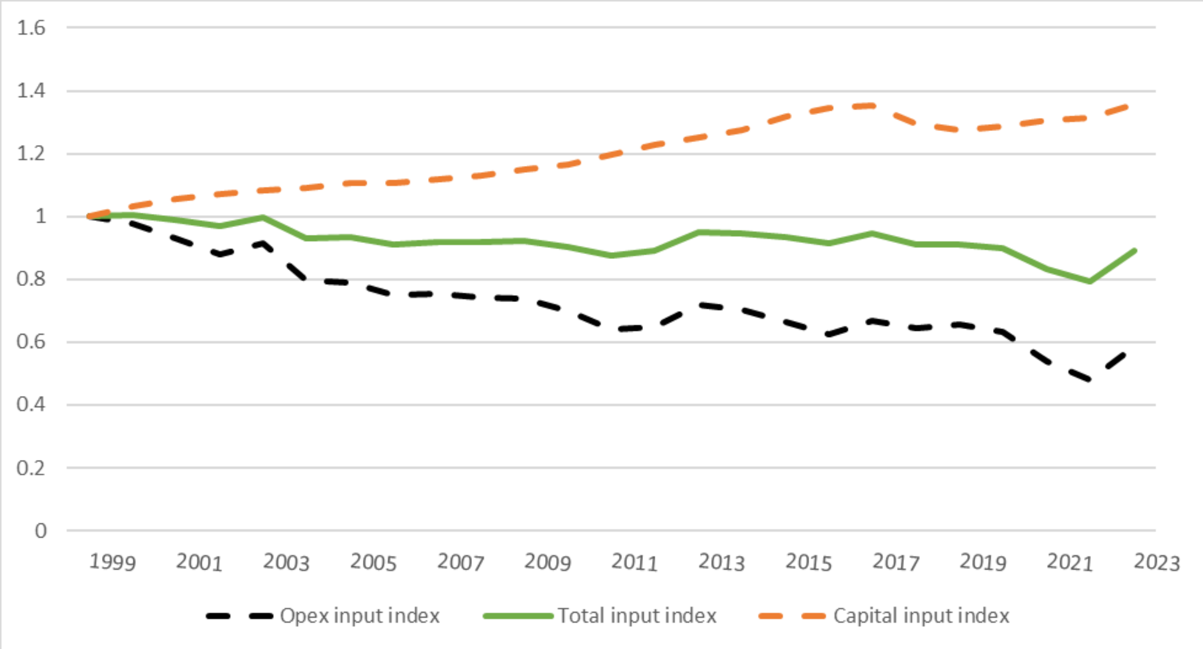


JGN data from 1999 to 2023.

61. The capital inputs are combined with opex to form the aggregate input index. The weighting used to combine opex and capital inputs is based on the relative contribution to the cost of capital and opex. Cost of capital is proxied using the difference between revenue and opex. We adopted this approach based on historical precedents.[25] The input indices are shown in Figure 3-6. It shows that while capital inputs have increased slightly over time, opex reduced over the same time period. The net result is a reduction in total input used.

[25] See page 36 in EI report (2019), Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), 24 April 2019

Figure 3-6: JGN input index



JGN data from 1999 to 2023.

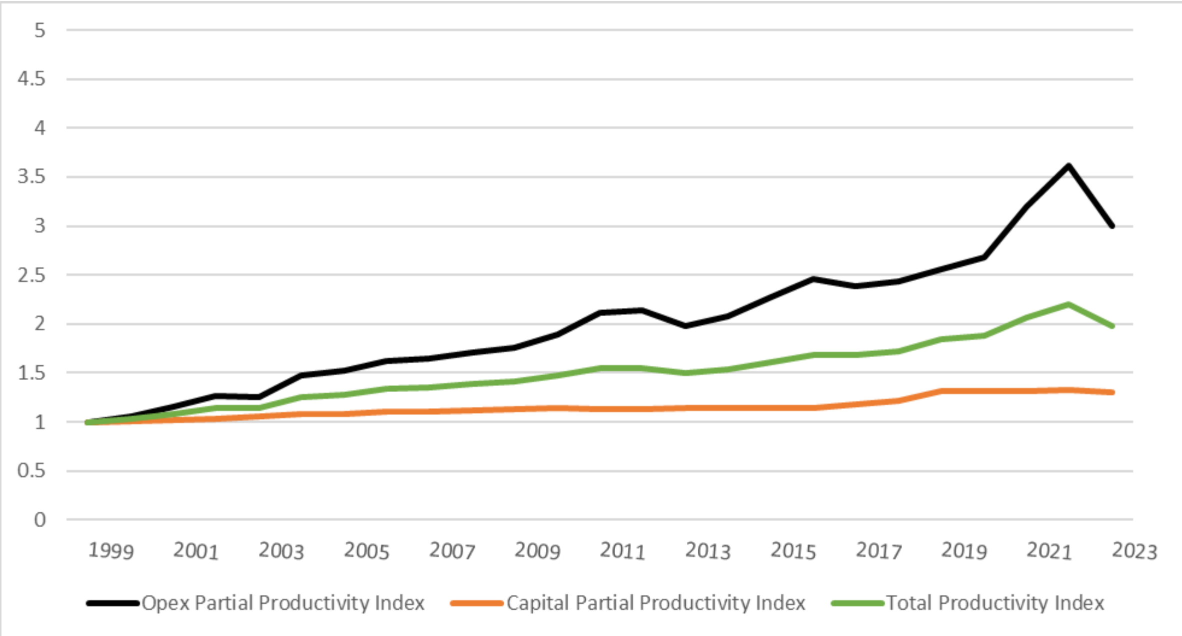
62. The ratio of the output index and aggregate input index gives the TFP index. This is shown in Figure 3-7 below which highlights that output has increased while inputs have reduced over the same period. As a result, JGN has experienced an increase in TFP of 1.98 over time. That is, JGN is 98% more efficient in 2023 than in 1999 (produces 98% more output per unit of input).

Figure 3-7: JGN TFP index

JGN data from 1999 to 2023.

63. Figure 3-8 shows all three JGN's productivity indices, opex, capital and total productivity. It shows an increase in productivity across opex and capital inputs.

