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QUANTITATIVE ECONOMICS

Final Report:

Benchmarking Study of the Western Australian gas distribution system

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Executive Summary

ATCO Gas Australia ('ATCO') commissioned Quantonomics to provide advice on productivity measurement and benchmarking of its gas distribution network operations in Western Australia (WA). This report examines the efficiency performance of ATCO over the period 2000–2022 within a group of 13 gas distribution businesses (GDBs), of which nine are in Australia and four in New Zealand. The report has been prepared for ATCO as an input to its sixth arrangement proposal (AA6) commencing 1 January 2025 (and ending 31 December 2029), to be approved by WA's Economic Regulator Authority (ERA).

Partial Performance Indicators

In chapter 2, a set of partial performance indicators is presented to compare the opex and capital input efficiency of thirteen businesses against one another. The Australian GDBs included in this part of the analysis are ATCO; Australian Gas Networks Victoria and Albury ('AGN Vic'); Multinet Gas ('Multinet'); AusNet Services ('AusNet'); Australian Gas Networks South Australia ('AGN SA'); Australian Gas Networks Queensland ('AGN Qld'), Allgas Energy ('Allgas'), Jemena Gas Networks ('Jemena'), and Evoenergy. The New Zealand GDBs are Powerco, Vector, GasNet and First Gas ('Firstgas'). The data used in this part of the study has been sourced from documents in the public domain. These data have been supplemented with information provided by several major Australian GDBs in response to common detailed data surveys.

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

- ATCO is the third largest GDB in the sample in terms of customer numbers; the second largest in terms of network length; and the fifth largest in terms of gas throughput. It is comparable in size to AusNet, Multinet, and AGN VIC.
- ATCO is among the six GDBs in the sample that have a comparatively high customer density. These are also mostly the larger size GDBs. ATCO's customer density is comparable to AGN Vic, Jemena and AGN-SA.
- ATCO's energy density per customer is the lowest in the sample. The most comparable GDBs in terms of energy density is AGN SA.
- ATCO has the third lowest energy deliveries per km, or 'network utilisation', among all the GDB in the sample. GDBs with comparable rates of network utilisation include Firstgas, AGN Qld and Evoenergy.

Partial indicators of cost efficiency are examined for two broad groups of costs, namely opex and asset costs, as well as total costs. The partial performance indicators presented are:

- Opex per customer relative to customer density

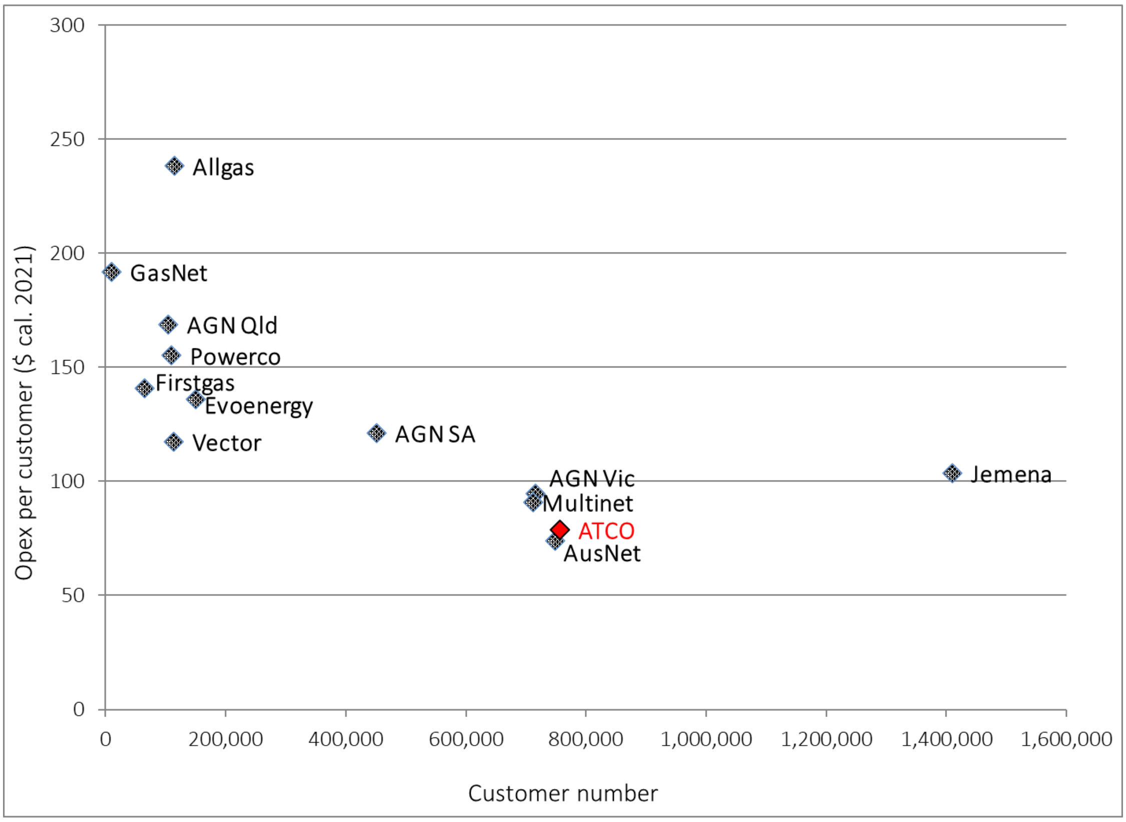
- Opex per mains kilometre (km) relative to customer density
- Asset cost per customer relative to customer density
- Asset cost per mains km relative to customer density
- Total cost per customer relative to customer density
- Total cost per mains km relative to customer density.

ATCO's comparative performance in terms of partial indicators is as follows:

- ATCO's average opex per customer (in $2021) over the latest five-year period was $79, which was well below the average opex per customer for the seven GDBs with highest customer density ($94). The six GDBs with higher customer density tended to have lower opex per customer than those with low customer density.
- ATCO's opex per km of mains was $4,231 over the latest five-year period, which is lower than the average of the GDBs with comparatively higher customer density ($5,505 for the latest five years).
- ATCO's capital asset cost per customer averaged $123 in the latest five-year period. This is well below the sample average of $313, and also below the average asset cost per customer of $235 for the group of GDBs with higher customer density. ATCO's capital asset cost per customer is the lowest in that group.
- ATCO's average asset cost per km was $6,460 over the latest five years, which is comparatively low when compared to the average for all GDBs ($12,089) or to the average for of GDBs with higher customer density ($13,727).
- The average total cost per customer of ATCO in the latest five-year period was $202. This is below the average total cost per customer for the six GDBs with comparatively high customer density ($329). ATCO's total cost per customer is the lowest in that group. The six GDBs with higher customer density tend to have lower total cost per customer than those with low customer density.
- ATCO's average total cost per km of mains ($10,838 in the latest five-year period) was below the average total cost per km for the GDBs with comparatively high customer density ($19,257). ATCO's average total cost per km of mains was also below the sample average of $16,940.

Figure A shows that there is a relationship between opex per customer and scale as measured by customer numbers. ATCO is the third largest GDB in terms of customer numbers, which is a contributing factor to its relatively low opex cost per customer compared to the larger GDBs. Among the largest GDBs, AusNet and ATCO have an average level of opex per customer which is significantly lower than other GDBs of similar or larger size (i.e., AGN Vic, Multinet and Jemena).

Figure A: Opex per Customer relative to Scale (2018-2022*)



* Or latest 5-year period. Source: Quantonomics gas utility database.

These comparisons of partial performance indicators do not control for other drivers of opex costs that may be relevant. That is, they do not enable influences such as scale economies or different mixes of inputs to be controlled in a rigorous fashion. While the partial performance indicators have the advantage of simplicity, generally speaking, because of the limited control for differences in operating environment characteristics, care is needed in interpretation, as individual partial performance indicators may give a misleading impression of overall efficiency. Hence, 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 chapter 3 of this report details analysis of ATCO'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 ATCO's productivity levels against other Australian GDBs using multilateral TFP.

The primary data source for this part of the study is information supplied by eight Australian GDBs, including ATCO in WA, Jemena in NSW, Evoenergy in the Australian Capital Territory (ACT), AusNet in Victoria, and lastly, the Australian Gas Infrastructure Group (AGIG) in relation to AGN SA, AGL Qld and in Victoria, AGN Vic and Multinet. The data was provided in response to common detailed data surveys, covering key output and input value, price and quantity information. For ATCO this data is available for 2000 to 2022 and for the other GDBs is mostly available for the period from 1999 to 2021 with some exceptions. Appendix A provides further details of the dataset used.

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, numbers of 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 ATCO are as follows:

- ATCO's TFP increased at an average annual rate of 0.5 per cent from 2000 to 2022. Productivity growth was stronger in the period up to 2007, averaging an annual rate of 3.9 per cent. From 2007 to 2014, TFP *decreased* at an average annual rate of 2.1 per cent. ATCO's TFP has been relatively constant over the period since 2014, averaging an annual rate of growth of –0.2 per cent.
- ATCO's Opex partial factor productivity (PFP) increased at an average annual rate of 2.4 per cent from 2000 to 2022. Opex PFP growth was strong in the period 2000 to 2007 (8.9 per cent) but growth was negative in the period from 2007 to 2014 (–1.3 per cent), with virtually no growth from 2014 to 2022 (0.2 per cent).
- Capital PFP *decreased* at an average annual rate of 0.4 per cent over the period 2000 to 2022. The decline in ATCO's Capital PFP mainly occurred in the period from 2007 to 2014 (–2.4 per cent) after an increase of 1.4 per cent per annum from 2000 to 2007. Capital PFP was static from 2014 to 2022, averaging –0.1 per cent annual growth.
- Comparing the average rates of TFP growth of GDBs, ATCO's TFP growth over the full sample period (0.5 per cent) was slightly below the sample average of 0.7 per cent per year. AusNet and AGN Vic had highest rates of TFP growth (1.4 and 1.3, respectively).
- Most GDBs had strong rates of growth in Opex PFP over the full sample period. The average annual rate of 2.8 per cent for all GDBs over the full sample period was comparable to the 2.4 per cent rate for ATCO. ATCO's decline in Capital PFP over the full sample period (–0.4 per cent per year) was similar to the average for all GDBs (–0.3 per cent per year).

- Over the most recent period from 2014 to 2022, ATCO's average annual rate of TFP growth was –0.2 per cent. Besides Evoenergy, which had a decline of 0.5 percent in TFP growth in this interval, the other GDBs all had some productivity growth in this period. AGN SA, AGN Vic and AusNet all had an average rate of TFP growth of 1.0 per cent per year in the 2014 to 2022 period and Multinet and Jemena had TFP growth rates of 1.7 and 0.8 per cent respectively.

- ATCO had above-average output growth averaging 2.1 per cent per year between 2000 and 2022, compared to the average for all GDBs of 1.8 per cent over the full period. The average rate of increase in inputs for ATCO over the period 2000 to 2022 was 1.6 per cent per year, which was above the average for all GDBs (1.1 per cent). Over the full period, ATCO's average rate of change of opex inputs was –0.3 per cent per year, compared to the average for all GDBs of –0.9 per cent per year. The average growth rate of capital inputs for ATCO over the period 2000 to 2022 was 2.5 per cent per year, compared to the average for all GDBs of 2.1 per cent.

The multilateral total factor productivity (MTFP) index is used to measure comparative productivity *levels*. The results for comparative TFP levels are as follows:

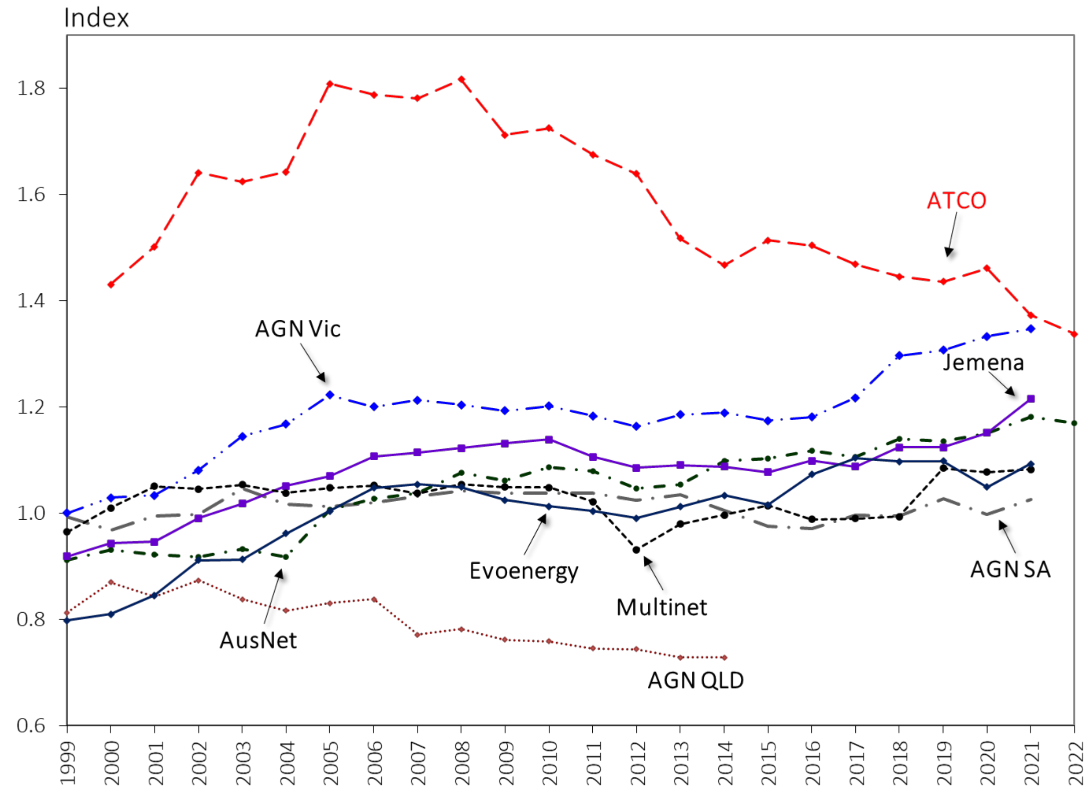
- The MTFP results indicate that, in the latest years available, ATCO has the second highest TFP—an MTFP index of 1.34 in 2022, which is slightly below AGN Vic's MTFP index of 1.35 (which is the first ranked). This can be compared to the following MTFP indexes for the other GDBs: Jemena (1.21), AusNet (1.17), Evoenergy (1.09), Multinet (1.08) and AGN SA (1.03). AGN Qld has a much lower TFP level (0.73).

- ATCO had the sixth highest Opex PFP level (1.78) in the last year of the sample. The Opex PFPs of the other GDBs are: AusNet (2.85), AGN Vic (2.18), Jemena (2.07), Multinet (2.05), Evoenergy (1.92), AGN SA (1.73) and AGN Qld (0.95).

- In the latest year, ATCO's Capital PFP index was 1.17, which is the highest among the GDBs. The next highest is AGN Vic (1.13), and the Capital PFPs of the other GDBs are: Jemena (0.95), Evoenergy (0.85), AGN SA (0.84), Multinet and AusNet (0.81) and AGN Qld (0.66).

Figure B shows the MTFP results, and as previously indicated, it shows that using the latest year available ATCO is found to have second highest TFP level.

Figure B: GDB multilateral TFP indexes, 1999–2022



Source: Quantonomics GDB database.

Opex Cost Function

In Chapter 4 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 ATCO relative to other GDBs. The econometric results are used to establish whether ATCO 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 ATCO's opex for the period 2025 to 2029. 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, 2016, 2019, 2020. This study uses additional data available since the last study was undertaken. It tests the preferred specification developed in the 2019 study and tests a simplification of that model.

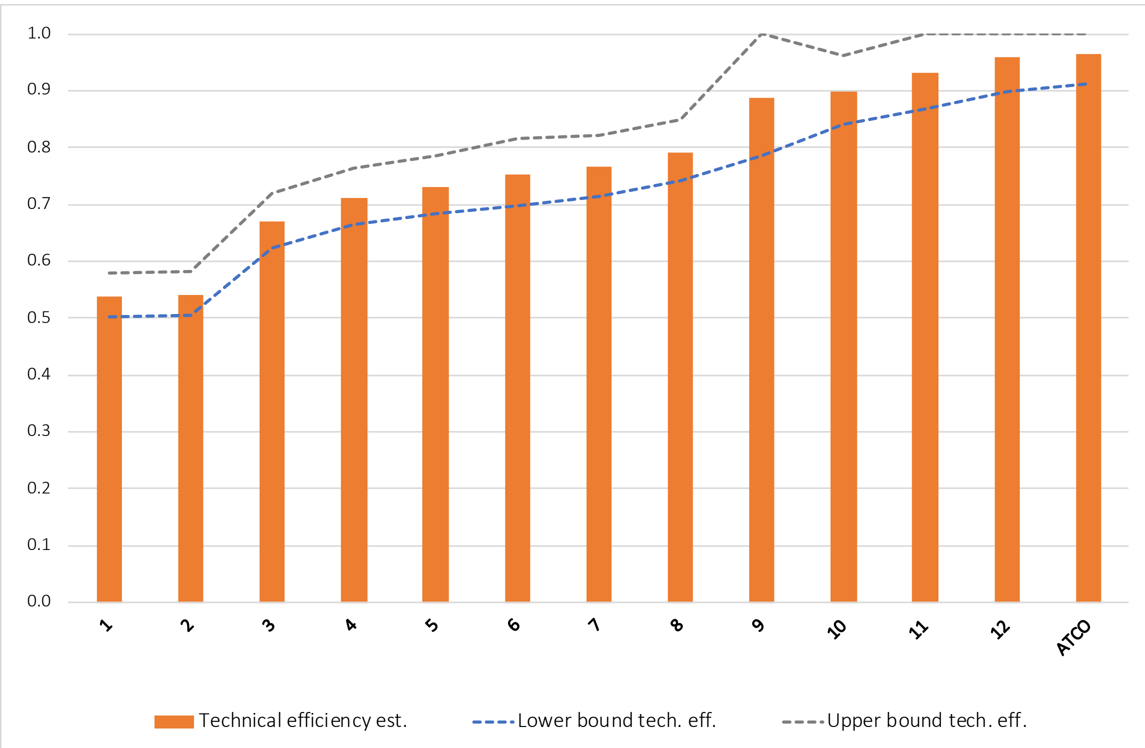
The main findings of the econometric analysis are as follows:

1. In the preferred specification, opex is a function of two outputs, customer numbers and gas throughput; the 'quasi-fixed' capital input measured by the constant price asset value; two operating environment variables, customer density and the proportion of

mains not made of cast-iron or unprotected steel, and finally a time trend variable to capture the effects of technical change.

2. The two methods of estimation used are Stochastic Frontier Analysis (SFA) with time-invariant inefficiencies and Feasible Generalized Least Squares (FGLS) allowing for heteroscedastic errors between panel groups, but do not allow for serial correlation within panels.
3. The elasticity of opex with respect to customer numbers is 0.15, and the elasticity of opex with respect to gas throughput is 0.20. The total of these two elasticities is the short-run elasticity of opex with respect to scale.
4. Weights for calculating an aggregate output index can be derived from the output elasticities. The estimated output weights are 0.43 for the customer numbers and 0.57 for gas throughput.
5. The rate of change in opex due to technical change is estimated to be –0.4 per cent per year from 1999 to 2022. This means that the industry average rate of change in opex-related technical change is 0.4 per cent per year over the same period.
6. ATCO's average technical efficiency scores of all SFA models estimated is the highest of the sample and it is equal to 1.0, indicating full efficiency. ATCO is one of four GDBs in the sample whose technical efficiency score are not significantly different from 1.0. This is shown in Figure C.

Figure C: Technical efficiency with output measured by customer numbers



7. The last finding indicates that ATCO's base-year opex is consistent with that of an efficient operator.

1 Introduction

1.1 Scope and purpose

ATCO commissioned Quantonomics to conduct productivity measurement and benchmark its gas distribution network operations in Western Australia (WA). This report is presented in three parts as follows:

(a) *Partial Performance Indicators*: Chapter 2 presents partial indicator comparisons between a set of nine Australian and four New Zealand GDBs. These partial performance indicators are similar to indicators published by the Australian Energy Regulator for electricity distribution businesses, and updates studies carried out by Economic Insights for AGN SA, the three Victorian GDBs, ATCO, Jemena and Evoenergy (Economic Insights 2015b; 2016a; 2018; 2019; 2020a; 2020b).

(b) *Total and Partial Factor Productivity Indexes*: The analysis presented in Chapter 3 details ATCO's total factor productivity (TFP) and partial factor productivity (PFP) trends, and comparison against the productivity trends of other Australian GDBs over time. This part of the study also provides a comparative analysis of ATCO's productivity levels against other Australian GDBs using multilateral TFP (MTFP). This updates analysis that Economic Insights previously carried out for Jemena AGN SA, the Victorian Gas GDBs and Evoenergy (Economic Insights 2015a; 2015c; 2016b; 2019; 2020a; 2020c).

(c) *Econometric Analysis*: The third part of the study, presented in Chapter 4, 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 by Economic Insights for Jemena, Multinet and Evoenergy (Economic Insights 2015a; 2016c; 2019; 2020a) and to use this model to:

- examine ATCO's opex efficiency;
- estimate the past rate of technical change; i.e. the rate of improvement in the efficient production frontier;
- estimate output index weights for use in projecting the opex rate of change over the next regulatory period; and
- examine evidence relating to the input index weights for the purposes of forecasting real opex.

1.2 Outline of the Report

Chapter 2 presents data on the business operating environment characteristics that influence the observed performance of GDBs and a summary comparison of partial performance indicators relating to costs per customer.

Chapter 3 briefly explains productivity measurement concepts and the methods used in this study. It also discusses measurement issues, including the definitions of outputs and inputs used. The index analysis results are presented, showing TFP and PFP *trends* for ATCO over the period 2000 to 2022 and providing comparative information for other GDBs. Multilateral indexes are presented showing comparative TFP and PFP *levels* of ATCO and the other major Australian GDBs in other states.

Chapter 4 presents an analysis of the real opex cost function of Australian and New Zealand GDBs. It explains the economic concepts of variable cost functions, the chosen functional specification of the variable cost function, and the alternative stochastic specifications. Then the choice of explanatory variables to be used in the analysis is addressed after reviewing earlier studies. Next, it explains how the results of the model can be used as part of projecting opex rates of change over a regulatory period. Lastly, chapter 4 presents the results of the preferred models of the econometric analysis of the real opex cost function of Australian and New Zealand GDBs; and drawing out the main inferences from the analysis in relation to ATCO'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 nine Australian GDBs and four New Zealand GDBs included in this analysis. Appendix B describes the databases used in the study and their limitations. Appendix C presents further details of the econometric results.

1.3 Quantonomics' experience

Quantonomics provides consulting services in the fields of economic and regulatory policy, quantitative economic analysis and pricing in infrastructure industries, especially the water, energy, telecommunications and transport industries, and quantitative analysis in competition law applications. Quantonomics was established in 2013 to provide high quality and robust quantitative analysis to support decision-making by Australia's infrastructure regulators, regulated infrastructure businesses and competition authorities.

2 Descriptive Information and Partial Performance Indicators

This chapter discusses the characteristics and efficiency performance of ATCO over the period 2000–2022 within a group of nine Australian and four New Zealand gas distribution businesses (GDBs). Appendix A briefly describes the operations of the 13 Australian and New Zealand GDBs included in this part of the study, and Appendix B describes the database used.

This chapter also reports partial productivity indicators to compare gas distribution businesses (GDBs) using cost indicators relative to individual outputs. For example, total cost per customer, per kilometre of main, or per terajoule (TJ) of gas supplied. These are graphed against measures of customer density (per km of main), and asset utilisation (gas volumes per km of main). Similarly, operating cost and capital cost are expressed relative to the same output metrics, and capital expenditure is expressed as a ratio of relevant metrics.

This information 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, ATCO in 2018 and Jemena in 2019, Evoenergy in 2020, for their respective access arrangement reviews (Economic Insights 2015b; 2016a; 2018; 2019; 2020a).

Section 2.1 presents data on the business characteristics that influence the observed performance of GDBs. Section 2.2 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.

2.1 Operating Environment Indicators

This section describes the key characteristics for the 13 GDBs included in this study, covering the years 1998 to 2022. The performance indicators discussed in this section are summarised in Tables 2.1 to 2.4 at the end of this section. Descriptive information on each GDB included in this study is presented in Appendix A.

The data available is:

- 1998 to 2022 for Multinet, AusNet
- 1999 to 2022 for AGN Vic;
- 1999 to 2021 for AGN SA, AGN Qld, Jemena, Evoenergy, GasNet;
- 2000 to 2022 for Allgas; ACTO;

- 2004 to 2021 for Powerco;
- 2005 to 2021 for Vector; and
- 2016 to 2022 for Firstgas.

Availability of earlier data for some New Zealand GDBs has been affected by merger and restructuring activity. The comparability of data for Vector from 2016 onwards, against earlier years is affected by its divestiture of gas pipelines outside Auckland in November 2015.

The 13 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 CBD customers. The GDB characteristics and operating environment indicators presented in this section are:

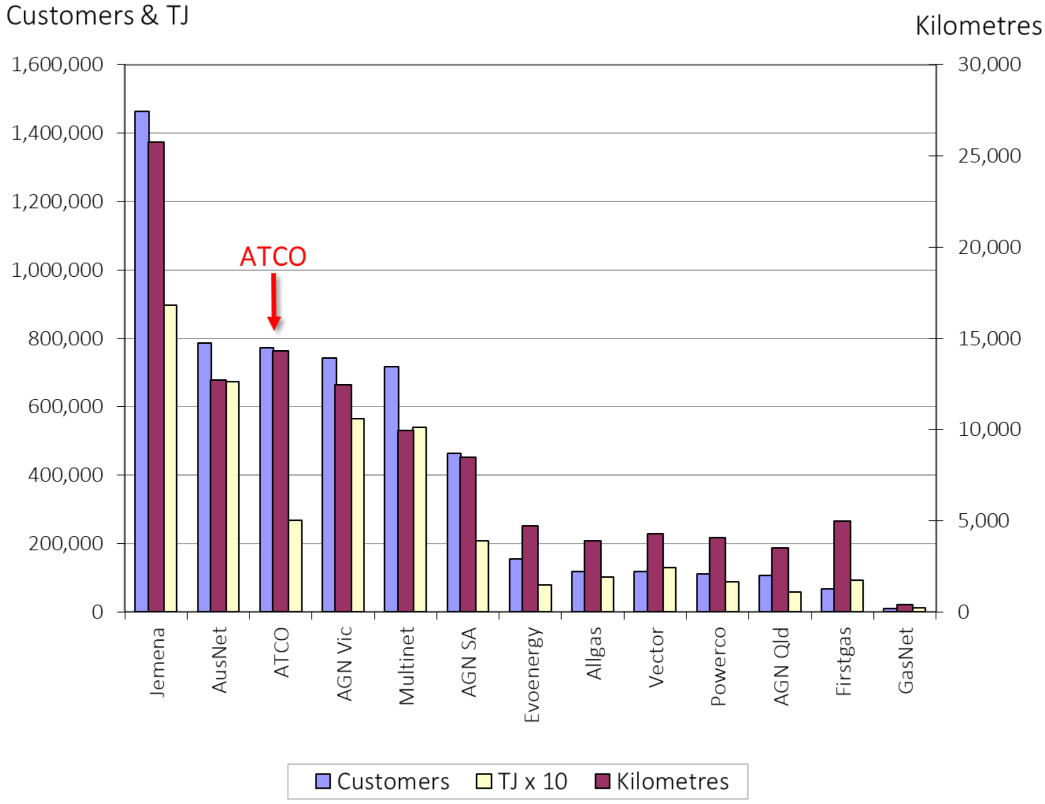
- Energy delivered (TJ), number of customers and network kilometres (Figure 2.1)
- Customer density—customers per kilometre (km) of mains (Figure 2.2)
- Energy density—terajoules (TJ) per customer (Figure 2.3)
- Network utilisation—TJ per kilometre (Figure 2.4).

Figure 2.1 shows, for each GDB in the sample, customer numbers, gas throughput (TJ) and mains length (km) in 2022 (or the latest year available). GDBs are ranked in terms of number of customers and the position of ATCO is highlighted. ATCO is the third largest GDB in the sample in terms of customer numbers; the second largest in terms of network length; and the fifth largest in terms of gas throughput. Among the other GDBs, Jemena in NSW is by far the largest. The three Victorian GDBs (Multinet, AusNet and AGN Vic) are comparable in size to ATCO on at least one of the three measures. The other GDBs are all much smaller.

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 the energy throughput (in TJ) per customer. A GDB with lower customer density will require more pipeline length to reach its customers than will a GDB with higher customer density but 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 will usually require less inputs to deliver a given volume of gas as it will require less pipeline than a less energy-dense GDB would need to deliver the same total volume.

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 energy throughput per km, or ‘network utilisation’. This measure is presented in Figure 2.4.

Figure 2.1: Key features of the operating environment, 2022*

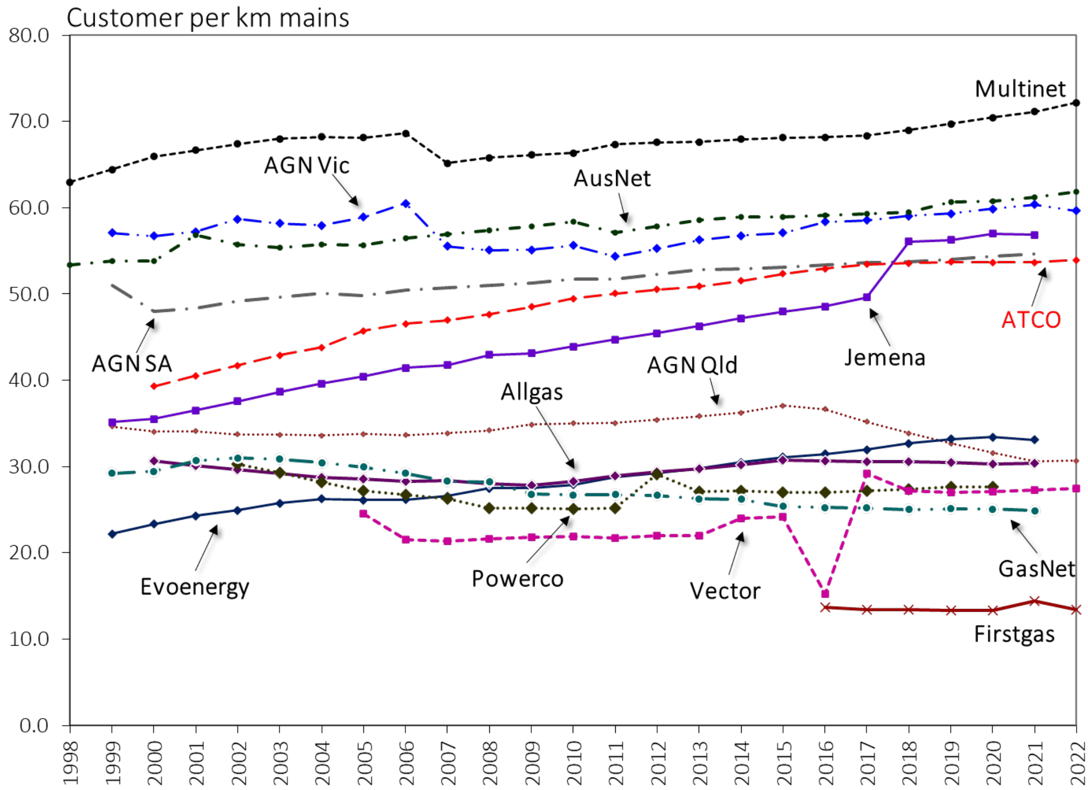


* Or latest year. Source: Quantonomics gas utility database.

The three Victorian GDBs have the highest customer densities. In terms of the five-year average to 2022 (or latest year available) Multinet, AusNet and AGN Vic had 70.5, 60.8 and 59.6 customers/km, respectively. ATCO has the sixth highest customer density in the sample (averaging 53.7 customers/km) and is comparable with Jemena (55.2 customers/km) and AGN SA (54.1 customers/km). The two smallest GDBs, Firstgas and GasNet, have also the lowest customer density, of 13.6 and 25.1 customers/km.

ATCO's customer density has increased quite strongly over the sample period, much like Jemena and Evoenergy. AGN Vic, AGN SA, AusNet, Multinet and Vector have had more moderate increases in customer density. The remaining smaller Australian GDBs (AGN Qld and Allgas), and three of the New Zealand businesses (Firstgas, GasNet and Powerco) have had declining customer densities over the sample period.

Figure 2.2: Customer density, 1998–2022*



* Or latest year. Source: Quantonomics gas utility database

ATCO had the lowest energy density of all the GDBs in the sample, an average of 35.4 gigajoules (GJ)[1] per customer over the five years to 2022. By comparison, AusNet, AGN Vic and Multinet had energy densities of 90.3, 79.1 and 78.4 GJ per customer respectively, and Jemena had an energy density of 62.8 GJ per customer (all in the latest five-year period). Three out of four New Zealand GDBs occupy the top three positions in the energy density ranking, Firstgas, GasNet and Vector (respectively 142.7, 126.0, and 123.5 GJ per customer, average over the last five years). The considerable diversity in the energy densities of the smaller Australian and New Zealand GDBs reflects wide variation in climates, the competitiveness of alternative fuels and the locations of industrial consumers.

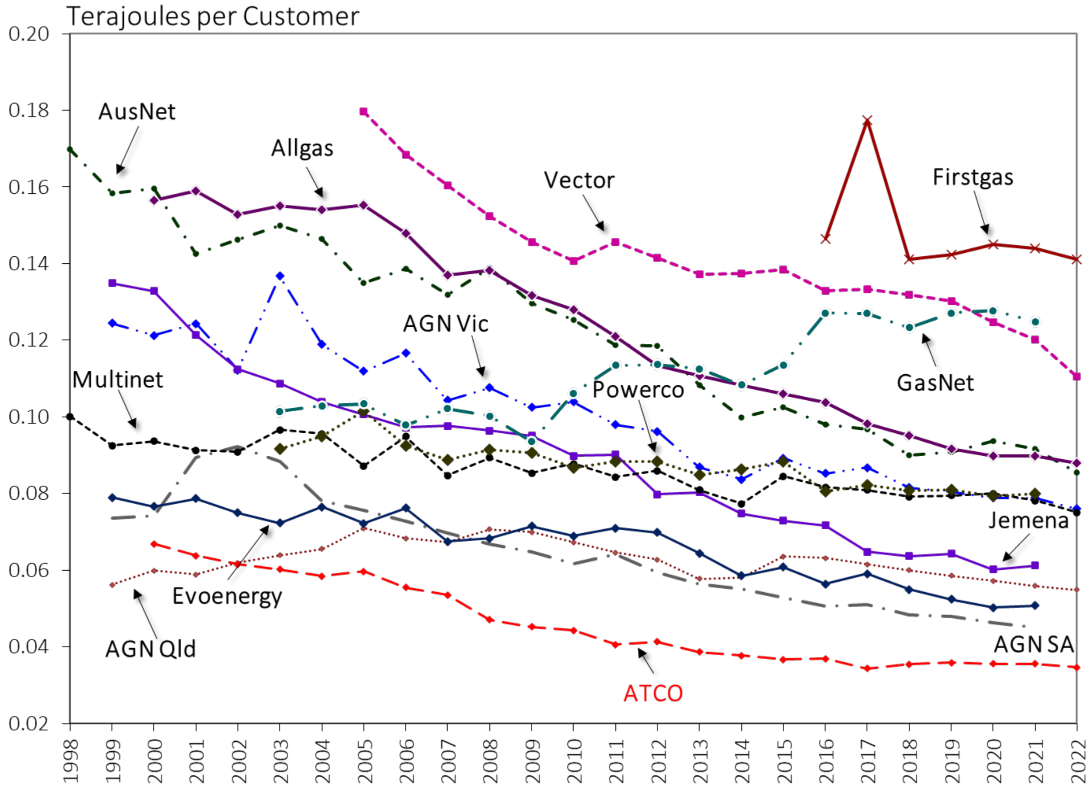
Energy use per customer has generally declined over the period from 1998 to 2022. For example, ATCO's energy density declined from 66.8 GJ/customer in 2000 to 34.6 GJ/customer in 2022 (a 48.1 per cent decrease). For comparison, AGN SA's energy density decreased from 73.5 GJ per customer in 1999 to 45.0 GJ/customer in 2021 (a 38.7 per cent cumulative decrease). Jemena's energy density decreased from 135.9 GJ per customer in 1999, to 61.1 GJ/customer in 2021 (a 54.7 per cent cumulative decrease). Evoenergy's energy

[1] A GJ is one thousandth of a TJ.

density decreased from 78.9 GJ/customer in 1999, to 50.7 GJ/customer in 2021 (a 35.7 per cent cumulative decrease), and AusNet has seen a decline from 169.7 GJ/customer in 1998 to 85.4 GJ/customer in 2022 (a 49.6 per cent decrease). AGN Vic's energy density decreased from 124.4 GJ/customer in 1999 to 76.0 GJ/customer in 2021 (a 39.0 per cent cumulative decrease); and Multinet's energy density decreased less strongly from 100.1 GJ/customer in 1999 to 75.1 GJ/customer in 2022 (a 25.0 per cent decrease).