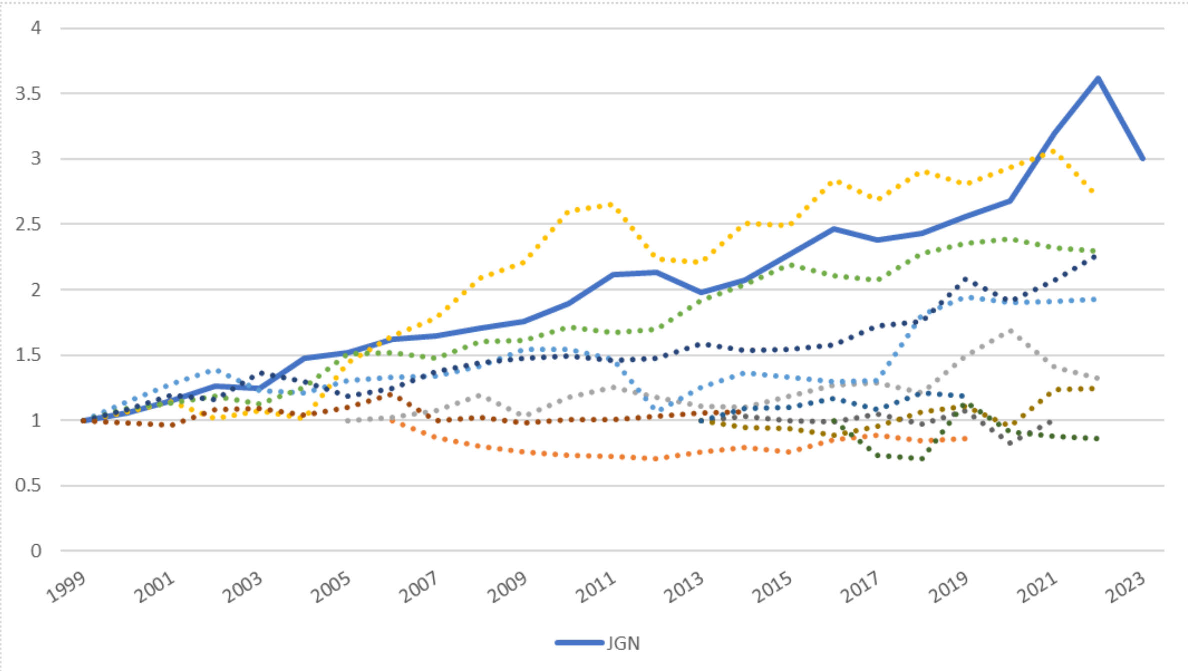
Figure 3-8: JGN TFP and PFPs



JGN data from 1999 to 2023.

64. Figure 3-9 compares opex PFP trends across GDBs. It can be seen that JGN achieved greater productivity growth compared to all Australian and New Zealand GDBs. We find that despite the reduction in opex productivity in 2023 compared to 2022, JGN's overall growth continues to be the strongest across all Australian and New Zealand GDBs. This indicates that JGN has consistently been the top performer on opex productivity compared to other GDBs historically.

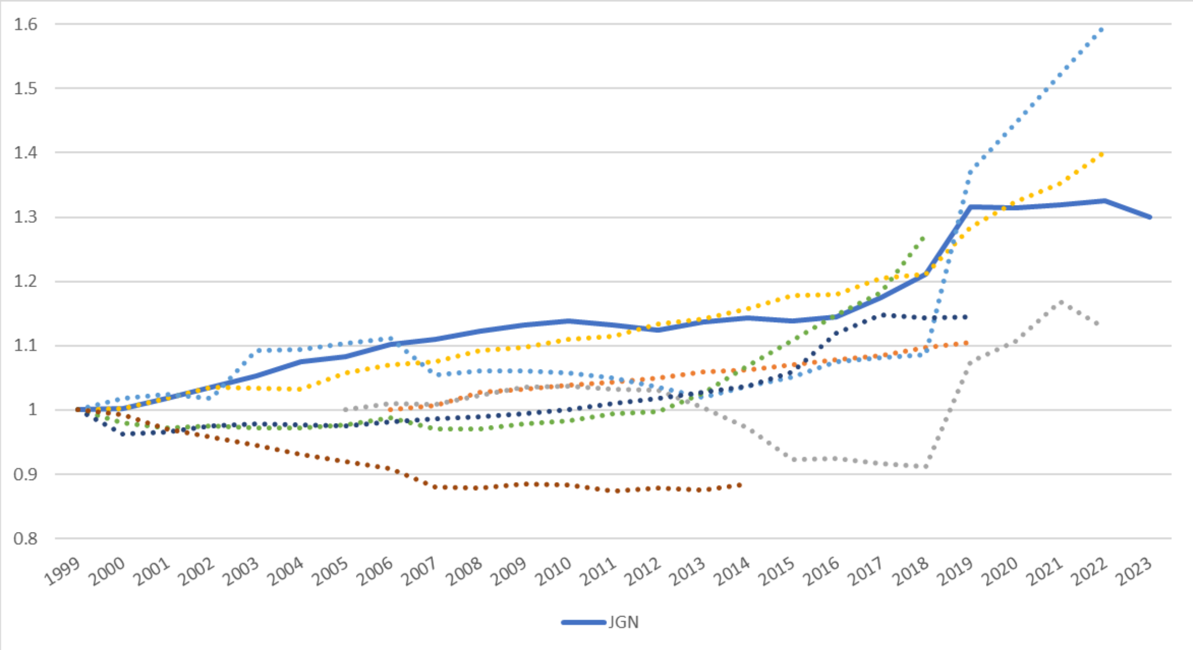
Figure 3-9: Opex partial productivity index comparison



JGN data from 1999 to 2023. Comparison made against Australian and New Zealand GDBs where data is available.

65. JGN's partial capital productivity has also increased at a faster than average rate for JGN than other GDBs. In 2019, the latest date for which we have comprehensive data for other GDBs, JGN's output divided by its total assets (capital index) was 1.3 times higher than in 1999. This was higher than all but two other networks[26]. In 2022 JGN has the third highest capital partial productivity growth (noting that the dataset is incomplete in 2022).