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 (air-conditioning and heating).

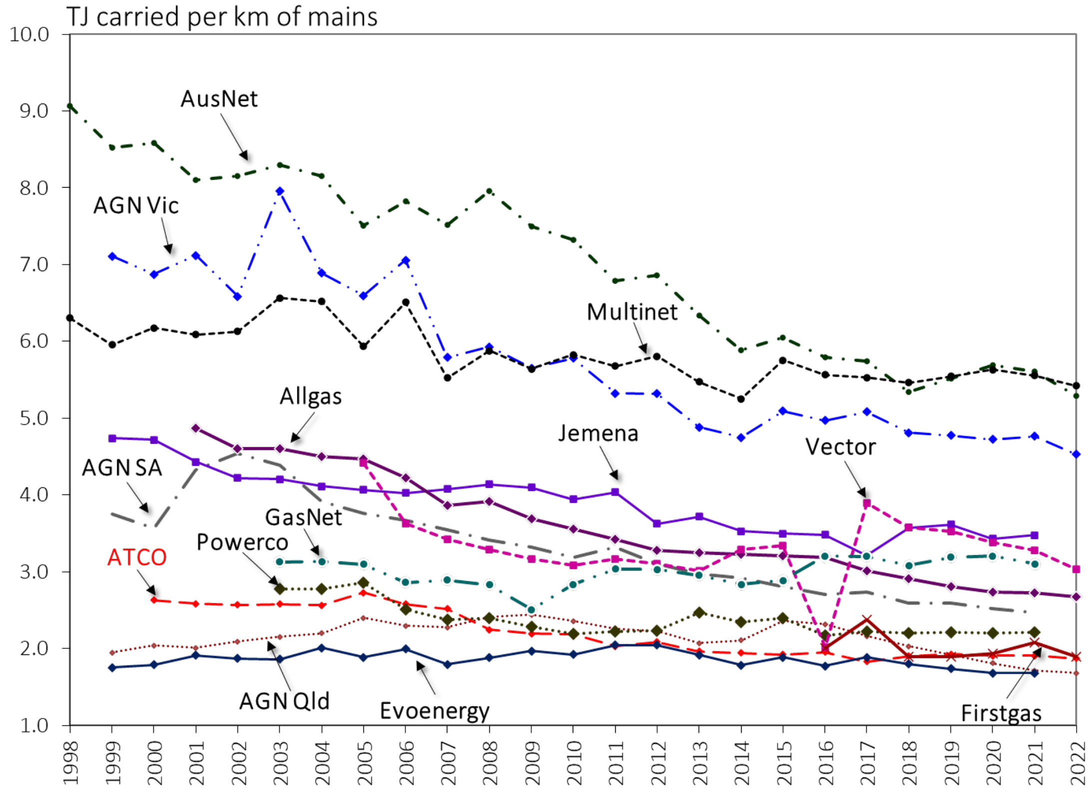
Figure 2.3: Energy density, 1998–2022*



* Or latest year. Source: Quantonomics gas utility database

The combined effect of customer density and energy density is the energy delivered per km of mains or 'network utilisation', which is shown in Figure 2.4. ATCO has the third lowest level of network utilisation, averaging 1.9 TJ/km over the latest five-year period. Evoenergy has a similarly low level of network utilisation at 1.8 TJ/km. Many of the smaller GDBs in the sample also have relatively low network utilisation: Powerco (2.2 TJ/km) and AGN Qld (1.8 TJ/km). GasNet, the smallest GDB, has a somewhat higher network utilisation (3.2 TJ/km, ranked sixth). Multinet, AusNet (both 5.5 TJ/km) and AGN Vic (4.7 TJ/km) have the highest network utilisation due to the presence of several large industrial consumers. Among the remaining larger GDBs, Jemena and AGN SA have average levels of network utilisation (3.5 and 2.6 TJ/km, respectively).

Figure 2.4: Network Utilisation (Energy per kilometre), 1998–2022*



* Or latest year. Source: Quantonomics gas utility database.

For most GDBs, network utilisation has declined over the period, reflecting the fact that declines in energy density per customer have typically outpaced increases in customer density per km. For example, AGN SA, ATCO and Jemena had cumulative decreases in network utilisation of 34.3, 28.8 and 26.6 per cent over the sample period, respectively. Allgas had a larger decline in network utilisation over the sample period (45.0 per cent), followed by AusNet (41.7 per cent) and Multinet and AGN Qld had smaller declines (14.0 and 13.6. per cent respectively), while Evoenergy remained relatively constant over the sample period and GasNet increased by 18.2 per cent over the period.

Table 2.1 shows averages for each of the operating environment indicators presented in Figures 2.1 to 2.4, for each GDB over the five-year period to 2022 (or the latest year). 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.

Table 2.2 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 2.3 shows the average growth rates of each partial performance indicator for each GDB over the last five years of the data sample.

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 VIC	2018-2022	56,650.67	716,211	12,007.11	59.6	4.7	0.1	1,196	95	5,640
Multinet	2018-2022	55,813.69	712,356	10,106.30	70.5	5.5	0.1	1,161	91	6,411
AusNet	2018-2022	67,571.05	748,451	12,312.58	60.8	5.5	0.1	819	74	4,493
AGN SA	2017-2021	21,509.15	451,341	8,345.09	54.1	2.6	0.0	2,543	121	6,552
AGN Qld	2018-2022	5,961.95	104,124	3,273.18	31.9	1.8	0.1	2,874	169	5,560
Allgas	2018-2022	10,399.43	114,564	3,759.95	30.5	2.8	0.1	2,622	238	7,260
Jemena	2017-2021	88,511.27	1,410,222	25,593.11	55.2	3.5	0.1	1,649	104	5,706
Evoenergy	2017-2021	8,007.96	150,066	4,564.81	32.9	1.8	0.1	2,547	136	4,465
ATCO	2018-2022	26,799.40	756,868	14,091.27	53.7	1.9	0.0	2,226	79	4,231
Powerco	2017-2021	8,809.20	109,201	3,987.85	27.4	2.2	0.1	1,924	155	4,249
Vector	2018-2022	13,925.40	112,922	4,151.77	27.2	3.4	0.1	956	117	3,193
GasNet	2017-2021	1,259.80	10,001	399.20	25.1	3.2	0.1	1,523	192	4,805
Firstgas	2018-2022	9,273.00	64,991	4,786.80	13.6	1.9	0.1	988	141	1,916
Average		**28,807**	**420,101**	**8,260**	**42**	**3.1**	**0.082**	**1,771**	**132**	**4,960**

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 2021 Australian dollars.

Table 2.1 (cont.)

Company	Period	Capex/TJ	Capex/cust	Capex/km	Assets/TJ	Assets/cust	Assets/km	Asset cost/cust	Total cost/cust
AGN VIC	2018-2022	2,200	173	10,349	30,103.9	2,383.1	142,111.7	256.7	351.3
Multinet	2018-2022	1,560	122	8,614	23,128.9	1,812.6	127,730.0	207.1	298.0
AusNet	2018-2022	1,351	122	7,414	25,886.7	2,337.8	142,000.8	204.1	278.1
AGN SA	2017-2021	4,495	215	11,622	76,814.9	3,656.2	197,734.5	361.2	482.4
AGN Qld	2018-2022	3,369	194	6,221	81,430.2	4,666.1	148,951.7	563.8	704.6
Allgas	2018-2022	3,094	282	8,608	60,948.9	5,537.8	168,769.6	609.9	848.1
Jemena	2017-2021	1,985	125	6,864	38,655.1	2,428.9	133,766.6	256.1	359.7
Evoenergy	2017-2021	1,801	97	3,183	48,449.1	2,588.7	85,022.4	288.0	423.9
ATCO	2018-2022	2,837	100	5,396	53,900.1	1,908.8	102,518.7	123.0	201.8
Powerco	2017-2021	1,995	161	4,409	44,045.8	3,553.9	97,297.2	339.5	494.7
Vector	2018-2022	1,723	212	5,773	30,769.3	3,789.8	103,057.5	308.4	425.8
GasNet	2017-2021	672	84	2,114	19,692.3	2,480.0	62,138.0	268.7	460.5
Firstgas	2017-2021	1,396	199	2,679	18,371.8	2,621.1	35,622.1	281.1	422.0
Average		**2,191**	**161**	**6,404**	**42,477**	**3,059**	**118,979**	**313**	**442**

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 2021 Australian dollars.

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

Company	Period	TJ	Cust.	Km	Cust/km	TJ/km	TJ/cust	Opex/TJ	Opex/cust	Opex/km
AGN Vic	1999-2022	0.2	2.38	2.19	0.19	-1.94	-2.12	-0.66	-2.77	-2.58
Multinet	1998-2022	-0.3	0.88	0.30	0.57	-0.63	-1.19	-0.54	-1.72	-1.16
AusNet	1998-2022	-0.2	2.70	2.08	0.61	-2.22	-2.82	-1.93	-4.70	-4.11
AGN SA	1999-2021	-0.6	1.68	1.36	0.32	-1.89	-2.20	-0.59	-2.77	-2.47
AGN Qld	1999-2022	1.8	1.87	2.36	-0.53	-0.63	-0.10	-2.32	-2.35	-2.89
Allgas	2000-2022	0.6	3.25	3.34	-0.03	-2.81	-2.58	2.49	-0.16	-0.29
Jemena	1999-2021	-0.6	3.07	0.84	2.21	-1.40	-3.53	-2.22	-5.68	-3.59
Evoenergy	1999-2021	1.3	3.32	1.46	1.83	-0.19	-1.99	-1.55	-3.50	-1.73
ATCO	2000-2022	-0.2	2.85	1.38	1.45	-1.53	-2.94	5.56	2.46	3.95
Powerco	2003-2021	-0.5	0.25	0.76	-0.51	-1.26	-0.76	-0.24	-1.00	-1.50
Vector	2005-2022	-3.5	-0.71	-1.35	0.65	-2.19	-2.82	-1.61	-4.39	-3.77
GasNet	1999-2021	1.5	-0.04	0.69	-0.73	0.76	0.95	0.26	1.76	1.02
Firstgas	2016-2022	0.6	1.29	1.62	-0.33	-0.96	-0.63	4.72	4.06	3.72
Average		**0.0**	**1.75**	**1.31**	**0.44**	**-1.30**	**-1.75**	**0.10**	**-1.60**	**-1.19**

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 2021 Australian dollars.

Table 2.2 (cont.)

Company	Period	Capex/TJ	Capex/cust	Capex/km	Assets/TJ	Assets/cust	Assets/km	Asset cost/cust	Total cost/cust
AGN Vic	1999-2022	5.64	3.40	3.59	0.84	-1.30	-1.11	0.56	-0.71
Multinet	1998-2022	2.95	1.73	2.31	-0.41	-1.59	-1.03	-0.69	-1.06
AusNet	1998-2022	2.40	-0.48	0.12	1.38	-1.48	-0.87	-1.20	-2.37
AGN SA	1999-2021	2.85	0.59	0.91	2.04	-0.20	0.11	1.83	5.21
AGN Qld	1999-2022	-1.92	-2.02	-2.54	0.03	-0.08	-0.61	3.09	0.98
Allgas	2000-2022	2.63	-0.22	-0.25	2.17	-0.67	-0.70	0.51	5.49
Jemena	1999-2021	1.95	-1.75	0.48	1.14	-2.43	-0.27	-3.02	-4.09
Evoenergy	1999-2021	-1.90	-3.80	-2.19	-0.84	-2.81	-1.02	-2.76	-3.00
ATCO	2000-2022	3.25	0.21	1.66	1.75	-1.24	0.19	-4.79	-2.83
Powerco	2003-2021	1.71	0.96	1.80	-1.94	-2.68	-3.18	-2.05	-1.72
Vector	2005-2022	7.14	4.51	6.29	2.23	-0.42	1.09	-3.79	-4.00
GasNet	1999-2021	2.32	4.81	4.16	-0.59	0.72	-0.09	-1.36	-0.21
Firstgas	2016-2022	19.46	18.71	18.32	3.54	2.89	2.55	-7.68	-4.49
Average		**3.73**	**2.05**	**2.67**	**0.87**	**-0.87**	**-0.38**	**-1.64**	**-0.98**

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 2021 Australian dollars.

2.2 Partial Performance Indicators

The Australian Energy Regulator (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 (Australian Energy Regulator (AER) 2014, 23).

This section presents information on the inputs per customer of GDBs compared to their network customer densities. Information on GDB inputs per mains km are 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 the input, output and customer density measures presented in this section are averages over the five-year period ending 2022 (or latest year). The partial performance indicators we present are:

- Opex per customer relative to customer density (Figure 2.5)
- Opex per mains km relative to customer density (Figure 2.6)
- Asset cost per customer relative to customer density (Figure 2.7)
- Asset cost per mains km relative to customer density (Figure 2.8)
- Total cost per customer relative to customer density (Figure 2.9)
- Total cost per mains km relative to customer density (Figure 2.10), and
- Opex per customer relative to scale measured by customer numbers (Figure 2.11).

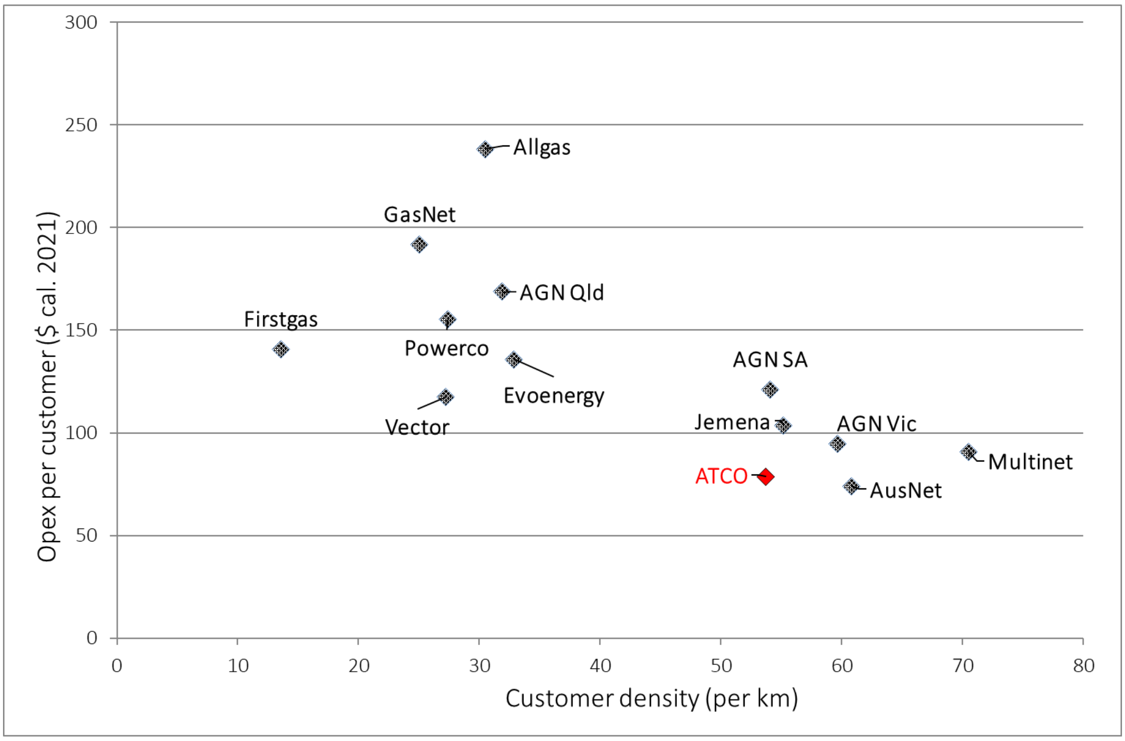
2.2.1 Opex per Customer

Figure 2.5 plots real opex per customer (in $2021) against customer density. GDBs with lower customer density, such as Firstgas, GasNet, Vector, Powerco, Allgas, AGN Qld and Evoenergy, usually have higher opex per customer, although with considerable variation. Overall, for these seven GDBs with lowest customer density, the average opex per customer was $164 for the latest five-year period. The wide range in opex per customer for GDBs with low customer density is indicated by Allgas and Vector, for which opex per customer averaged $238 and $117 respectively for the latest five-year period (see Table 2.1).

GDBs with higher customer density— such as Multinet, AusNet, AGN Vic, Jemena, AGN SA and ATCO—tend to have lower opex per customer. For example, the average opex per customer of Multinet, AusNet and AGN Vic over the latest five-year period was $91, $74 and

$95, respectively. Average opex per customer of Jemena and AGN SA over the latest five-year period was $104 and $121, respectively. ATCO's opex per customer averaged $79 over the same period, which is the second lowest average among all GDBs after AusNet. The average opex per customer of the six GDBs with higher customer density was $94 over the latest five years. ATCO's opex per customer was 16 per cent below this average.

Figure 2.5: Opex per customer relative to customer density (avg. 2018–2022*)

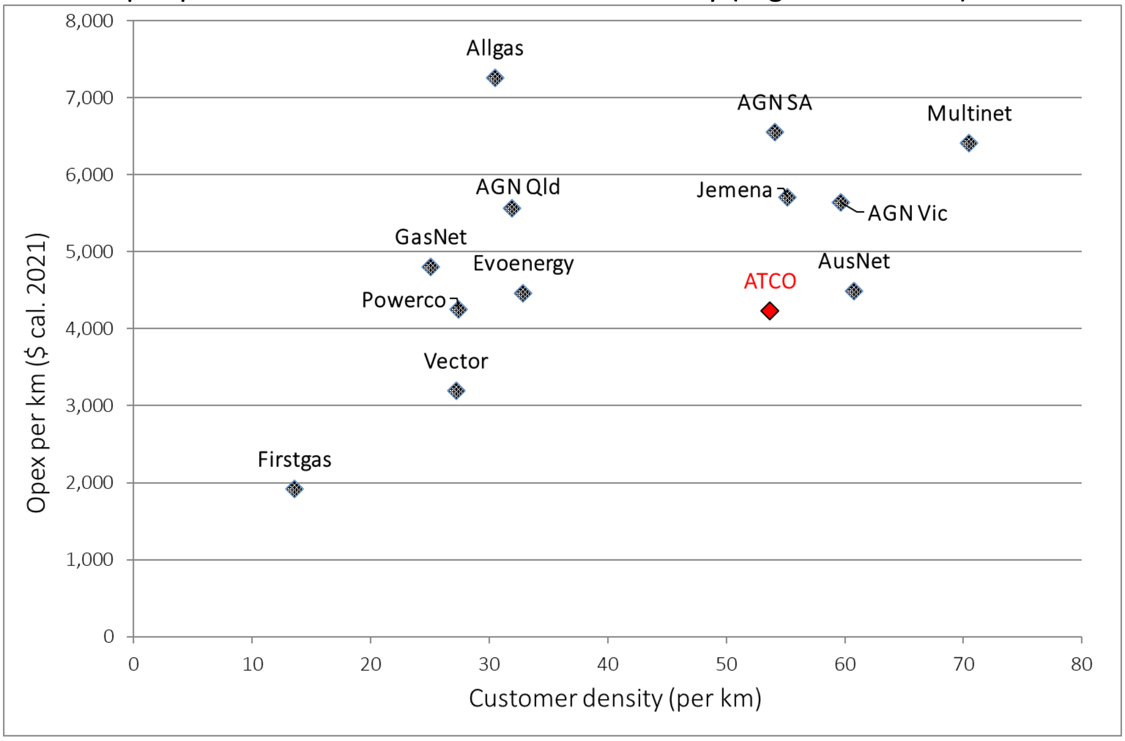


* Or latest 5-year period. Source: Quantonomics gas utility database.

Figure 2.6 plots real opex per mains km against customer density. Among the six GDBs with higher customer density, the average opex per km was $5,505 over the latest five years. The average opex per km for the seven GDBs with relatively low customer density was $4,493 over the latest five years, which is slightly lower than for the GDBs with higher customer density. There is a very wide variation in opex per km among the GDBs with relatively low customer density. Although opex per km appears to increase with customer density, there is too much variation between the GDBs to be able to draw that conclusion firmly. ATCO's opex per km was $4,231 over the same period, which is below the average for the group of GDBs with higher customer density; and below the sample average of $4,960 for the latest five years.

ATCO's average opex per km is the lowest for GDBs with relatively high customer density. It should be noted 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 2.6: Opex per mains km relative to customer density (avg. 2018–2022*)



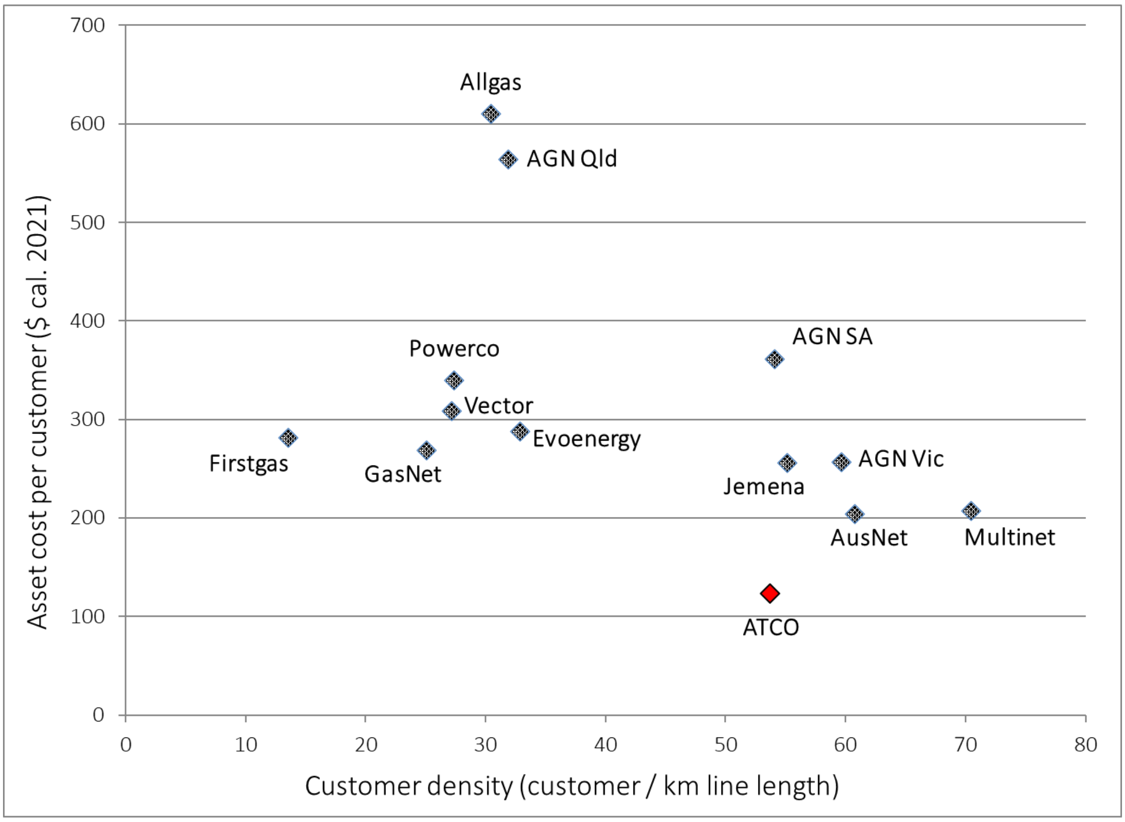
* Or latest 5-year period. Source: Quantonomics gas utility database.

2.2.2 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 in electricity benchmarking) because insufficient information is available from public sources to derive a measure based on the latter approach (AER, 2013).

Figure 2.7 plots the average asset cost per customer (in $2021) against average customer density in the period 2018 to 2022 (or latest five-year period available), where asset cost is measured by the actual return to and return of capital (or gross return including depreciation). There is an apparent relationship between asset cost per customer and customer density, since the asset cost per customer of the seven GDBs with lower customer density averages $380, compared to $235 for the six GDBs with higher customer density. However, there is considerable variation. ATCO's asset cost per customer was $123 in this period, which is the lowest among all of GDBs in the sample. The asset costs per customer of the three Victorian GDBs are $207 for Multinet, $204 for AusNet and $257 for AGN Vic. AGN SA's average asset cost per customer is $361, and Jemena's is $256. The four New Zealand GDBs had an average asset cost per customer of $299.

Figure 2.7: Asset cost per customer relative to customer density (avg. 2018–2022*)

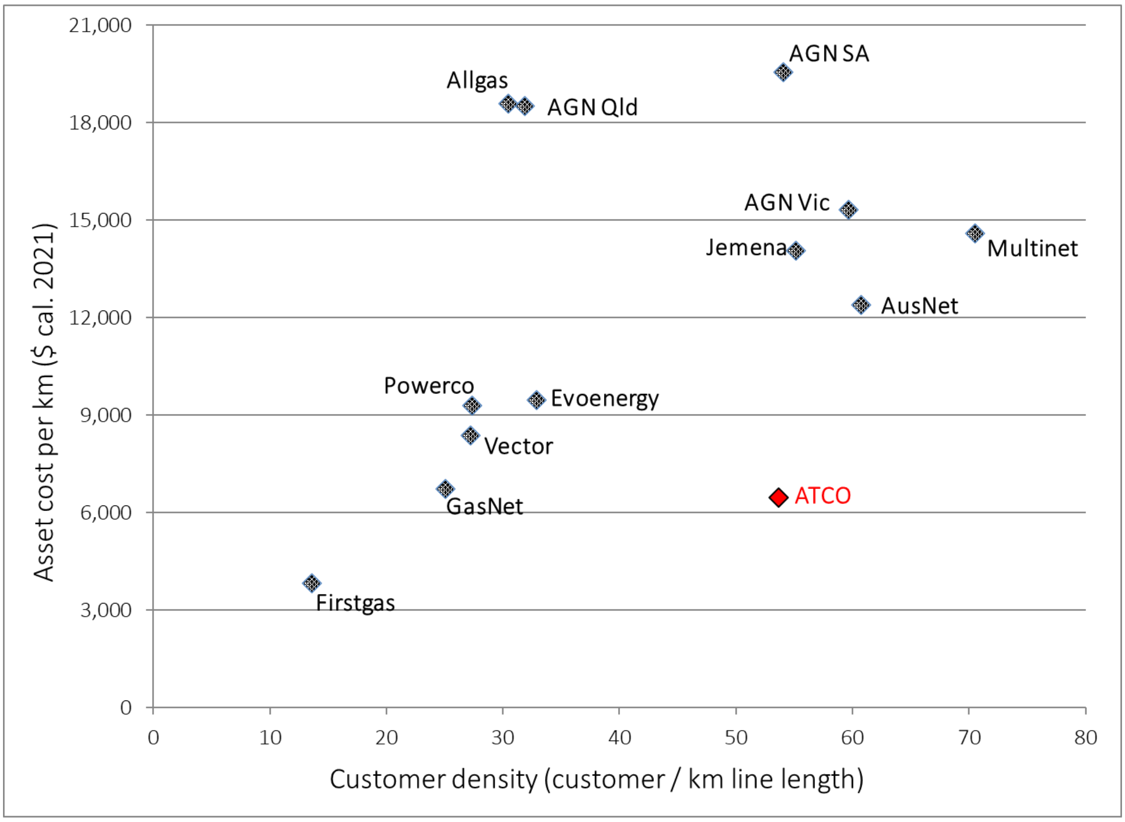


* Or latest 5-year period. Asset cost is defined as real revenue minus real opex. Source: Quantonomics gas utility database.

Figure 2.8 shows average asset cost per km of mains for the latest five-year period for each GDB, plotted against customer density. The chart shows that GDBs with lower customer density tend to have lower asset cost per kilometre than the GDBs with higher customer density. The average asset cost per km for the seven GDBs with lower customer density was $10,684. Over the latest five year period, which is lower than the average of $13,727 for the six GDBs with higher customer density.

ATCO's average asset cost per km was $6,460 over the latest five years, which is comparatively low when compared to the average for all GDBs shown (i.e. $12,089). 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 this chart. It suggests that ATCO has below-average asset cost per customer.

Figure 2.8: Asset cost per mains km relative to customer density (avg. 2018–2022*)

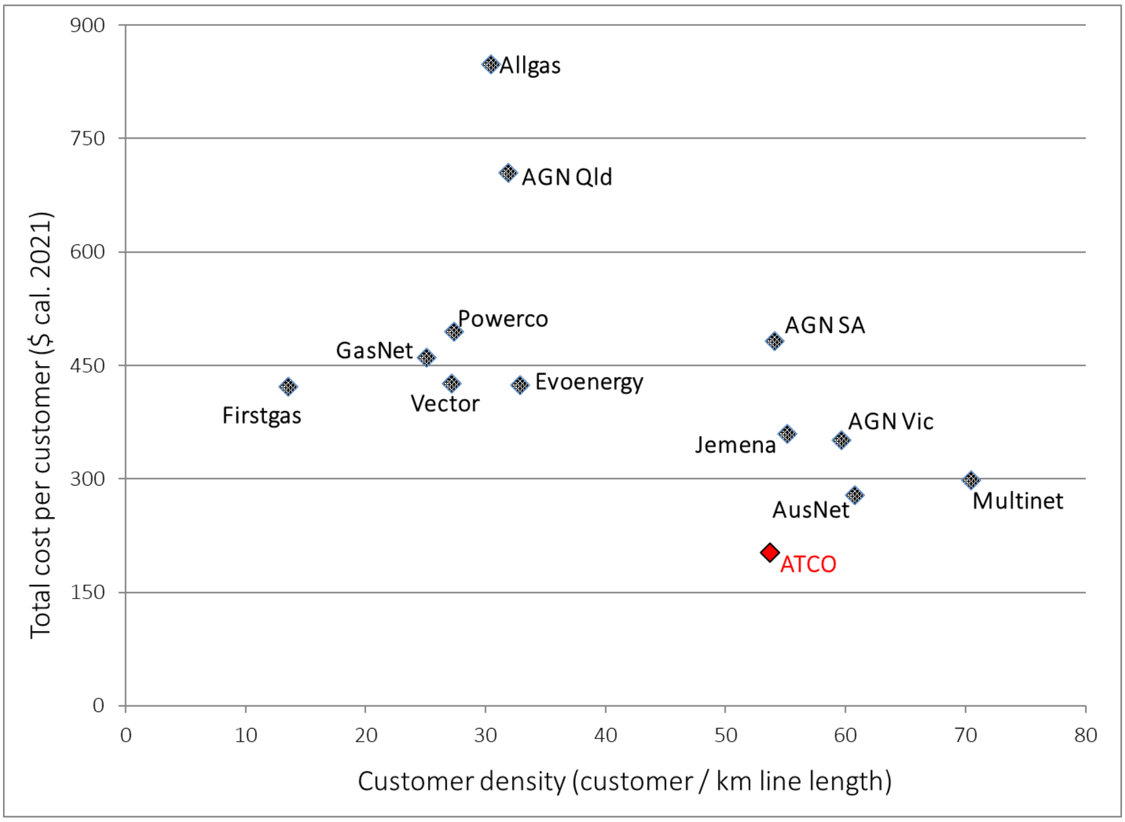


* Or latest 5-year period. Asset cost is defined as real revenue minus real opex. Source: Quantonomics gas utility database.

2.2.3 Overall cost efficiency

Figure 2.9 plots total cost per customer against customer density, where total cost is the sum of opex and asset cost shown in Figures 2.5 and 2.7 respectively. This chart shows the relationship between cost per customer and customer density. The average total cost per customer of ATCO in the period 2018 to 2022 was $202, which is the lowest among all the GDBs. Allgas and AGN Qld are among the GDBs with low customer density and had the highest total cost per customer in the sample ($848 and $705 respectively). The total costs per customer for seven GDBs with lower customer density averaged $540 over the latest five years. The GDBs with relatively high customer density typically had lower levels of total cost per customer over the latest five-year period. For example, Multinet ($298); AusNet ($278); AGN Vic ($351); Jemena ($360), and AGN SA ($482). For the six GDBs with higher customer density, the average total cost per customer was $329. ATCO's average total cost per customer is considerably lower than the average for GDBs with higher customer density.

Figure 2.9: Total cost per customer relative to customer density (avg. 2018–2022*)



* Or latest 5-year period. Source: Quantonomics gas utility database

Figure 2.10 shows total cost per km of mains plotted against customer density. There is considerable variation among the GDBs and it is not clear whether there is a relationship between total cost per km and customer density. Several low-density GDBs have relatively low total cost per km including the New Zealand GDBs, GasNet ($11,539), Firstgas ($5,734), Powerco ($13,541), and Vector ($11,578) with an overall average total cost of $10,598 per km. The Queensland GDBs, Allgas and AGN Qld, have relatively high total cost per km ($24,849 and $22,506 respectively). The total cost per km for seven GDBs with lower customer density averaged $14,953.

Among the GDBs with relatively high customer density, ATCO has a low total cost per km, of $10,838. The Victorian GDBs have comparatively high levels of total cost per km (AGN Vic, $20,952; Multinet, $21,007; and AusNet, $16,895). The other GDBs with high customer density, Jemena and AGN SA, had total costs per km of $19,758 and $26,095 respectively. The average for the GDBs with higher customer density was $19,257. ATCO's total cost per km is considerably lower than the average for GDBs with higher customer density.

Once again, caution is needed in drawing strong conclusions for these comparisons alone. That said, the results tend to indicate that ATCO has below average total cost per customer among the GDBs with relatively high customer density.