Figure 3-10: Capital partial productivity index comparison



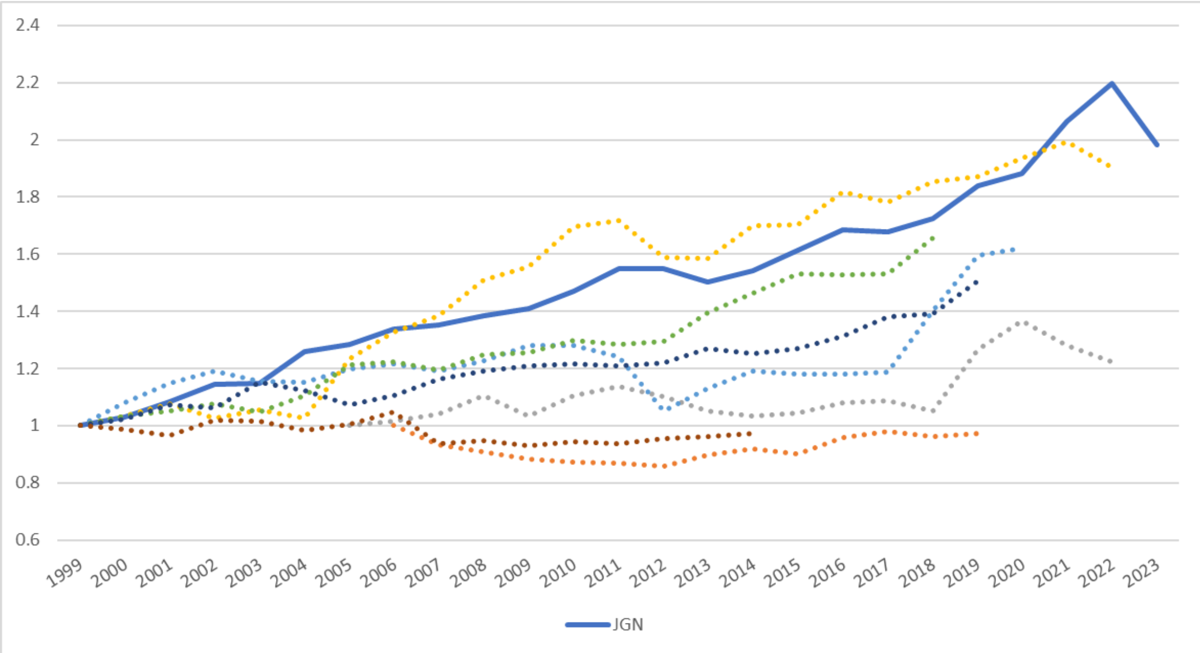
JGN data from 1999 to 2023. Comparison made against Australian GDBs where data is available. New Zealand GDBs not included due to lack of data.

66. Consistent with having the fastest opex partial productivity growth and above average capital partial productivity growth, JGN has had the fastest total factor productivity (TFP) growth of any GDB between 1999 and 2023, as shown in Figure 3-11 below.

67. JGN's total factor productivity has approximately doubled over that period. By contrast, the average increase in total factor productivity for other GDBs was 50% between 1999 and the most recent date that we have data for (which varies by GDB).

[26] For the GDB that saw the largest increase in capital partial productivity (dotted blue line), its large increase in capital productivity is due to a 70% reduction of low pressure distribution network in 2019.

Figure 3-11: Total factor productivity index comparison



JGN data from 1999 to 2023. Comparison made against Australian GDBs where data is available. New Zealand GDBs not included due to lack of data.

3.2.2 Multilateral productivity index

68. This section presents the productivity index calculated based on the multilateral translog TFP (MTFP) index methodology. Traditional productivity index measures allow a comparison of productivity either across time or across firms. However, they are not useful in determining relative productivity differences across both time and firms due to the inability to satisfy the transitivity requirement.

69. An example of transitivity is if A is twice as efficient as B and B is twice as efficient as C, then A ought to be four times as efficient as C. Traditional productivity index measures maintain transitivity when comparisons are made either across time or across firm, but not when comparisons are made across time and firms.

70. To address this limitation of traditional productivity indices, Caves, Christensen and Diewert (1982) developed the MTFP index which satisfies the requirement of transitivity when comparisons are made across time and firms. The trade-off is that this methodology imposes assumptions on the data and, therefore, an element of scepticism is appropriate when comparing efficiency across firms and across time. Details on the methodology are in Appendix D.4.

71. Nonetheless, the MTFP results for JGN are consistent with the PFP and TFP results (i.e., JGN has the fastest growth in productivity since 1999). We have applied the MTFP methodology to produce 3 indices which can be compared across time and GDBs, which include the:

    a. Multilateral Opex PFP index,

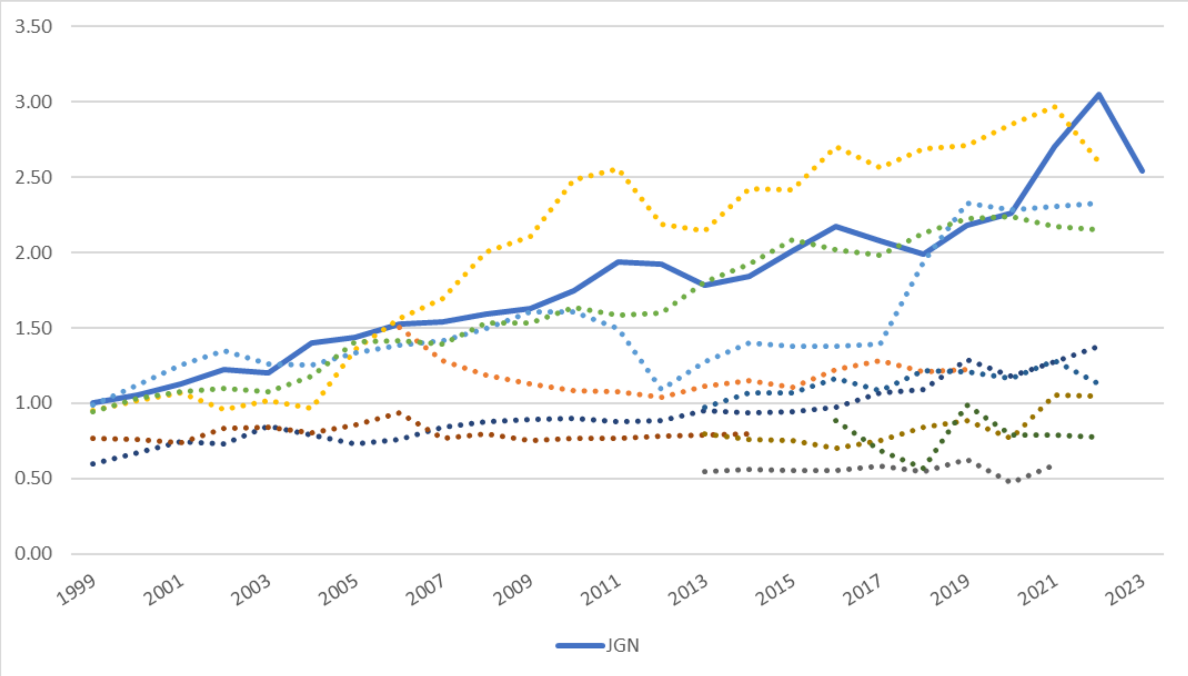
    b. Multilateral Capital PFP index, and

    c. MTFP index

72. These differ in the same ways as the non-multilateral versions of each index (i.e., being derived from an opex or capital index or both).

73. Figure 3-12 shows JGN's opex partial productivity compared across time and compared to other Australian and New Zealand GDBs. The result shows JGN consistently ranks in the top two or three amongst all the GDBs. In 2022, the most recent period we have data for the other Australian and New Zealand GDBs, JGN is ranked first across all the GDBs. While, in 2023, JGN's measure decreased from the 2022 level post-COVID, it would still rank second compared to the 2022 productivity measure of Australian and New Zealand GDBs.

Figure 3-12: Multilateral Opex PFP index[27]

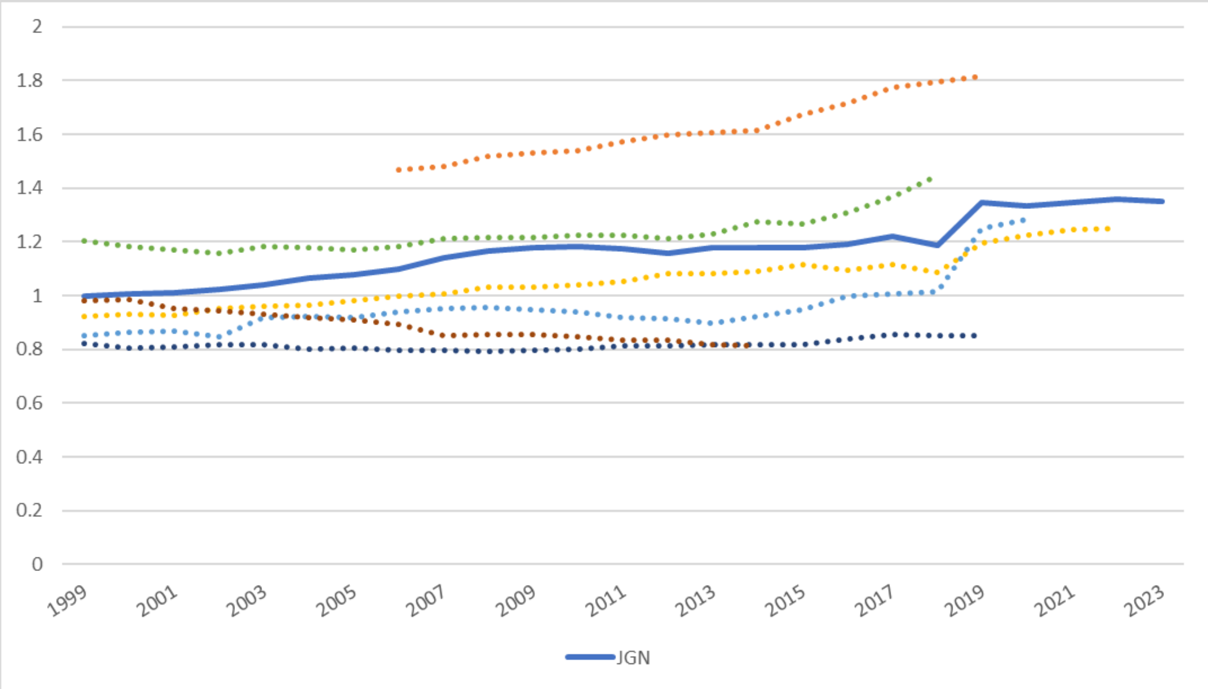


JGN data from 1999 to 2023. Comparison made against Australian and New Zealand GDB where data is available.

74. Figure 3-13 compares JGN's capital productivity against Australian GDBs. This figure shows that JGN is ranked amongst the top three Australian GDBs consistently over time.

[27] ATCO is not included in the analysis due to lack of data breakdown of pipes by pressure.

Figure 3-13: Multilateral Capital PFP index[28]

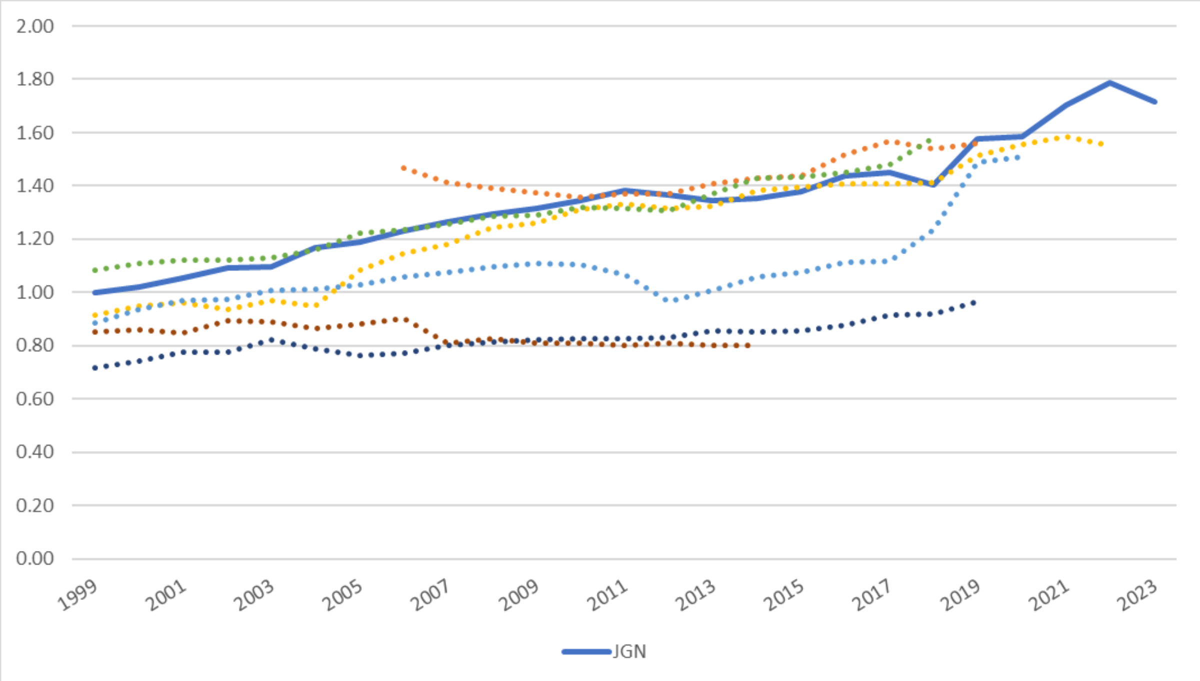


JGN data from 1999 to 2023. Comparison made against Australian GDBs where data is available. New Zealand GDBs not included due to lack of data.