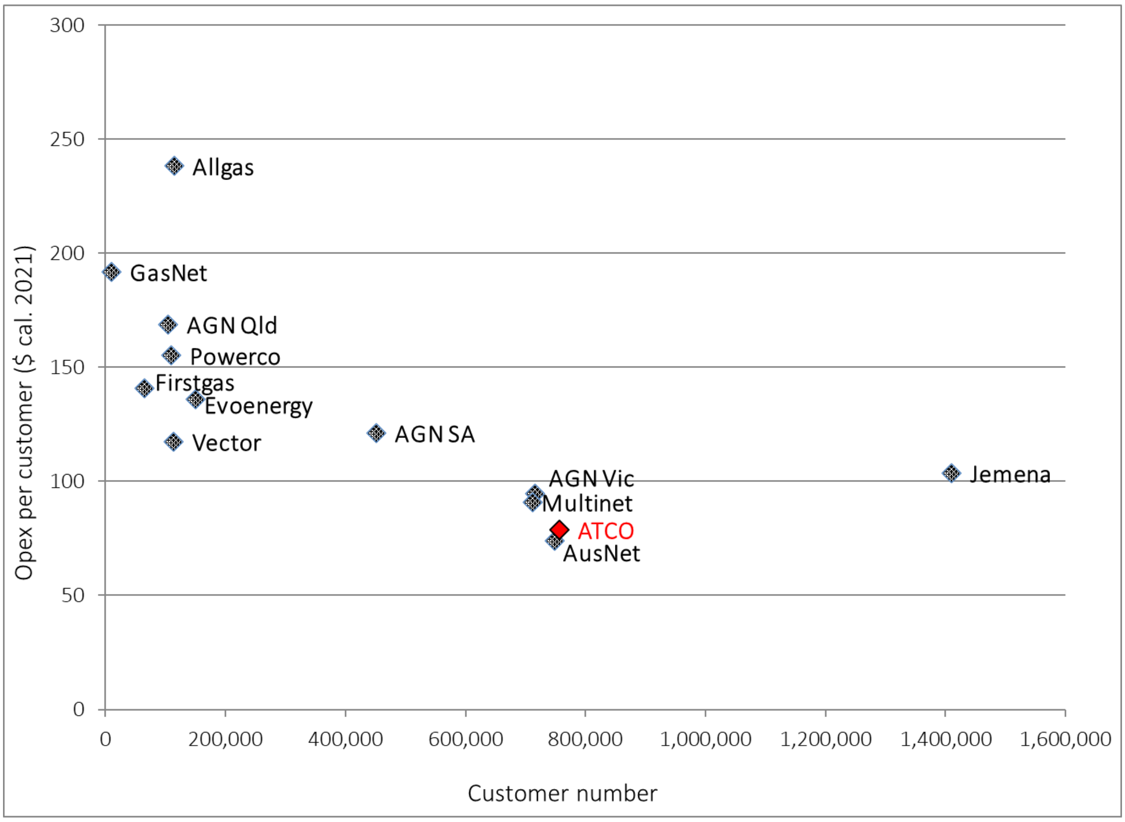
Figure 2.10: Total cost per mains km relative to customer density (avg. 2018–2022*)

* Or latest 5-year period. Source: Quantonomics gas utility database.

2.2.4 Opex per customer and scale

Figure 2.5 shows a clear relationship between opex per customer and customer density (i.e. customers per km of mains). Figure 2.11 shows that there is also a relationship between opex per customer and scale as measured by customer numbers. ATCO is the third largest GDB, which is a contributing factor to its relatively low opex cost per customer compared to the larger GDBs. Among the largest GDBs, AusNet and ATCO have an average level of opex per customer which is lower than other GDBs of similar or larger size (i.e., AGN Vic, Multinet and Jemena).

Figure 2.11: Opex per Customer relative to Scale (2018-2022*)



* Or latest 5-year period. Source: Quantonomics gas utility database.

2.2.5 Limitations

These comparisons of partial performance indicators do not control for other drivers of opex costs that may be relevant. That is, they do not enable influences such as scale economies or different mixes of inputs to be controlled in a rigorous fashion. While the partial performance indicators have the advantage of simplicity, generally speaking, because of the limited control for differences in operating environment characteristics, care is needed in interpretation, as individual partial performance indicators may give a misleading impression of overall efficiency. 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. Hence, only qualified conclusions can be drawn.

2.3 Summary Conclusions

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

- ATCO is the third largest GDB in the sample in terms of customer numbers; the second largest in terms of network length; and the fifth largest in terms of gas throughput. It is comparable in size to the AusNet and AGN Vic.
- ATCO is among six GDBs in the sample that have comparatively high customer density. These are also mostly the larger sized GDBs. ATCO's customer density is comparable to AGN SA.
- ATCO's energy density per customer is the lowest in the sample. The most comparable GDBs in terms of energy density are AGN SA.
- ATCO has the third lowest energy deliveries per km, or 'network utilisation', among all the GDBs in the sample. GDBs with comparable rates of network utilisation include Firstgas, AGN Qld and Evoenergy.

ATCO's comparative performance in terms of partial indicators is as follows:

- ATCO's average opex per customer (in $2021) over the latest five-year period was $79, which was below the average opex per customer for the six GDBs with highest customer density ($94). The seven GDBs with lower customer density tended to have higher opex per customer.
- ATCO's opex per km of mains was $4,231 over the latest five-year period, which is lower than the average of for the GDBs with comparatively high customer density ($5,505), and the overall sample average ($4,960).
- ATCO's capital asset cost per customer averaged $123 in the latest five-year period. It is well below the average asset cost per customer of $235 for the group of GDBs with higher customer density. ATCO's capital asset cost per customer is the lowest for all GDBs.
- ATCO's average asset cost per km was $6,460 over the latest five years, which is comparatively low when compared to the average for all GDBs ($12,089) or to the average for of GDBs with higher customer density ($13,727).
- The average total cost per customer of ATCO in the latest five-year period was $202. This is lowest average total cost per customer for all GDBs. The seven GDBs with higher customer density tended to have lower total cost per customer than GDBs with lower customer density. Nevertheless, ATCO's average total cost per customer is below that of its closest peers.
- ATCO's average total cost per km of mains ($10,838 in the latest five-year period) was below the average total cost per km for the GDBs with comparatively high customer density ($19,257). It was also below the sample average of $16,940.

The partial indicators analysis presented in this report do 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. Based on these indicators, ATCO has performed better than the average for GDBs with relatively high customer density on all measures; and better than the average for the sample as a whole.

3 Productivity Index Analysis

The analysis presented in chapter 3 of this report details analysis of ATCO'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 ATCO's productivity levels against other Australian GDBs using multilateral TFP.

The primary data source for this part of the study is information supplied by eight Australian GDBs, including ATCO in WA, Jemena in NSW, Evoenergy in the Australian Capital Territory (ACT), AusNet in Victoria, and lastly, the Australian Gas Infrastructure Group (AGIG) in relation to AGN SA, AGL Qld and in Victoria, AGN Vic and Multinet. The data was provided in response to common detailed data surveys, covering key output and input value, price and quantity information. For ATCO this data is available for 2000 to 2022 and for the other GDBs is mostly available for the period from 1999 to 2021 with some exceptions. Appendix A provides further details of the dataset used.

Section 3.1 briefly explains productivity measurement concepts and the productivity index methods used in this study. Section 3.2 discusses measurement issues, including the definitions of outputs and inputs. The index analysis results for TFP and PFP *trends* are presented in section 3.3 for ATCO in detail and comparisons against trends for other GDBs. Multilateral indexes are presented in section 3.4, showing comparative TFP and PFP *levels* of ATCO and the other major Australian GDBs in other states. Section 3.5 summarises the findings from the productivity index analysis.

3.1 Productivity Index Methods

3.1.1 Productivity Concepts

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 and, hence, lower the prices charged to consumers. 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. 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 (eg, 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):

$$TFP = Q/I \tag{3.1}$$

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

$$T\dot{F}P = \dot{Q} - \dot{I} \tag{3.2}$$

where a dot above a variable represents the rate of change of the variable.[2] In this study the partial productivity of factor I is defined as:

$$PFP_i = Q/I_i \tag{3.3}$$

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.

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 over time, and a means of 'benchmarking' its performance relative to its peers. Productivity studies can play a key role in setting the annual revenue requirement used in energy infrastructure regulation. By providing a means of benchmarking GDB performance they assist the regulator in determining whether the GDB in question is operating at efficient cost levels, and they may also assist the regulator in determining possible future rates of productivity growth to build into annual revenue requirement forecasts.

3.1.2 TFP and PFP Chain 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

[2] 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 (see: Coelli et al. 2005, 64–65).

changes from one period to another or comparisons between other situations, such as comparisons between localities or groups of consumers. To operationalise TFP measurement we need 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.

For this study the Fisher ideal index was chosen as the preferred index formulation for the TFP time series analysis, consistently with previous studies of gas industry productivity by Economic Insights. The Fisher ideal index is increasingly the index of choice of leading national statistical agencies.

$$Q_{tB}^{F} = \sqrt{\left(\sum_i P_{iB}Y_{it} \Big/ \sum_i P_{iB}Y_{iB}\right)\left(\sum_i P_{it}Y_{it} \Big/ \sum_i P_{it}Y_{iB}\right)} \quad (3.4)$$

where:

- Q_{tB}^{F} is the Fisher ideal output index for period t, relative to the base-period B;
- P_{iB} and P_{it} are the prices of the ith output in the periods B and t respectively;
- Y_{iB} and Y_{it} are the quantities of the ith output in periods B and t respectively.

$$I_{tB}^{F} = \sqrt{\left(\sum_j W_{jB}X_{jt} \Big/ \sum_j W_{jB}X_{jB}\right)\left(\sum_i W_{jt}X_{jt} \Big/ \sum_i W_{jt}X_{jB}\right)} \quad (3.5)$$

where:

- I_{tB}^{F} is the Fisher ideal input index for period t, relative to the base-period B;
- W_{jB} and W_{jt} are the prices of the jth input in the periods B and t respectively;
- Y_{jB} and Y_{jt} are the quantities of the jth input in periods B and t respectively.

The Fisher Ideal TFP index is then given by:

$$TFP_{tB}^{F} = Q_{tB}^{F} / I_{tB}^{F} \quad (3.6)$$

This represents the Fisher Ideal index between a base period B and period t. The chained form as a linked series of bilateral comparisons between adjacent periods. For a chained index, the Fisher Ideal index is preferred because the weights are closely matched to each of the pairwise period comparisons. The chained Fisher Ideal output index between observations 1 and t is given by:

$$Q_{t1}^{F} = 1 \times Q_{21}^{F} \times Q_{32}^{F} \times \ldots \times Q_{t,t-1}^{F} \quad (3.7)$$

The productivity trend results presented in section 3.3 are derived using the chained Fisher Ideal index number method to calculate output and input indexes, TFP and partial productivity measures.

3.1.3 Multilateral Total Factor Productivity Indexes

Chained time series TFP indexes such as those discussed in section 3.1.2 enable comparisons to be made of rates of change of productivity between GDBs but do not enable comparisons to be made of differences in the absolute levels of productivity between GDBs.

Caves, Christensen and Diewert (1982) developed the multilateral translog TFP (MTFP) index to allow comparisons of the absolute levels as well as growth rates of productivity in combined time series, cross section data. It satisfies the technical properties of transitivity and characteristicity which are required to accurately compare TFP levels within panel data. This method has been used in many utility benchmarking studies. For example, Lawrence (2007) used it to compare TFP levels across the three Victorian GDBs. Economic Insights has used this method in a number of GDB studies. The AER uses this method to benchmark electricity networks.

MTFP indexes can be used to make comparisons of productivity levels and of productivity growth rates between gas distribution businesses. The rate of change in TFP is equal to the rate of change in the multilateral output index minus the rate of change in the multilateral input index. The rates of change in the output index, the input index, and the TFP index are given respectively by equations (3.8), (3.9) and (3.10):

$$\ln(Y_m/Y_n) = \frac{1}{2}\sum_i (R_{im} + \bar{R}_i)(\ln Y_{im} - \ln \bar{Y}_i) - \frac{1}{2}\sum_i (R_{in} + \bar{R}_i)(\ln Y_{in} - \ln \bar{Y}_i) \quad (3.8)$$

$$\ln(X_m/X_n) = \frac{1}{2}\sum_j (S_{jm} + \bar{S}_j)(\ln X_{jm} - \ln \bar{X}_j) - -\frac{1}{2}\sum_j (S_{jn} + \bar{S}_j)(\ln X_{jn} - \ln \bar{X}_j) \quad (3.9)$$

$$\ln(TFP_m/TFP_n) = \ln(Y_m/Y_n) - \ln(X_m/X_n) \quad (3.10)$$

Y_m is the aggregate output quantity index at observation m, Y_{im} is the quantity of output i at observation m, and $\bar{Y}_i$ is the average level of output i over all observations; R_{im} is the revenue share of output i at observation m, $\bar{R}_i$ is the average revenue share of output i over all observations; and Σ_i represents summation over all outputs at a given observation. Further, X_m is the aggregate input quantity index at observation m, X_{jm} is the quantity of input j at observation m, and $\bar{X}_j$ is the average level of input j over all observations; S_{jm} is the cost share of input j at observation m, $\bar{S}_j$ is the average cost share of input j over all observations; and Σ_j represents summation over all inputs at a given observation. Lastly, TFP_m is the total factor productivity index.

Equations (3.8), (3.9) and (3.10) represent rates of change between period n and period m. These are converted into output, input and TFP indexes by setting the value for the index at the first observation of the sample as equal to 1.0 and applying the rates of change sequentially for every subsequent observation in the sample. The choice of index base is arbitrary (here the first observation in the dataset) since it affects neither the comparisons (i.e., relativities) between GDBs nor the calculated TFP growth rates. The index base for this study is AGN Vic in 1999 = 1.0. All other indexes are measured relative to this base. This means that when using equations (3.8), (3.9) and (3.10), 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.

3.2 Measuring Inputs, Outputs and Operating Environment Variables

3.2.1 Measurement Issues

To measure productivity performance, we require data on the price and quantity of each output and input, and data on key operating environment conditions. We require 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. Weights for outputs are generally based on output value shares, and weights for inputs are generally based on cost shares. Hence, we require either the price and quantity of each output and input or, alternatively, their values and quantities, or their values and prices. 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.

In a competitive market, revenue shares can be used as output weights. However, regulated natural monopoly businesses are not constrained by market forces to set prices for their different outputs in proportion to the marginal costs of those outputs. 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). In these circumstances, it is more appropriate to value outputs using 'shadow prices' (related to marginal costs) which are estimated using an econometric cost function to determine the cost and individual outputs. This is a standard approach in applying productivity analysis to regulated businesses: see Denny, Fuss and Waverman (1981), and Coelli et al (2003 ch. 3).

Quantity information can be obtained either directly or indirectly. Direct quantity data are physical measures of a particular output or input, e.g. terajoules 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. Some argue that the indirect method allows greater differences in the quality of outputs or inputs to be captured and for a greater range of items to be captured within the one measure (e.g. a greater extent of automation reflected in a higher capital value). 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).

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

3.2.2 Measuring GDB outputs

This analysis uses the same output specification as used by Economic Insights in previous studies of gas industry productivity in Australia, which used three outputs: gas throughput, customer numbers and network capacity and connection numbers. This follows Lawrence (2007), which 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.

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

1) *Throughput:* As 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*: This captures the GDB's functional responsibility of making capacity available to meet the needs of customers. This measure is somewhat analogous to the MVA–kilometre system capacity measure used in electricity network TFP studies (see: AER 2022a; 2022b) but, in this case, it also captures the interim storage function of pipelines. It is defined as 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. Transmission pipelines are excluded from the calculation.

As previously discussed, output weights are derived from econometric analysis of the total cost function. In this study we use the output cost shares weights estimated by Economic Insights (2012b), which have been used in previous Economic Insights studies. The method used by Economic Insights to derive these weights is documented in Appendix C of Economic Insights (2020). The weights are:

- Gas throughput: 13.1 per cent
- Customer numbers: 48.9 per cent, and
- System capacity: 38.1 per cent.

3.2.3 Measuring GDB inputs

This analysis uses the same input specification as previously used by Economic Insights in its studies of gas industry productivity in Australia. In this specification, non-capital inputs are measured by operating expenditure deflated using a suitably defined price index for non-capital inputs. Capital inputs are measured by quantity inputs for seven different asset categories.

The quantity of a GDB's non-capital input is derived by deflating the value of opex by the opex price deflator originally developed by PEG (2006), and used by Economic Insights in its gas productivity studies, as well as by ACIL Allen (2022). The opex price index is constructed using several price indexes published by the Australian Bureau of Statistics (ABS) and uses fixed weights, as follows:

- Labour price index (62.6 per cent), from ABS Wage Price Index (6345.0) Ordinary time hourly rates of pay excluding bonuses; Australia; Private and Public; Electricity, gas, water and waste services;
- Business services prices (19.3 per cent), from ABS Producer Price Indexes (6427.0) Intermediate; Domestic;
- Computer services prices (8.1 per cent) from ABS Producer Price Indexes (6427.0) 592 Data processing, web hosting and electronic information storage services;

- Secretarial services (6.0 per cent) from ABS Producer Price Indexes (6427.0) 729 Other administrative services;
- Legal and accounting services (3.0 per cent) from ABS Producer Price Indexes (6427.0) 693 Legal and accounting services; and
- Advertising services (1.0 per cent) from ABS Producer Price Indexes (6427.0) 695 Market research and statistical services.

To ensure consistency with previous gas industry productivity studies by Economic Insights, a number of adjustments have been made to the functional coverage of opex to ensure more like-with-like comparisons between GDBs. For example, government levies and unaccounted for gas are excluded from opex for all GDBs.

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 either directly in quantity terms (eg, using pipeline length measures) or indirectly using a constant dollar measure of the value of assets. As previously discussed, quantity measures of capital inputs are generally preferred and are used here for all but one of the capital inputs. The "other" capital input is measured indirectly by the constant dollar value of the relevant component of the asset base.

The capital inputs are defined as follows:

1) *Transmission network*: Proxied by transmission pipeline length (for JGN this is defined as the sum of its 'trunk' and 'primary' mains length). This input is not used for MTFP analysis.
2) *High pressure network*: Proxied by high pressure pipeline length.
3) *Medium pressure network*: Proxied by its medium pressure pipeline length.
4) *Low pressure network*: Proxied by its low pressure pipeline length.
5) *Services network*: Proxied by its estimated services pipeline length.
6) *Meters*: Proxied by its total number of meters.
7) *Other assets*: 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. We form disaggregated constant price depreciated capital stock estimates 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.

The annual cost of using capital inputs can be measured either 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 minus operating costs. The indirect approach of allocating a residual or ex post cost to capital of the difference between revenue and operating costs was used in PEG (2006) and has been used by Economic Insights in its various gas industry productivity studies. We note this differs from the amortisation approach when the effect of sunk costs and financial capital maintenance are fully allowed for as in Economic Insights (2009) but it will provide a close approximation in this case.

Using this approach, the value of total costs equals total revenue by definition. 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 to obtain the input index weights for each capital input. This is done using the share of each of the seven asset categories' asset values in the total asset value for that year.

3.2.4 Operating Environment Factors (OEFs)

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.