75. Figure 3-14 compares JGN's total productivity against Australian GDBs. It can be seen that on this measure JGN is the most efficient firm in 2022 and JGN's level of efficiency in 2022 is higher than all other GDB's level of efficiency as estimated in the last year for which we have data (noting that the recent data we are missing are capital inputs for GDBs). We also find JGN's 2023 measure would continue to rank it as the most efficiency firm compared to the 2022 level of other Australian GDBs.

[28] ATCO is not included in the analysis because we don't have correct breakdown of ATCO's pipes by pressure.

Figure 3-14: Multilateral total factor productivity index[29]



JGN data from 1999 to 2023. Comparison made against Australian GDBs where data is available. New Zealand GDBs not included due to lack of data.

76. In summary, our analysis on the Multilateral Opex PFP, Multilateral Capital PFP and MTFP indices have shown that JGN ranks highly when compared to other individual GDB's and in aggregate, evidenced by JGN being above the average of the Australian and New Zealand GDB's in all periods.

77. Furthermore, the MTFP results for JGN are consistent with the PFP and TFP results (i.e., JGN has the fastest growth in productivity since 1999) which provides consistent evidence that JGN is operating efficiently.

[29] ATCO is not included in the analysis because we don't have correct breakdown of ATCO's pipes by pressure.

4 Econometric based output weight, productivity trend and efficiency

78. We fit a regression to Australian GDB data to derive

    a. JGN's base year efficiency score;

    b. the relative weight of different outputs in their impact on opex; and

    c. productivity time trend for Australian GDBs.

    We adopted the same model specification that Economic Insights (EI) adopted in 2019[30], which the AER relied on to forecast opex over the current regulatory period (July 2020 – June 2025).[31]

79. The regression estimates the real value of opex on the following variables:

    a. Outputs: Customer numbers and mains length

    b. Fixed capital: real value of the regulatory asset base (lnRAV)

    c. Time trend

    d. Operating environmental variables

        i. Proportion of mains not cast iron or unprotected steel (lnNCI);

        ii. Number of city gates (lnCG); and

        iii. Tariff customer share of total gas throughput (lnVSHR).

80. The model takes the Cobb-Douglas form where all the terms are in log form except for the time trend. The result is based on data from 2000 to 2022

81. The Australian GDBs' opex cost data is first converted to nominal terms (where necessary) using the "All Groups Consumer Price Index" in Australia. The nominal series is then converted to a real series expressed in 2022 dollars using the same price index.

82. Consistent with the methodology in EI 2019, we adopt two econometric methodologies, Feasible Generalised Least Squared (FGLS) and Stochastic Frontier Analysis (SFA). Details on the two methodologies are discussed in the Appendix E.

83. Economic Insights explained their choice of model in section 8 and Appendix D of their report. The following quote summarises the basis for selecting this model.[32]

    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;*

[30] Economic Insights, Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), April 2019, Section 8 and Appendix D

[31] https://www.aer.gov.au/documents/aer-final-decision-jgn-access-arrangement-2020-25-alternative-estimate-opex-model-june-2020

[32] Economic Insights, Relative Efficiency and Forecast Productivity Growth of Jemena Gas Networks (NSW), April 2019, Section 8 and Appendix D

- *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 SFA or FGLS models.*

84. Our regression results are as follows.

Table 4-1: Regression results (estimated using FGLS and SFA methods)

	SFA Model coefficients	FGLS Model coefficients
Outputs		
Ln (Customer numbers)	0.41	0.46
Ln (Mains length)	0.46	0.47
Output weight		
Customer numbers	47.6%	49.5%
Mains length	52.4%	50.5%
Environmental variables		
lnRAV	0.01	0.02
lnNCI	-1.47	-2.33
lnVSHR	-1.07	-0.04
lnCG	0.04	0.04
Time trend		
Time trend	-1.03%	-0.69%
Sample size	234	234

Based on data from 2000 to 2022.

85. In our regression real RAB has a positive sign (higher real RAB is associated with higher opex). This is the same sign as EI 2019. The result indicates that larger businesses with increased capital have larger opex.

86. Our estimate of the coefficient for proportion of mains not cast iron or unprotected steel is negative, the same sign as EI 2019. This is because a higher percentage of protected pipes implies lower maintenance and repair expenses. Our estimates of the coefficient for the number of city gates is positive, same as EI 2019. Increased number of city gates implies more inputs are needed to maintain a more geographically dispersed network. Our estimate of the coefficient for proportion of tariff V customers is negative. This suggests the average cost per low volume tariff V customer, customers that typically use less than 10TJ/year, is less than the average cost per high volume customer.

4.1 Productivity trend change

87. The estimated coefficient on the time variable measures the estimated average rate of opex change per annum holding other factors constant.

Table 4-2: Coefficient on time trend

	SFA	FGLS	Average
Time trend	-1.03%	-0.69%	-0.86%

Based on data from 2000 to 2022.

88. The time trend picks up any residual trends in opex that are not explained by changes in outputs and other variables in the regression. The estimates obtained are -1.03 and -0.69 per cent per annum (with an average of -0.86 per cent). This represents the average reduction in real opex requirements per year associated from frontier shift.

4.2 Output growth

89. This section presents the weights that are applied to customer numbers and mains length in order to determine the weighted average output growth rate. The weights are determined by the relative value of the coefficients on each output in the regression model.

Table 4-3: Estimated output weight

	SFA	FGLS	Average
Customer Weight	47.6%	49.5%	48.6%
Mains length Weight	52.4%	50.5%	51.4%

Based on data from 2000 to 2022.

4.3 Efficiency

90. JGN's efficiency score in the 22 year period from 2000 to 2022 is 0.84, which is significantly higher than the average efficiency score of all GDBs of 0.72.

91. However, this efficiency is not indicative of JGN's current's relative efficiency. It is only indicative of the average efficiency from 2000 to 2022. In order to compare JGN's current relative efficiency, we use the below methodology to calculate the 2022 only efficiency score for Australian and New Zealand GDBs.

92. The first step in the methodology is to calculate predicted opex of the Australian and New Zealand GDBs based on their 2022 values assuming all the GDBs are at the same particular efficiency level. This is calculated by applying estimated coefficients on the 2022 values of each GDB. The estimated dummy variables are not used in this case because the intent in the first step is to calculate the log of opex assuming all GDBs are at the same efficiency level, and the estimated dummy variables is a proxy for the difference in efficiencies. The formula is shown below.

$$\begin{aligned} Normalised\ ln\ Opex_{j,2022} &= \beta_{cust}\, ln\ Cust_{j,2022} + \beta_{main\ length}\, ln\ Main\ Length_{j,2022} + \beta_{RAV}\, ln\ RAV_{j,2022} \\ &+ \beta_{NCI}\, ln\ NCI_{j,2022} + \beta_{VSHR}\, ln\ VSHR_{j,2022} + \beta_{CG}\, ln\ CG_{j,2022} + \beta_{time} 2022 \end{aligned}$$

where

$ln\ Cust_{j,2022}$ is the log of number of customers for GDB j in 2022;

$ln\ Main\ Length_{j,2022}$ is the log of main length for GDB j in 2022;

$ln\ RAV_{j,2022}$ is the log of real value of regulatory asset base for GDB j in 2022;

$ln\ NCI_{j,2022}$ is the log of proportion of mains not cast iron or unprotected steel for GDB j in 2022;

$ln\ VSHR_{j,2022}$ is the log of tariff customer share for GDB j in 2022;

$ln\ CG_{j,2022}$ is the log of number of city gates for GDB j in 2022;

β_i is the estimated coefficient for variable i.

93. The second step is to calculate the difference in the log of actual opex and normalised opex. We call the difference, the residual. The formula is show below.

$$Residual_j = ln\ Actual\ Opex_{j,2022} - Normalised\ ln\ Opex_{j,2022}$$

94. The third step is to calculate the relative efficiency of each GDB. The formula is given as follows. It follows the same methodology as the formula used to calculate the standard efficiency score.

$$Efficiency\ score_j = \exp\left(\min_k(Residual_k) - Residual_j\right)$$

where

$\min_k(Residual_k)$ is the min value of the residual across all the GDBs.

95. The formula for the standard efficiency score is commonly adopted in benchmarking of opex efficiency for electricity distribution businesses.[33]

96. The results indicate that JGN is the most efficient GDB in 2022 with an efficiency score of 0.98. The average efficiency score across all GDBs in 2022 is 0.80.

[33] See Section A5.1 in Economic Insights (2020), "Economic Benchmarking Results for the Australian Energy Regulator's 2020 DNSP Annual Benchmarking Report." 13 October 2020.

Appendix A List of GDBs included in the study

97. The Australian and New Zealand GDBs included in this study are

    a. AGN Queensland
    b. AGN South Australia
    c. AGN Victoria
    d. ATCO
    e. AusNet
    f. Evoenergy
    g. First Gas
    h. GasNet
    i. JGN
    j. Multinet
    k. Powerco
    l. Vector

COMPETITION ECONOMISTS GROUP

Appendix B Data

98. The analysis of the opex partial performance indicator section of the report uses a dataset that includes 12 GDBs, including 8 Australian and 4 New Zealand GDBs. The data for the eight Australian GDBs (AusNet, AGN QLD, AGN SA, AGN Vic, Evoenergy, ATCO, JGN and Multinet) is sourced from survey data obtained for this study and publicly available Regulatory Information Notices (RINs) published by AER. For the New Zealand GDBs included in this study, data has been sourced from publicly available data published by the New Zealand Commerce Commission (NZCC) and from annual reports.

99. Data used includes throughput, customer numbers, tariff V customers, pipeline characteristics, opex, capex and regulatory asset value.

100. 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 2022 or 2023). In cases where we were not provided data from the survey, data from the AER RINs have been used to supplement the missing observations in a manner that is consistent with the survey.

101. While every effort has been made to make the supplement of the missing observations with the RINs, the limitations of currently available public domain data need to be recognised. Data coverage of some of the business environment variables is less complete. 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. 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.

102. In a number of cases adjustments were made to ensure the data related to comparable activities and measures (e.g. 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.

103. 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.

Appendix C Normalised opex per customer using Economic Insights methodology applied for AGN

104. A limitation of the analysis undertaken in Figure 3-2 is that if there are more than one cost driver this comparison could be problematic. This is because the differences in cost driven by the additional cost driver would not be captured and would be incorrectly attributed to efficiency. When there are multiple cost drivers, a common approach to control the impact of the cost drivers using an econometric approach. In its 2020 analysis for AGN,[34] Economic insights applied a linear regression including customer density and minimum temperatures in the regression. We have performed a similar regression on our dataset.[35]

105. In the EI report (2020), it adopted scale as a cost driver. This is problematic because JGN, with 1.4 million customers, is approximately twice the size of the next largest GDB in the sample at around 0.75 million customers in 2020. According to the EI report (2020), the minimum efficient scale is reached at approximately 0.75 million customers.[36] Therefore the estimated parameter will only capture the impact of scale on opex per customer as a GDB grows to reach minimum efficient scale, it will not be able to capture the impact of scale on opex per customer after minimum efficient scale has been reached. As a result, scale is dropped from our regression as it is not able to precisely estimate the impact of scale on opex per customer for such a large GDB.

106. Our regression result is as follows.

Table C-1: Regression result for linear model 1 (opex per customer as dependent variable and customer density and temperature as the explanatory variables)

	Coefficient	Standard error
Constant	136.4***	14.6
Customer per km main	-1.5***	0.2
Avg. Min. Temperature	3.8**	1.7
Adjusted R-squared	0.32	

*** implies p-value less than 1%, ** implies p-value less than 5%, * implies p-value less than 10%, Based on data from 2010 to 2022.

107. We then use the above estimated coefficients to adjust all GDB's actual opex per customer to the predicted opex per customer for a firm with the average line length and temperatures. The method of normalisation is as follows. The averages over the most recent period of the sample (from 2010 or from 2018 onwards), for the explanatory variables customer density (CDen) and average minimum temperature (Temp) and denoted with a bar above.

$$OpexCust_{normalised} = OpexCust_{actual} + \beta_{CDen}(\overline{CDen} - CDen) + \beta_{Temp}(\overline{Temp} - Temp)$$

108. To illustrate, if a GDB had customer density that was two units higher than the average, then their opex per customer would be adjusted down by 3.0 $/customer (=2*1.5) in order to be comparable