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. That said, when interpreting TFP index results, it is important bear in mind that there are operating environment conditions that are not accounted for in this analysis.

3.3 Productivity Trend Results

3.3.1 ATCO trends

In this section we present the key productivity results for ATCO for the 23-year period to 2022. Results are derived using the output index specification outlined in section 3.2.2 (throughput, customer numbers and system capacity) and with two broad inputs (real opex and capital). Table 3.1 shows the total factor and partial factor productivity index results for ATCO.

Table 3.1: ATCO productivity indexes, 2000–2022

Year	Output	Input	Opex	Capital	PP Opex	PP Capital	TFP
2000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2001	1.028	0.985	0.955	1.005	1.077	1.023	1.044
2002	1.060	0.931	0.803	1.015	1.320	1.044	1.138
2003	1.094	0.950	0.833	1.026	1.313	1.066	1.152
2004	1.132	0.956	0.808	1.053	1.401	1.075	1.185
2005	1.188	0.918	0.696	1.064	1.708	1.116	1.294
2006	1.219	0.936	0.713	1.082	1.709	1.127	1.303
2007	1.259	0.962	0.693	1.139	1.816	1.105	1.309
2008	1.267	0.945	0.627	1.156	2.021	1.097	1.341
2009	1.285	1.005	0.747	1.173	1.720	1.096	1.279
2010	1.310	1.012	0.747	1.185	1.754	1.106	1.295
2011	1.334	1.055	0.744	1.262	1.793	1.058	1.265
2012	1.368	1.105	0.784	1.319	1.744	1.038	1.238
2013	1.425	1.237	0.819	1.517	1.741	0.939	1.153
2014	1.453	1.285	0.874	1.558	1.662	0.932	1.131
2015	1.488	1.255	0.771	1.586	1.931	0.938	1.186
2016	1.517	1.265	0.752	1.619	2.016	0.937	1.199
2017	1.523	1.286	0.774	1.638	1.967	0.930	1.184
2018	1.545	1.317	0.816	1.652	1.892	0.935	1.173
2019	1.553	1.323	0.808	1.673	1.921	0.928	1.174
2020	1.563	1.286	0.737	1.688	2.120	0.926	1.215
2021	1.581	1.389	0.888	1.711	1.779	0.924	1.138
2022	1.592	1.429	0.943	1.725	1.687	0.923	1.113
Average Annual Change							
2000–2007	3.3%	-0.6%	-5.1%	1.9%	8.9%	1.4%	3.9%
2007–2014	2.1%	4.2%	3.4%	4.6%	-1.3%	-2.4%	-2.1%
2014-2022	1.1%	1.3%	1.0%	1.3%	0.2%	-0.1%	-0.2%
2000–2022	2.1%	1.6%	-0.3%	2.5%	2.4%	-0.4%	0.5%

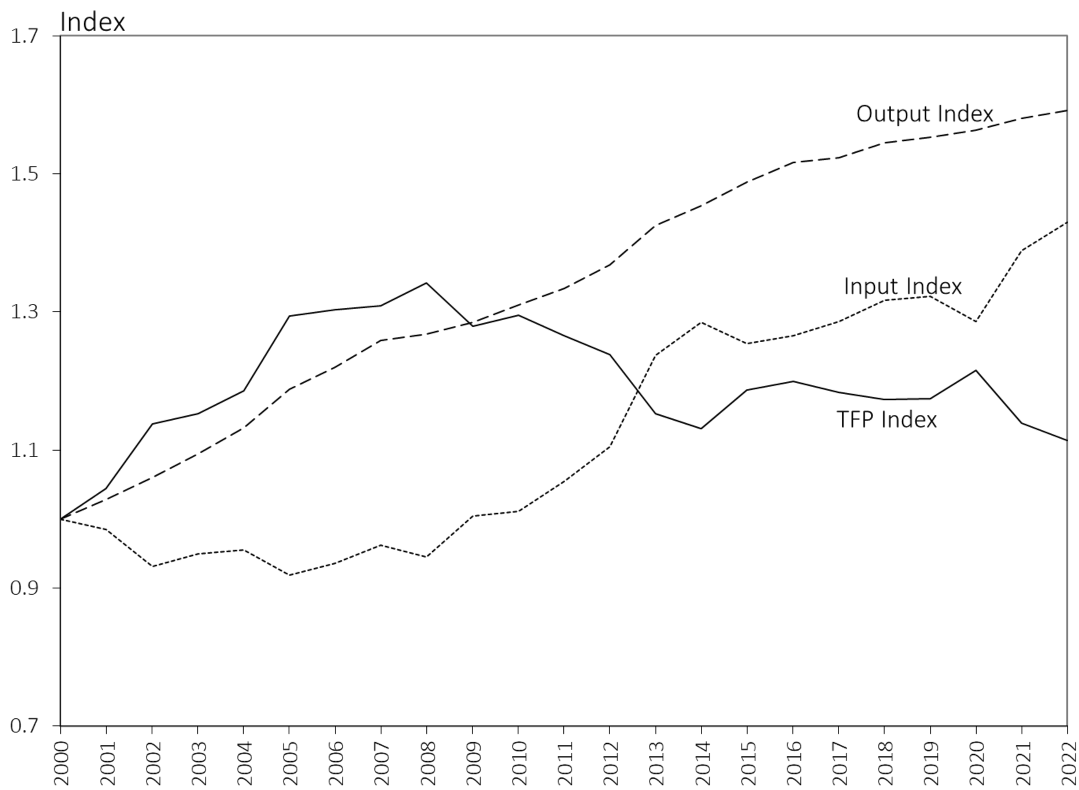
Source: Calculations using Quantonomics GDB database

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 3.2.3.

ATCO had an average rate of growth in output over the period 2000 to 2007 of 3.3 per cent per year. Its input decreased at an average of 0.6 per cent per year over the same period, resulting in annual TFP growth of 3.9 per cent in that period. Output grew at a lower rate in subsequent periods. From 2007 to 2014, output growth was 2.1 per cent per year, whereas input growth increased much more strongly, at an average rate of 4.2 per year over this period, resulting in TFP growth averaging –2.1 per cent per year from 2007 to 2014. Output growth averaged 1.1 per cent per year from 2014 to 2022. During this period inputs continued to increase at the comparatively high rate of 1.3 per cent per year on average, and consequently, TFP growth averaged –0.2 per cent annually in the latest period. Over the whole period from 2000 to 2022, annual output growth averaged 2.1 per cent per year and input growth averaged 1.6 per cent, with TFP growth averaging 0.5 per cent annually.

These trends are depicted in Figure 3.1, which plots ATCO's output and inputs indexes, and the TFP index, which is the ratio of the output and input indexes. The output trend has been relatively stable and movements in TFP tend to be driven by input movements. Inputs have increased slightly more strongly than outputs in the period since 2007, causing TFP to decline.

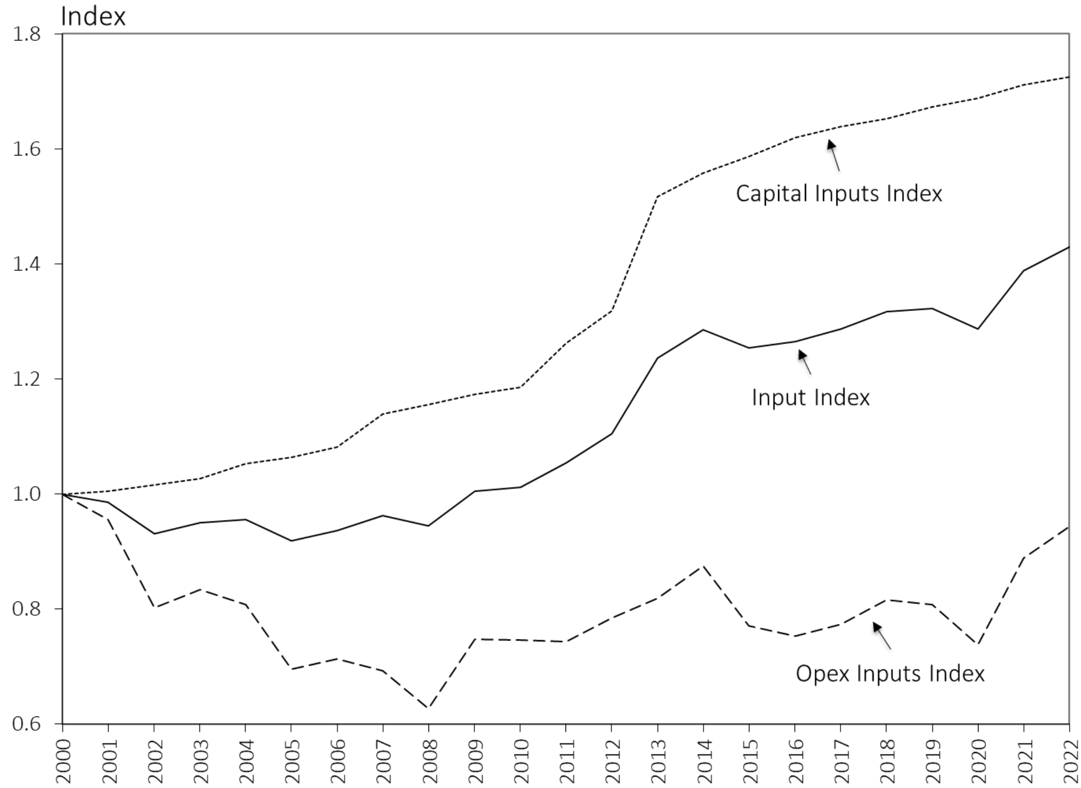
Figure 3.1: ATCO output, input and TFP indexes, 2000–2022



Source: Quantonomics GDB database

Figure 3.2 shows the divergent trends in the use of real opex inputs and capital inputs. On average, over the period from 2000 to 2022, opex inputs decreased at an average annual rate of 0.3 per cent. There were significant reductions in opex in the period before 2007, 5.1 per cent, but these were eased in the subsequent periods. Capital inputs index increased over the whole period from 2000 to 2022, averaging an annual increase of 2.5 per cent. The movements in the input index are the aggregate effect of the increases in capital inputs, and flat real opex inputs (on a net basis for the whole period).

Figure 3.2: ATCO inputs indexes, 2000–2022



Source: Quantonomics GDB database

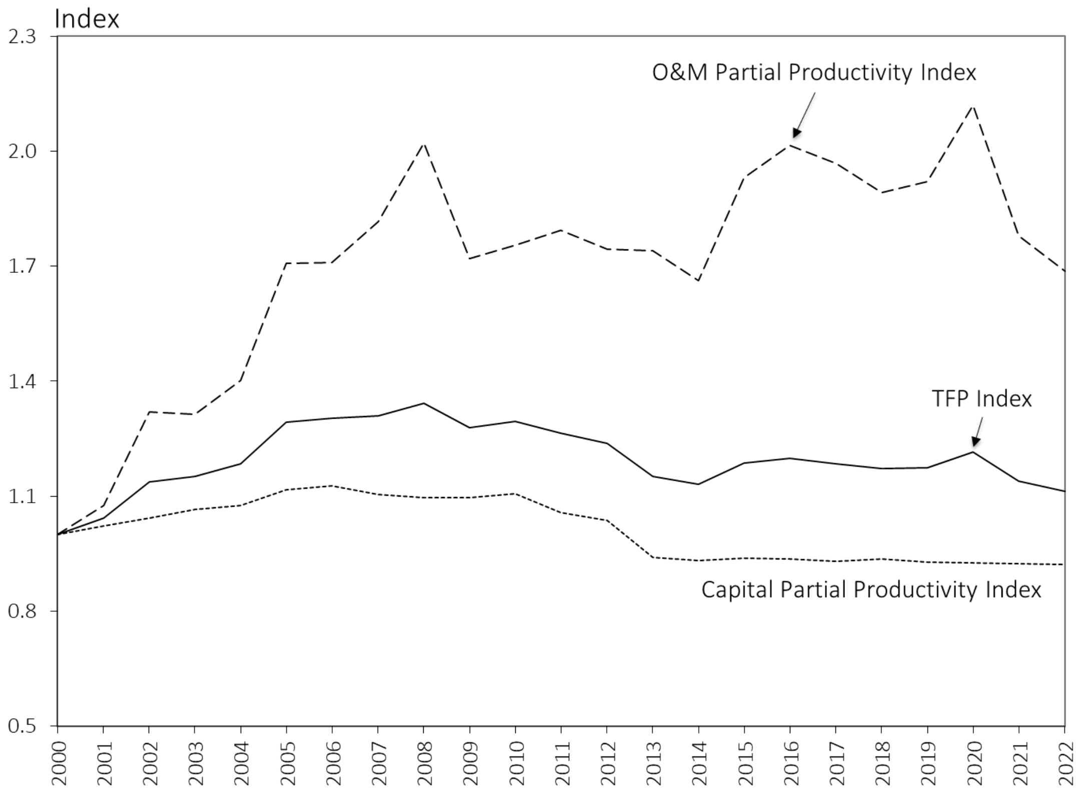
Figure 3.3 shows the movements in opex partial productivity and capex partial productivity indexes. These indexes represent the ratios of the output index shown in Figure 3.1, to each individual input index shown in Figure 3.2. Because of the combined effect of the growth of output and the decline in real opex inputs in the period from 2000 to 2007, opex partial productivity increased at an average annual rate of 8.9 per cent. In the period from 2007 to 2014, output growth was slower and opex inputs increased, resulting in -1.3 per cent annual growth of opex partial productivity. From 2014 to 2022, growth of output and of real opex both continued at a slightly slower rate to the preceding period, leading to opex partial productivity increasing at an average annual rate of 0.2 per cent.

Capital partial productivity increased in the period up to 2007 and decreased by around one per cent per year thereafter; averaging a decline of 0.4 per cent per year over the whole period from 2000 to 2022. This results from similar rates of growth in output and capital inputs.

The results for the period 2020 to 2022 deserve particular attention, since it strongly influences growth rates calculated over full sample period and over the period from 2014 to 2022. The

2020 to 2022 time frame was marked by challenges imposed by the Covid19 pandemic. Within this period, opex input increased by 13.1 per cent in total, and capital input increased by 1.1 per cent. Consequently, the total increase of the input index was 5.4 per cent. This, when combined with the small increase of 0.9% in outputs over the same period, resulted in a decrease of 10.8 per cent in the Opex PFP index, while the Capital PFP index remained virtually unchanged (decreasing only 0.2 per cent). The TFP index decreased between 2020 to 2022 by 4.3 per cent.

Figure 3.3: ATCO partial productivity indexes, 2000–2022



Source: Quantonomics GDB database

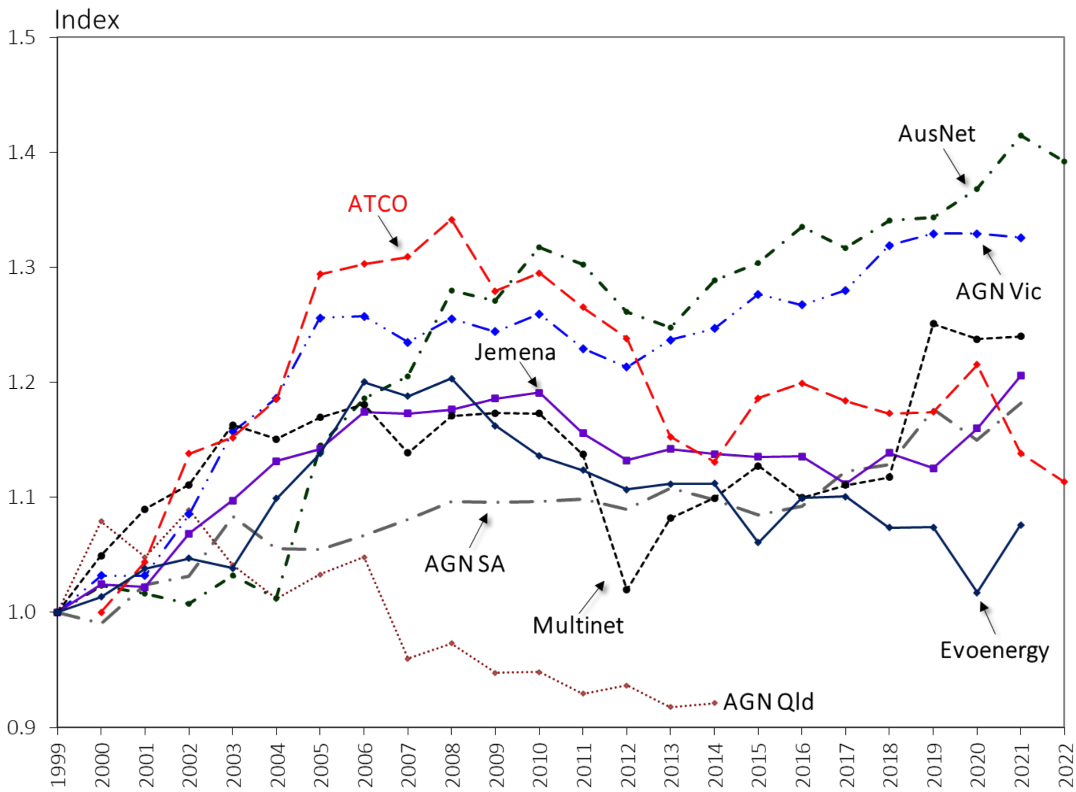
3.3.2 Comparison with Interstate GDB Productivity Growth

This section compares ATCO's productivity growth with that of the interstate GDBs. Comparative TFP, PFP, output and real opex input indexes for the eight GDBs included in the sample are presented in Figures 3.4 to 3.8. Similarly, comparative TFP, PFP, output and input indexes and growth rates are presented in Tables 3.2 to 3.8.