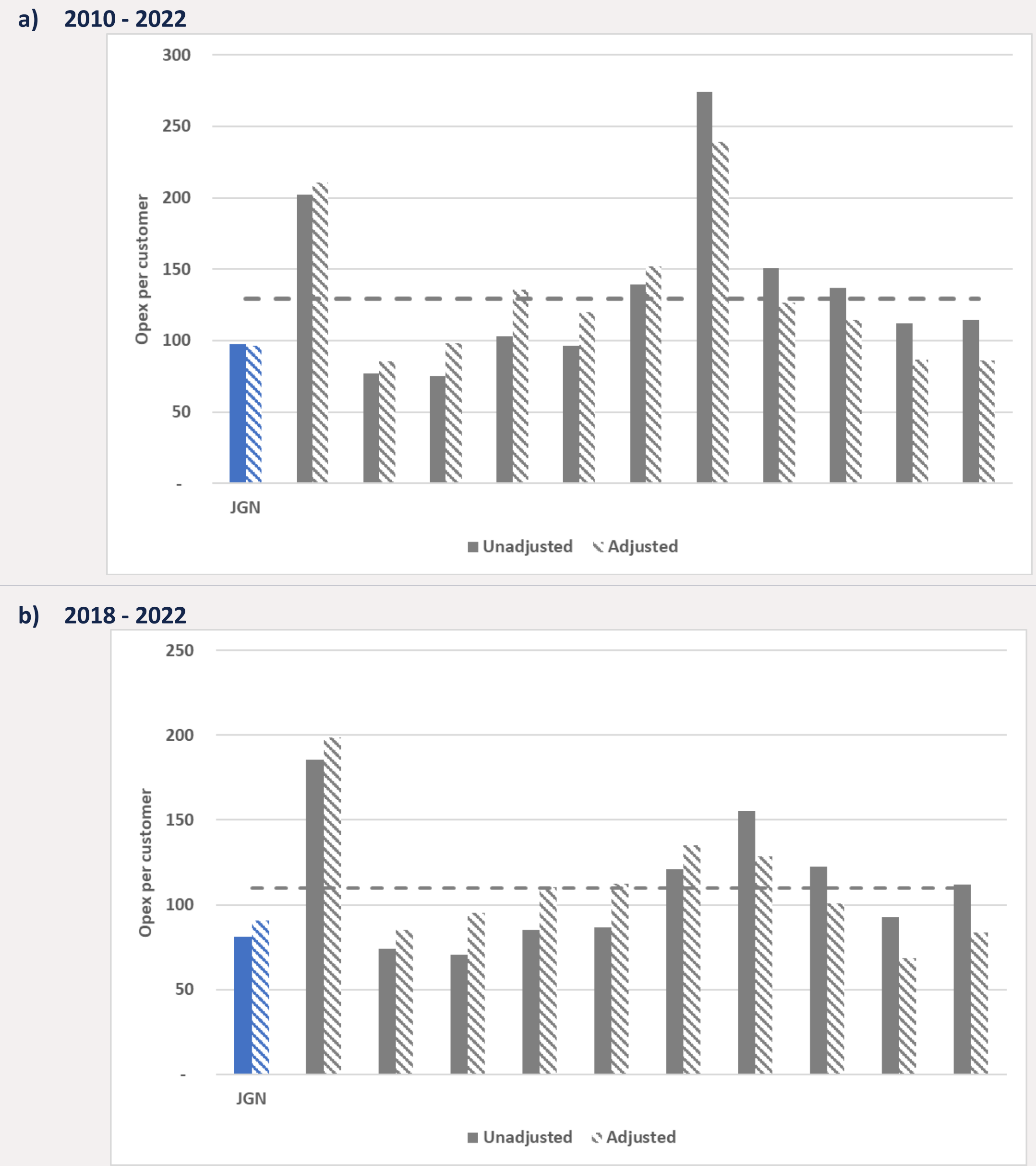
[34] Benchmarking Operating and Capital Costs of Australian Gas Networks' South Australian Network Using Partial Productivity Indicators Report prepared for Australian Gas Networks 15 June 2020 Michael Cunningham Economic Insights.

[35] EI report (2020) restricted the data to post-2004 for regression. We do not find the change makes any material impact on the result.

[36] See page 31 in EI 2020

with the average GDB (and *vice versa* for a GDB that had lower than average customer density). The adjusted values are shown as the orange bars (and the orange line is the average of the orange bars).

Figure C-1: Normalisation based on linear model 1 (2022 AUD)



109. It can be seen that JGN's adjusted opex per customer is slightly lower than its actual opex per customer while some other GDBs see increases. This is because these GDBs have relatively low customer density (which tend to raise costs per customer) and/or operate in relatively higher temperature states (which also tends to raise costs per customer).

Appendix D Methodology for productivity index

110. 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.

111. 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):

$$TFP = Q/I$$

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

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

where a dot above a variable represents the change of the variable over time.

113. 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.

Appendix D.1 Output

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

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

b. System capacity: The system capacity measure 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.[37]

c. 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.

115. To aggregate a diverse range of outputs into an aggregate output index using indexing procedures, weights need to be allocated to each of the three outputs. We adopt the same weighting as EI report (2019)[38] which is throughput of 13 per cent, for customers of 49 per cent and for system capacity of 38 per cent. The same weighting has been adopted since 2012 by Economic Insights in its report for Envestra Victoria, Multinet and SP Ausnet.[39] The same weights are used as recently in Economic Insights' report for AGN SA in 2020[40] and Quantonomics' report for ATCO in 2023.[41]

Appendix D.2 Inputs

116. The inputs used by GDBs are defined in this report as:

a. Opex: The quantity of the GDB's opex is derived by deflating the value of opex by the opex price deflator. 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 across GDBs, 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.

Australian opex cost data are converted to real values using 62% weight on Electricity, water and gas wage price index and 38% weight evenly divided between Domestic Materials; Data processing, web hosting and electronic information storage services; Legal and accounting services; Market research and statistical services; and Other administrative services.[42]

Similar New Zealand indices are used for New Zealand GDBs' opex. The costs are converted to the FY1999 base year so that the New Zealand data are then converted to Australian dollars using the FY1999 average monthly exchange rate data published by the RBA. Then the Australian index is used to express monetary values in 2022 Australian dollar.

b. Transmission network: The quantity of transmission network for each GDB is proxied by its transmission pipeline length.

[37] For Ausnet, Multinet ang AGN SA, distribution pipeline data is not provided. Therefore, we adopt Victorian GDBs average pressure for high, medium and low pressure pipelines. See page 19 in EI (2012) "The total Factor Productivity Performance of Victoria's Gas Distribution Industry" 26 March 2012

[38] See page 38 in EI report (2019)

[39] EI Report (2012), The total Factor Productivity Performance of Victoria's Gas Distribution Industry, 26 March 2012

[40] EI Report (2020), The Productivity Performance of Australian Gas Networks' South Australian Gas Distribution System, 15 June 2020

[41] Quantonomics (2023), Benchmarking Study of the Western Australian gas distribution system. 10 May 2023

[42] The weights are consistent with EI report (2019). See page 39 in EI report (2019)

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

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

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

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

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

h. 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.

117. 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.

118. 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.

Appendix D.3 Total factor Productivity

119. 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.

120. 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:

a. the Laspeyres base period weight index;

b. the Paasche current period weight index;

c. the Fisher ideal index which is the square root of the product of the Paasche and Laspeyres index; and

d. the Törnqvist index.

121. We adopt EI report (2019)'s approach in using the Fisher idea index to measure productivity. EI report (2019) used the Fisher idea index based on research by Diewert (1992)[43] which found the Fisher idea index to be best suited to TFP calculations based on its test of conditions that a productivity index should satisfy.

122. Mathematically, the Fisher ideal output index is given by:

$$Q_t = \left[\left(\frac{\sum_i P_{i,0}Y_{i,t}}{\sum_i P_{i,0}Y_{i,0}}\right)\left(\frac{\sum_i P_{i,t}Y_{i,t}}{\sum_i P_{i,t}Y_{i,0}}\right)\right]^{0.5}$$

Where Q_t is the Fisher ideal output index at time t, $P_{i,t}$ is the output share of output i at time t and $Y_{i,t}$ is the quantity of output i at time t.

123. Similarly, the Fisher ideal input index is given by:

$$I_t = \left[\left(\frac{\sum_j W_{j,0}X_{j,t}}{\sum_j W_{j,0}X_{j,0}}\right)\left(\frac{\sum_j W_{j,t}X_{j,t}}{\sum_j W_{j,t}X_{j,0}}\right)\right]^{0.5}$$

Where I_t is the Fisher ideal input index at time t, $W_{i,t}$ is the input share of input j at time t and $X_{i,t}$ is the quantity of input i at time t.

124. The Fisher ideal TFP index is then given by.

$$TFP_t = {}^{Q_t}/_{I_t}$$

125. For partial productivity index, the productivity is calculated against a subset of the inputs $TFP_t = {}^{Q_t}/_{I_{M,t}}$ where $I_{M,t} = \left[\left(\frac{\sum_j^M w_{j,0}x_{j,t}}{\sum_j^M w_{j,0}x_{j,0}}\right)\left(\frac{\sum_j^M w_{j,t}x_{j,t}}{\sum_j^M w_{j,t}x_{j,0}}\right)\right]^{0.5}$.

Appendix D.4 Multilateral total factor productivity

126. Traditional measures of TFP have enabled comparisons to be made of rates of change of productivity between GDBs or across time 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.

127. Caves, Christensen and Diewert (1982)[44] 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 other characteristics which are required to accurately compare TFP levels within panel data. This approach has previously been adopted in productivity benchmarking of GDBs.[45]

128. The multilateral translog index is given by:

[43] Diewert, W.E. (1992), "Fisher Ideal Output, Input , and Productivity Indexes Revisited", Journal of Productivity Analysis, Vol 3, Pages 211-248

[44] 66. Caves, Christensen and Diewert (1982), "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity, Econometrica, Vol. 50, No 6

[45] See chapter 6 in EI report (2019).

$$\ln\left({}^{TFP_m}/{}_{TFP_b}\right) = \sum_i \frac{(R_{im} + \bar{R}_i)(\ln Y_{im} + \overline{\ln Y_i}) - (R_{ib} + \bar{R}_i)(\ln Y_{ib} + \overline{\ln Y_i})}{2} + \sum_j \frac{(S_{jm} + \bar{R}_j)(\ln X_{jm} + \overline{\ln X_j}) - (S_{jb} + \bar{R}_j)(\ln Y_{jb} + \overline{\ln Y_j})}{2}$$

Where

TFP_m is the total factor productivity for observation m. Each observation is a value for a GDB at a given time. b is denoted for the base observation.

R_{im} is the revenue share of output i for observation m.

$\bar{R}_i$ is the average revenue share of output i across time and GDBs.

Y_{im} is the quantity of output i at for observation m.

$\bar{Y}_i$ is the average quantity of output i across time and GDBs.

S_{jm} is the cost share of input j for observation m.

$\bar{S}_i$ is the average cost share of input i across time and GDBs.

X_{jm} is the quantity of input i for observation m.

$\bar{X}_i$ is the average quantity of input i across time and GDBs.

129. This formula gives the proportional change in TFP between an observation (denoted as m) and the base(denoted as b). The MTFP index for observation m is then calculated by taking exponential of the change calculated above.

$$MTFP_m = e^{\left[\ln\left({}^{TFP_m}/{}_{TFP_b}\right)\right]}$$

130. The index for the base is naturally equal to 1. Due to the transitivity characteristics of MTFP, the methodology is invariant to which observation is set as the base year.

Appendix E Econometric methodology

Appendix E.1 FGLS model

131. Traditional regression methodology, Ordinary Least Squared (OLS), estimates are only efficient under the assumption of homoscedasticity and no serial correlation in the residuals. When these assumptions are violated, the OLS estimates are inefficient, and sometimes become biased in the case of serially correlated residuals.

132. Homoscedasticity is the assumption that the variance of residual is constant across all observations. No serial correlation is the assumption that residual over time for the same GDB is independent.

133. To address these problems, a common solution is to adopt the FGLS estimator. Instead of assuming a constant variance term for all the error terms, FGLS can accept complicated variance-covariance matrices that allows for the heteroscedasticity and autocorrelation of the disturbances in the variance-covariance matrix.

134. While OLS estimation minimises the sum of squared residuals, FGLS minimises an appropriately weighted sum of squared residuals, which gives lower weights to those residuals that are expected to be large because their variance is large or those residuals that are expected to be large because other residuals are large.

135. In this case, we've allowed for the presence of both heteroskedasticity and correlation in residual over time. Our estimate finds the residuals to be strongly correlated over time for some GDBs. The average correlation between residuals in one period and the residual in the next period (for the same GDB) is 0.55.

Appendix E.2 SFA model

136. The stochastic frontier analysis (SFA) model assumes that the residual of the fitted cost model is a mixture of an inefficiency term and the idiosyncratic error. The model takes the form of

$$lnOpex_i = \alpha + \sum \beta_j lnX_{ij} + v_i + u_i$$

where

$lnOpex_i$ is the log of opex for observation I;

α is the constant term;

β_j is the coefficient for parameter j;

lnX_{ij} is the explaining variable j for observation i

v_i is a random error typically assumed to be normally distributed; and

u_i is the inefficiency for observation i. The inefficiency term is assumed to be positive and often assumes a truncated normal distribution.

137. SFA model is estimated using maximum likelihood by relying on the assumed distribution function for v_i and u_i.