The TFP performance of the GDBs in the sample is plotted in Figure 3.4, and the index numbers and average growth rates are shown in Table 3.2. Two GDBs, had stronger rates of TFP growth than the other GDBs over the period 1999 to 2022, namely AusNet (whose TFP growth rate of averaged 1.4 per cent per year) and AGN Vic (1.3 per cent). ATCO's TFP growth over the same period of 0.5 per cent per year, was below the sample average (0.7 per cent), but was broadly similar to those of Jemena (with average growth of 0.9 per cent) and AGN SA (0.8 per cent). Less data is available for AGN Qld, however the trend for the period up to 2014 suggests an ongoing decline in TFP. The time pattern of ATCO's TFP index is similar to Jemena, Evoenergy and Multinet, all having strong TFP growth in the period from 1999 to 2007 and declines in TFP in the period from 2007 to 2014. From 2014 to 2022 (or latest year), Jemena's increased slowly, Multinet considerably increased and Evoenergy's and ATCO's continued to decrease. AGN SA's time pattern of TFP movements is different, with constant slightly growth occurring in all periods.

Figure 3.5 plots the Opex PFP indexes and Table 3.3 shows the Opex PFP index numbers and the growth rates.

Figure 3.4: Comparative TFP indexes, 1999–2022



Source: Quantonomics gas utility database.

Table 3.2: TFP indexes comparison, 1999-2022*

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	1.000	1.000	1.000	1.000	1.000		1.000
2000	1.079	0.991	1.032	1.023	1.024	1.049	1.000	1.014
2001	1.048	1.024	1.032	1.016	1.022	1.090	1.044	1.038
2002	1.089	1.031	1.085	1.007	1.069	1.111	1.138	1.047
2003	1.041	1.083	1.157	1.032	1.097	1.163	1.152	1.038
2004	1.012	1.055	1.186	1.012	1.132	1.151	1.185	1.099
2005	1.033	1.054	1.256	1.145	1.142	1.169	1.294	1.138

Table 3.2: (cont.)

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
2006	1.048	1.067	1.257	1.186	1.174	1.181	1.303	1.200
2007	0.960	1.081	1.235	1.205	1.173	1.139	1.309	1.188
2008	0.973	1.096	1.255	1.280	1.176	1.171	1.341	1.203
2009	0.947	1.095	1.244	1.271	1.186	1.173	1.279	1.162
2010	0.948	1.096	1.259	1.317	1.191	1.173	1.295	1.136
2011	0.929	1.099	1.229	1.302	1.156	1.137	1.265	1.124
2012	0.937	1.089	1.213	1.261	1.132	1.019	1.238	1.107
2013	0.918	1.108	1.237	1.247	1.142	1.082	1.153	1.112
2014	0.921	1.098	1.247	1.288	1.137	1.099	1.131	1.112
2015		1.084	1.276	1.303	1.135	1.127	1.186	1.061
2016		1.093	1.267	1.335	1.135	1.100	1.199	1.099
2017		1.123	1.280	1.317	1.112	1.111	1.184	1.101
2018		1.128	1.319	1.341	1.139	1.118	1.173	1.074
2019		1.177	1.329	1.343	1.125	1.251	1.174	1.074
2020		1.149	1.329	1.368	1.160	1.237	1.215	1.017
2021		1.182	1.326	1.415	1.206	1.240	1.138	1.076
2022				1.392			1.113	
Average Annual Change								
1999–2007	-0.5%	1.0%	2.7%	2.4%	2.0%	1.6%	3.9%	2.2%
2007–2014	-0.6%	0.2%	0.1%	1.0%	-0.4%	-0.5%	-2.1%	-0.9%
*2014-2022**	.	1.1%	0.9%	1.0%	0.8%	1.7%	-0.2%	-0.5%
*1999–2022**	-0.5%	0.8%	1.3%	1.4%	0.9%	1.0%	0.5%	0.3%

Figure 3.5: Comparative Opex PFP indexes, 1999 – 2022*

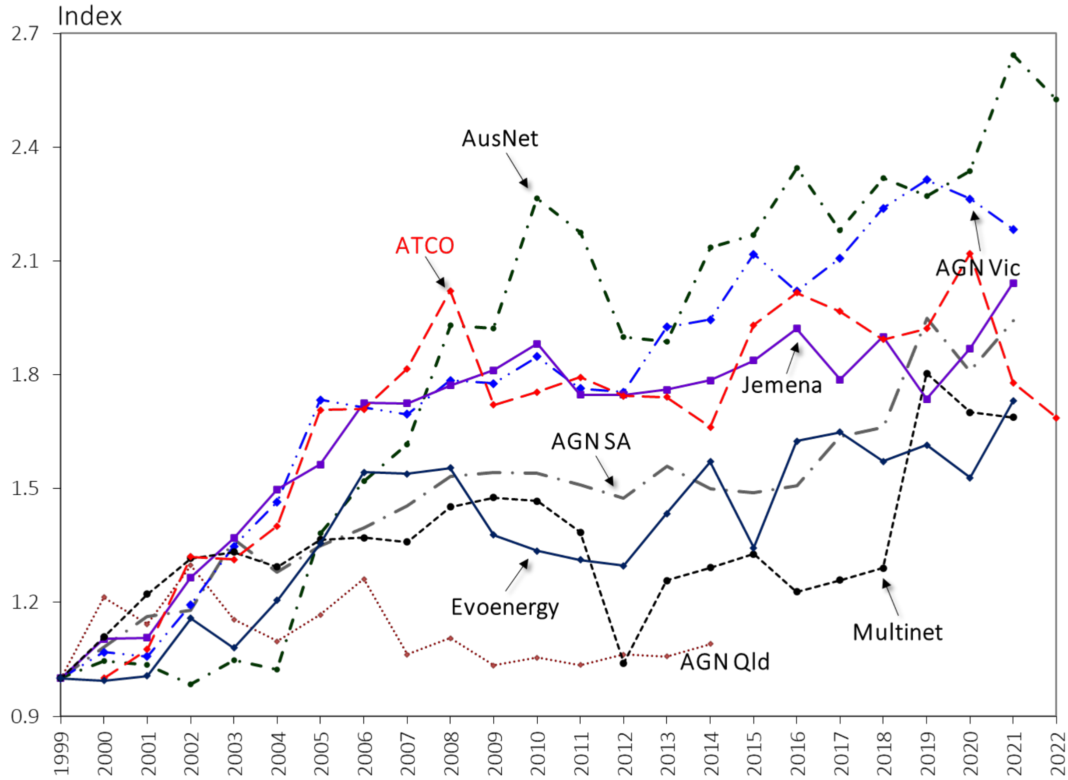


Table 3.3: Opex PFP indexes comparison, 1999–2022*

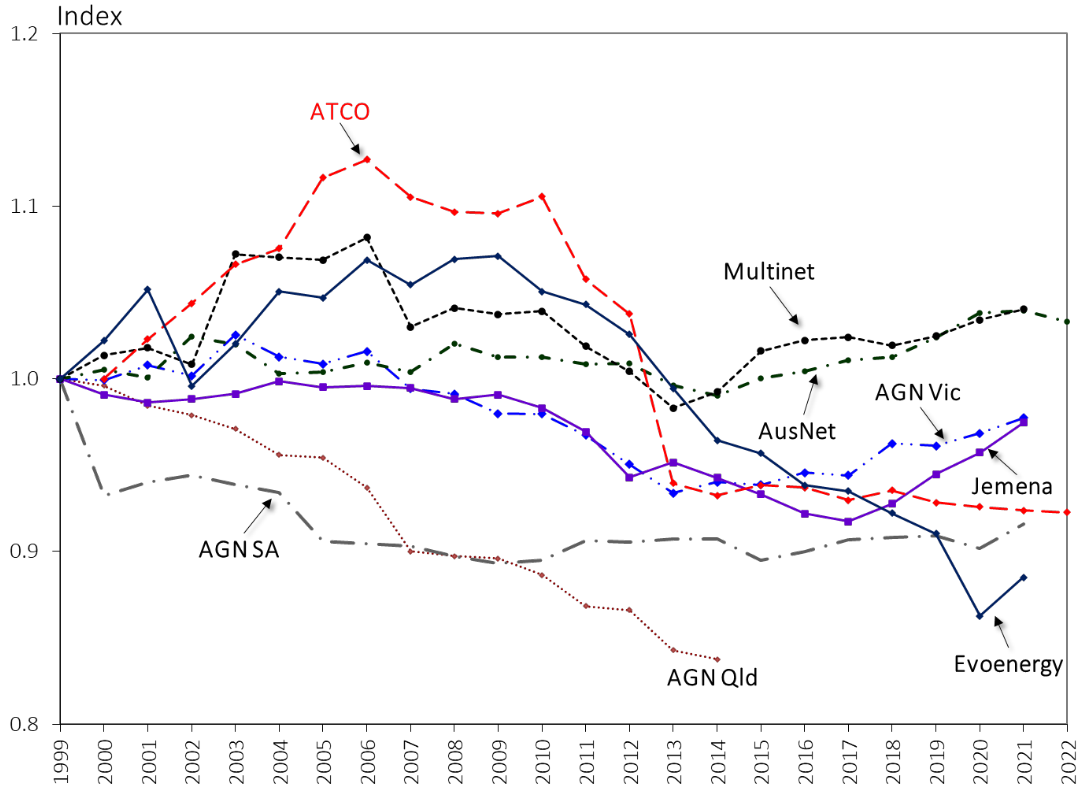
Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	1.000	1.000	1.000	1.000	1.000		1.000
2000	1.214	1.083	1.068	1.045	1.104	1.108	1.000	0.994
2001	1.143	1.163	1.058	1.035	1.107	1.222	1.077	1.007
2002	1.298	1.179	1.194	0.984	1.266	1.316	1.320	1.158
2003	1.156	1.366	1.348	1.047	1.370	1.333	1.313	1.080
2004	1.097	1.280	1.465	1.024	1.498	1.294	1.401	1.205
2005	1.167	1.349	1.733	1.382	1.564	1.365	1.708	1.355
2006	1.262	1.397	1.715	1.520	1.726	1.370	1.709	1.543
2007	1.063	1.454	1.696	1.617	1.724	1.359	1.816	1.539
2008	1.106	1.532	1.785	1.930	1.771	1.452	2.021	1.555
2009	1.034	1.543	1.777	1.923	1.812	1.476	1.720	1.377
2010	1.055	1.540	1.847	2.264	1.882	1.467	1.754	1.336
2011	1.035	1.510	1.763	2.174	1.748	1.385	1.793	1.312
2012	1.063	1.475	1.755	1.900	1.747	1.040	1.744	1.297
2013	1.058	1.558	1.925	1.888	1.760	1.257	1.741	1.434
2014	1.090	1.500	1.946	2.136	1.785	1.291	1.662	1.570
2015		1.489	2.117	2.168	1.837	1.328	1.931	1.344
2016		1.508	2.020	2.345	1.922	1.228	2.016	1.625
2017		1.638	2.108	2.181	1.788	1.259	1.967	1.649
2018		1.661	2.239	2.319	1.900	1.291	1.892	1.571
2019		1.948	2.314	2.270	1.736	1.803	1.921	1.615
2020		1.810	2.264	2.338	1.869	1.701	2.120	1.528
2021		1.942	2.183	2.643	2.042	1.688	1.779	1.731
2022				2.526			1.687	
Average Annual Change								
1999–2007	0.8%	4.8%	6.8%	6.2%	7.0%	3.9%	8.9%	5.5%
2007–2014	0.4%	0.4%	2.0%	4.1%	0.5%	-0.7%	-1.3%	0.3%
*2014-2022**	.	3.8%	1.7%	2.1%	1.9%	3.9%	0.2%	1.4%
*1999–2022**	0.6%	3.1%	3.6%	4.1%	3.3%	2.4%	2.4%	2.5%

* Or latest year. Source: Calculations using Quantonomics GDB database.

ATCO's Opex PFP growth over the full period from 2000 to 2022 was 2.4 per cent per year; which was close to the average for all the GDBs (2.8 per cent). Multinet and ATCO had a lower Opex PFP growth rate (2.4 per cent); whereas GDBs with higher Opex PFP growth rates over the same period included: AusNet (4.1 per cent); AGN-Vic (3.6 per cent); Jemena (3.3 per cent); AGN SA (3.1 per cent). For most GDBs, Opex PFP growth was particularly strong in the period from 1999 to 2007 (averaging 5.5 per cent per year for all GDBs), but was relatively weak in the following period from 2007 to 2014 (averaging 0.7 per cent per year for all GDBs). In the period 2014 to 2022, Opex PFP growth increased (averaging 2.1 per cent per year for all GDBs). In this period ATCO's Opex PFP growth was 0.2 per cent per year.

Figure 3.6 plots the Capital PFP indexes shown in Table 3.4. For most GDBs, Capital PFP indexes have had small increases or small decreases. Examples of the first are Multinet (0.2 per cent per year from 1999 to 2022) and AusNet (0.1 per cent). Examples of small declines include AGN Vic and Jemena (both –0.1 per cent per year), AGN-SA and ATCO (both –0.4 per cent), Evoenergy (–0.6 per cent) and AGN Qld (-1.2 per cent per year from 1999 to 2014).

Figure 3.6: Comparative Capital PFP indexes, 1999–2022*



* Or latest year. Source: Calculations using Quantonomics GDB database.

Table 3.4: Capital PFP indexes comparison, 2000–2022*

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	1.000	1.000	1.000	1.000	1.000		1.000
2000	0.996	0.932	0.999	1.005	0.991	1.014	1.000	1.022
2001	0.984	0.940	1.008	1.001	0.986	1.018	1.023	1.052
2002	0.979	0.944	1.002	1.025	0.988	1.008	1.044	0.996
2003	0.971	0.939	1.025	1.020	0.991	1.072	1.066	1.020
2004	0.956	0.934	1.013	1.003	0.999	1.070	1.075	1.051
2005	0.954	0.906	1.009	1.004	0.995	1.069	1.116	1.047
2006	0.937	0.905	1.016	1.009	0.996	1.082	1.127	1.069
2007	0.900	0.903	0.994	1.004	0.995	1.030	1.105	1.054
2008	0.897	0.897	0.991	1.020	0.988	1.041	1.097	1.069
2009	0.896	0.893	0.980	1.012	0.991	1.037	1.096	1.071
2010	0.886	0.895	0.980	1.013	0.983	1.039	1.106	1.051
2011	0.868	0.906	0.967	1.009	0.969	1.019	1.058	1.043
2012	0.866	0.905	0.950	1.009	0.943	1.004	1.038	1.026
2013	0.843	0.907	0.934	0.996	0.952	0.983	0.939	0.994
2014	0.837	0.907	0.940	0.990	0.943	0.992	0.932	0.964
2015		0.895	0.939	1.000	0.933	1.016	0.938	0.957

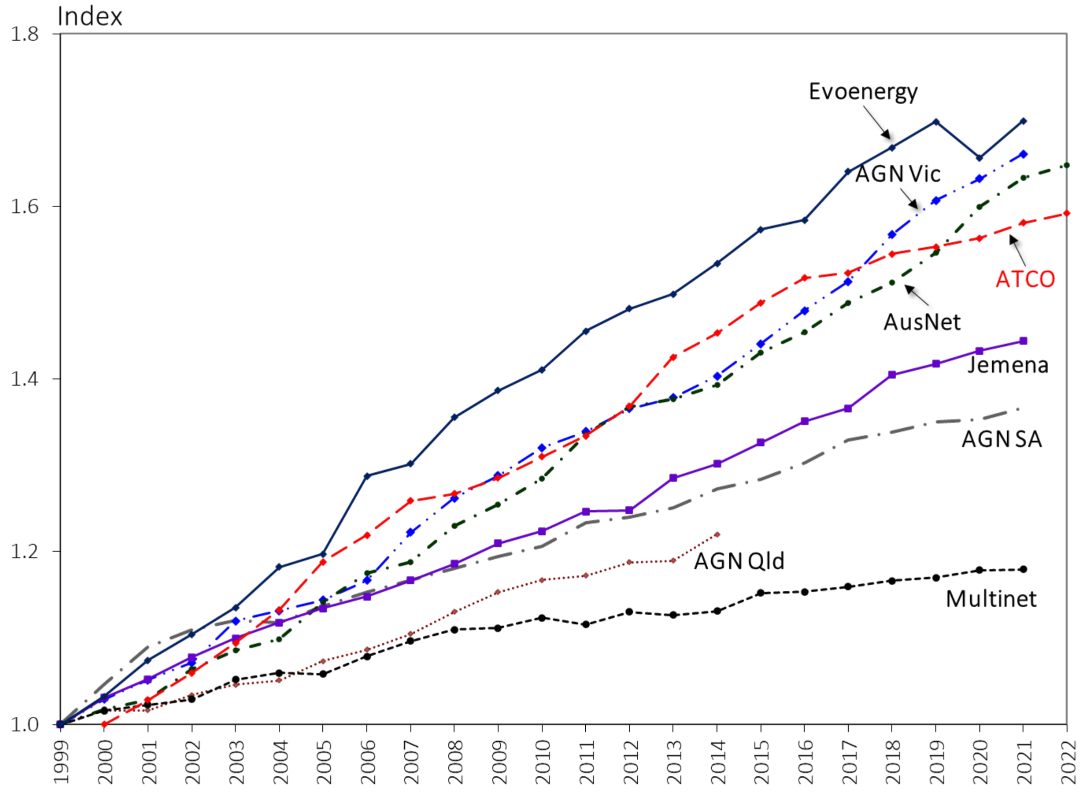
Table 3.4: (cont.)

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
2016		0.900	0.946	1.004	0.922	1.022	0.937	0.938
2017		0.907	0.944	1.011	0.917	1.024	0.930	0.935
2018		0.908	0.962	1.012	0.928	1.019	0.935	0.922
2019		0.909	0.961	1.024	0.945	1.025	0.928	0.910
2020		0.902	0.968	1.038	0.957	1.034	0.926	0.863
2021		0.916	0.977	1.039	0.975	1.040	0.924	0.885
2022				1.033			0.923	
Average Annual Change								
1999–2007	-1.3%	-1.3%	-0.1%	0.0%	-0.1%	0.4%	1.4%	0.7%
2007–2014	-1.0%	0.1%	-0.8%	-0.2%	-0.8%	-0.5%	-2.4%	-1.3%
*2014-2022**	.	0.1%	0.6%	0.5%	0.5%	0.7%	-0.1%	-1.2%
*1999–2022**	-1.2%	-0.4%	-0.1%	0.1%	-0.1%	0.2%	-0.4%	-0.6%

* Or latest year. Source: Calculations using Quantonomics GDB database.

Figure 3.7 shows the comparative output indexes, which are also presented in Table 3.5.

Figure 3.7: Comparative Output indexes, 1999–2022*



* Or latest year. Source: Calculations using Quantonomics GDB database.

ATCO had above-average output growth averaging 2.1 per cent per year between 2000 and 2022, compared to the average for all GDBs of 1.8 per cent over the same period. Other GDBs with relatively high output growth were AGN Vic, Evoenergy and AusNet, averaging 2.3, 2.4

and 2.2 per cent per annum respectively over the full sample period. Those with the lowest output growth were AGN Qld and Multinet Gas. The latter services a mature urban area which already has high rates of gas penetration.

Table 3.5: Output indexes comparison, 1999–2022*

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	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	1.032
2001	1.016	1.089	1.051	1.028	1.052	1.022	1.028	1.074
2002	1.034	1.109	1.072	1.064	1.078	1.029	1.060	1.104
2003	1.046	1.120	1.120	1.086	1.100	1.052	1.094	1.135
2004	1.051	1.118	1.132	1.098	1.118	1.059	1.132	1.182
2005	1.073	1.137	1.144	1.142	1.135	1.058	1.188	1.197
2006	1.086	1.153	1.167	1.175	1.148	1.079	1.219	1.288
2007	1.105	1.167	1.222	1.188	1.167	1.096	1.259	1.302
2008	1.130	1.181	1.262	1.230	1.186	1.110	1.267	1.356
2009	1.153	1.194	1.288	1.254	1.210	1.111	1.285	1.387
2010	1.167	1.206	1.320	1.285	1.224	1.124	1.310	1.411
2011	1.172	1.234	1.339	1.336	1.247	1.116	1.334	1.455
2012	1.188	1.240	1.366	1.368	1.248	1.130	1.368	1.481
2013	1.190	1.251	1.378	1.377	1.285	1.127	1.425	1.498
2014	1.220	1.273	1.403	1.393	1.302	1.131	1.453	1.534
2015		1.284	1.441	1.431	1.326	1.152	1.488	1.573
2016		1.303	1.479	1.454	1.351	1.154	1.517	1.584
2017		1.329	1.513	1.488	1.366	1.160	1.523	1.640
2018		1.338	1.567	1.512	1.405	1.166	1.545	1.668
2019		1.351	1.607	1.546	1.418	1.170	1.553	1.698
2020		1.353	1.632	1.599	1.432	1.179	1.563	1.656
2021		1.367	1.661	1.633	1.444	1.179	1.581	1.699
2022				1.648			1.592	
Average Annual Change								
1999–2007	1.3%	1.9%	2.5%	2.2%	1.9%	1.2%	3.3%	3.4%
2007–2014	1.4%	1.3%	2.0%	2.3%	1.6%	0.4%	2.1%	2.4%
*2014-2022**	.	1.0%	2.4%	2.1%	1.5%	0.6%	1.1%	1.5%
*1999–2022**	1.3%	1.4%	2.3%	2.2%	1.7%	0.8%	2.1%	2.4%

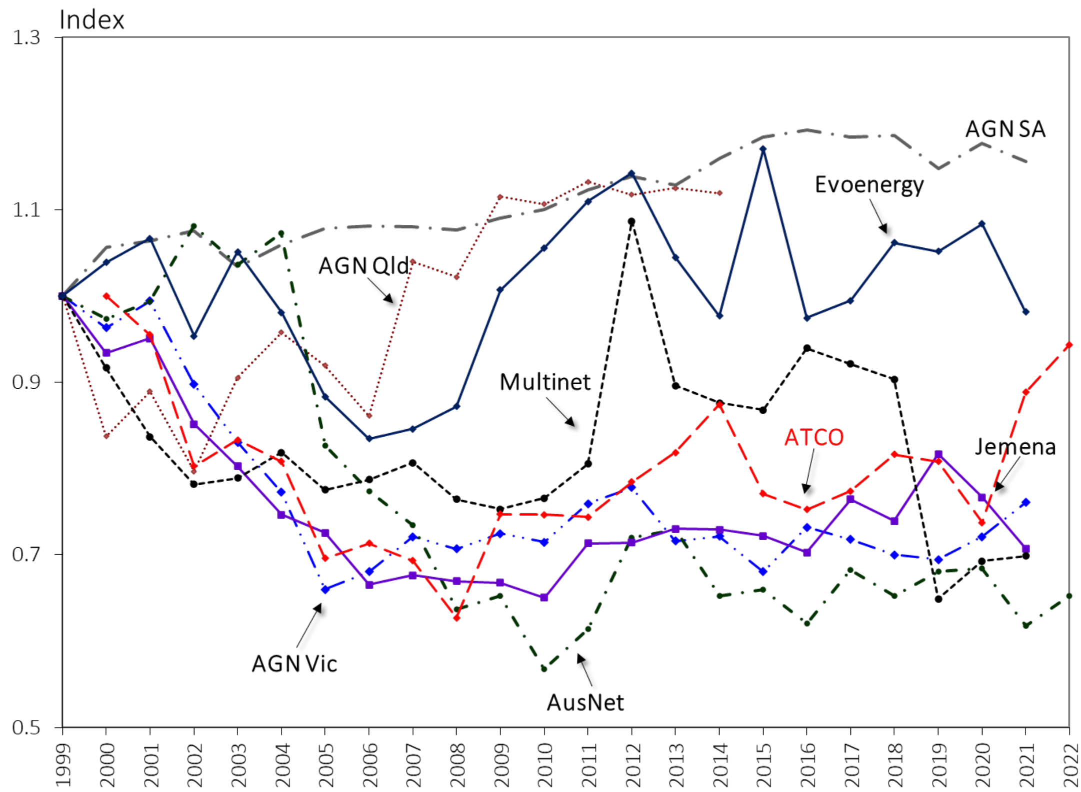
* Or latest year. Source: Calculations using Quantonomics GDB database

Figure 3.8 and Table 3.6 show the comparative opex input indexes. There is a general time-pattern to movements in opex inputs across the sample of GDBs; and ATCO followed it. In the period 1999 to 2007, opex inputs generally decreased substantially. Averaging across GDBs, the average rate of increase in opex was –3.1 per cent per year in that period. In the following period from 2007 to 2014, opex inputs generally increased; with an average rate of increase in opex inputs for all GDBs of 1.0 per cent per year. In the period 2014 to 2022 (or latest), the trends have been more mixed, with some GDBs reducing and others increasing opex inputs. The average rate of increase for all GDBs in that period was –0.6 per cent per year. Over the full period from 1999 to 2022, the average rate of change of opex inputs was –0.9 per cent per year.

ATCO's trend was broadly similar to other GDBs in the period 1999 to 2007, with its opex inputs *decreasing* at an average rate of 5.1 per cent per year. This decrease was higher than the average. In the period 2007 to 2014, ATCO's opex inputs increased at an average rate of 3.4 per cent per year. Although opex inputs also increased from most other GDBs in this period, ATCO's increase was higher than the average. In the period from 2014 to 2022, ATCO's opex inputs increased at 1.0 per cent per year. In the last two periods mentioned, ATCO stronger increases in opex inputs compared to other GDBs.

Over the full period from 2000 to 2022, ATCO's average rate of change of opex inputs was –0.3 per cent per year. Except for AGN Qld (0.8 per cent of increasement), for all GDBs, opex inputs decreased over the full sample period. For example: AusNet (–1.8 per cent per year); AGN-SA, Multinet and Jemena (all –1.6 per cent); AGN-Vic (–1.2) and Evoenergy (–0.1 per cent).

Figure 3.8: Comparative Opex indexes, 1999–2022*



* Or latest year. Source: Calculations using Quantonomics GDB database.

Table 3.6: Opex input indexes comparison, 1999–2022*

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	1.000	1.000	1.000	1.000	1.000		1.000
2000	0.837	0.966	0.963	0.974	0.934	0.917	1.000	1.039
2001	0.889	0.936	0.994	0.994	0.951	0.837	0.955	1.067
2002	0.797	0.941	0.897	1.081	0.851	0.782	0.803	0.954
2003	0.905	0.820	0.831	1.037	0.803	0.789	0.833	1.051
2004	0.958	0.873	0.772	1.073	0.746	0.819	0.808	0.981
2005	0.920	0.843	0.660	0.826	0.726	0.775	0.696	0.883
2006	0.861	0.825	0.681	0.773	0.665	0.787	0.713	0.834
2007	1.040	0.803	0.721	0.735	0.677	0.807	0.693	0.846
2008	1.022	0.770	0.707	0.637	0.669	0.764	0.627	0.872
2009	1.115	0.774	0.725	0.652	0.668	0.753	0.747	1.007
2010	1.106	0.783	0.715	0.568	0.650	0.766	0.747	1.056
2011	1.132	0.817	0.759	0.614	0.713	0.806	0.744	1.110
2012	1.117	0.841	0.778	0.720	0.714	1.087	0.784	1.142
2013	1.125	0.803	0.716	0.729	0.730	0.896	0.819	1.045
2014	1.119	0.849	0.721	0.652	0.729	0.876	0.874	0.977
2015		0.862	0.681	0.660	0.722	0.868	0.771	1.170
2016		0.864	0.732	0.620	0.703	0.939	0.752	0.975
2017		0.812	0.718	0.682	0.764	0.921	0.774	0.995
2018		0.805	0.700	0.652	0.739	0.903	0.816	1.062
2019		0.693	0.694	0.681	0.817	0.649	0.808	1.052
2020		0.748	0.721	0.684	0.766	0.693	0.737	1.084
2021		0.704	0.761	0.618	0.707	0.699	0.888	0.981
2022				0.652			0.943	
Average Annual Change								
1999–2007	0.5%	-2.7%	-4.0%	-3.8%	-4.8%	-2.6%	-5.1%	-2.1%
2007–2014	1.1%	0.8%	0.0%	-1.7%	1.1%	1.2%	3.4%	2.1%
*2014-2022**	.	-2.6%	0.8%	0.0%	-0.4%	-3.2%	1.0%	0.1%
*1999–2022**	0.8%	-1.6%	-1.2%	-1.8%	-1.6%	-1.6%	-0.3%	-0.1%

* Or latest year. Source: Calculations using Quantonomics GDB database

Tables 3.7 and 3.8 show the indexes and growth rates for capital inputs and for the combined inputs index. The average growth rate of capital inputs for ATCO over the period 2000 to 2022 was 2.5 per cent per year, which was significantly higher than the average for all GDBs (2.1 per cent). Most GDBs had a similar trend to the average, one exception being Multinet, which had lower growth of capital inputs.

The growth of capital inputs was generally sufficient to cause the overall index of inputs to increase, notwithstanding reductions in opex inputs. The average rate of increase in inputs for ATCO over the period 2000 to 2022 was 1.6 per cent per year, which was above the average for all GDBs (1.1 per cent).

Table 3.7: Capital input indexes comparison, 1999–2022*

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	1.000	1.000	1.000	1.000	1.000		1.000
2000	1.020	1.123	1.030	1.012	1.040	1.002	1.000	1.010
2001	1.032	1.158	1.043	1.028	1.067	1.005	1.005	1.021
2002	1.056	1.175	1.070	1.039	1.090	1.021	1.015	1.109
2003	1.077	1.193	1.092	1.065	1.110	0.981	1.026	1.113
2004	1.099	1.196	1.118	1.095	1.120	0.990	1.053	1.125
2005	1.125	1.255	1.134	1.138	1.140	0.990	1.064	1.144
2006	1.159	1.275	1.149	1.164	1.153	0.997	1.082	1.205
2007	1.228	1.292	1.230	1.184	1.173	1.065	1.139	1.235
2008	1.260	1.316	1.273	1.205	1.200	1.066	1.156	1.268
2009	1.287	1.337	1.315	1.239	1.221	1.071	1.173	1.295
2010	1.317	1.348	1.348	1.269	1.245	1.081	1.185	1.343
2011	1.350	1.361	1.385	1.324	1.286	1.095	1.262	1.395
2012	1.371	1.370	1.437	1.356	1.323	1.125	1.319	1.444
2013	1.412	1.379	1.476	1.382	1.351	1.146	1.517	1.507
2014	1.457	1.403	1.493	1.407	1.381	1.140	1.558	1.591
2015		1.435	1.535	1.430	1.421	1.134	1.586	1.644
2016		1.448	1.564	1.448	1.465	1.128	1.619	1.688
2017		1.466	1.603	1.473	1.489	1.132	1.638	1.754
2018		1.474	1.628	1.493	1.514	1.144	1.652	1.809
2019		1.486	1.672	1.510	1.500	1.142	1.673	1.865
2020		1.500	1.685	1.540	1.496	1.140	1.688	1.920
2021		1.492	1.699	1.571	1.482	1.134	1.711	1.919
2022				1.595			1.725	
Average Annual Change								
1999–2007	2.6%	3.3%	2.6%	2.1%	2.0%	0.8%	1.9%	2.7%
2007–2014	2.5%	1.2%	2.8%	2.5%	2.4%	1.0%	4.6%	3.7%
*2014-2019**	.	0.9%	1.9%	1.6%	1.0%	-0.1%	1.3%	2.7%
*1999–2019**	2.5%	1.8%	2.4%	2.1%	1.8%	0.6%	2.5%	3.0%

* Or latest year. Source: Calculations using Quantonomics GDB database.

Table 3.8: Input indexes comparison, 1999–2022*

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
1999	1.000	1.000	1.000	1.000	1.000	1.000		1.000
2000	0.942	1.057	0.997	0.995	1.006	0.968	1.000	1.019
2001	0.970	1.064	1.019	1.012	1.030	0.938	0.985	1.035
2002	0.950	1.076	0.987	1.057	1.008	0.926	0.931	1.055
2003	1.005	1.034	0.968	1.052	1.002	0.904	0.950	1.093
2004	1.039	1.059	0.954	1.085	0.988	0.921	0.956	1.076
2005	1.039	1.078	0.911	0.997	0.993	0.905	0.918	1.052
2006	1.037	1.081	0.928	0.991	0.978	0.914	0.936	1.073
2007	1.151	1.080	0.990	0.986	0.995	0.963	0.962	1.096
2008	1.162	1.077	1.005	0.961	1.008	0.948	0.945	1.127
2009	1.217	1.090	1.036	0.987	1.020	0.947	1.005	1.193
2010	1.231	1.100	1.049	0.975	1.028	0.958	1.012	1.242
2011	1.261	1.123	1.089	1.026	1.079	0.981	1.055	1.295
2012	1.268	1.138	1.126	1.084	1.102	1.108	1.105	1.339

Table 3.8: (cont.)

Year	*AGN-Qld*	*AGN-SA*	*AGN-Vic*	*AusNet*	*JGN*	*Multinet*	*ATCO*	*Evoenergy*
2013	1.297	1.129	1.115	1.104	1.125	1.041	1.237	1.348
2014	1.325	1.159	1.126	1.081	1.144	1.029	1.285	1.380
2015		1.184	1.129	1.098	1.168	1.022	1.255	1.483
2016		1.193	1.167	1.089	1.190	1.049	1.265	1.441
2017		1.184	1.182	1.131	1.229	1.044	1.286	1.490
2018		1.186	1.188	1.128	1.234	1.044	1.317	1.553
2019		1.148	1.209	1.151	1.260	0.935	1.323	1.581
2020		1.177	1.228	1.169	1.235	0.952	1.286	1.628
2021		1.156	1.253	1.155	1.198	0.951	1.389	1.579
2022				1.184			1.429	
Average Annual Change								
1999–2007	1.8%	1.0%	-0.1%	-0.2%	-0.1%	-0.5%	-0.6%	1.2%
2007–2014	2.0%	1.0%	1.9%	1.3%	2.0%	1.0%	4.2%	3.3%
*2014-2022**	.	0.0%	1.5%	1.1%	0.7%	-1.1%	1.3%	1.9%
*1999–2022**	1.9%	0.7%	1.0%	0.7%	0.8%	-0.2%	1.6%	2.1%

* Or latest year. Source: Calculations using Quantonomics GDB database.

3.4 Productivity Level Results

The multilateral TFP indexes for eight GDBs are presented in table 3.9 and figure 3.9. 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, which are mostly not controlled for in this comparison.

Table 3.9: GDB multilateral TFP indexes, 1999–2022*

Year	*AGN Vic*	*Multinet*	*AusNet*	*JGN*	*AGN SA*	*AGN Qld*	*ATCO*	*Evoenergy*
1999	1.000	0.964	0.912	0.918	0.993	0.812		0.797
2000	1.029	1.010	0.930	0.943	0.967	0.869	1.430	0.809
2001	1.033	1.050	0.921	0.945	0.995	0.843	1.501	0.845
2002	1.080	1.045	0.917	0.990	0.997	0.873	1.641	0.911
2003	1.145	1.053	0.931	1.018	1.046	0.838	1.624	0.912
2004	1.167	1.038	0.917	1.051	1.016	0.816	1.643	0.961
2005	1.222	1.047	1.006	1.070	1.012	0.830	1.808	1.004
2006	1.200	1.051	1.027	1.107	1.020	0.837	1.788	1.047
2007	1.213	1.037	1.037	1.114	1.031	0.771	1.781	1.054
2008	1.204	1.054	1.076	1.122	1.041	0.781	1.816	1.049
2009	1.193	1.049	1.060	1.131	1.037	0.761	1.712	1.024
2010	1.201	1.048	1.086	1.138	1.037	0.758	1.725	1.012
2011	1.183	1.021	1.079	1.106	1.037	0.745	1.675	1.004
2012	1.163	0.931	1.046	1.085	1.024	0.744	1.639	0.990
2013	1.185	0.979	1.053	1.090	1.034	0.728	1.517	1.012
2014	1.189	0.996	1.099	1.088	1.005	0.728	1.467	1.034
2015	1.174	1.014	1.102	1.077	0.975		1.514	1.015
2016	1.181	0.988	1.118	1.098	0.970		1.504	1.072
2017	1.217	0.989	1.106	1.088	0.996		1.468	1.104

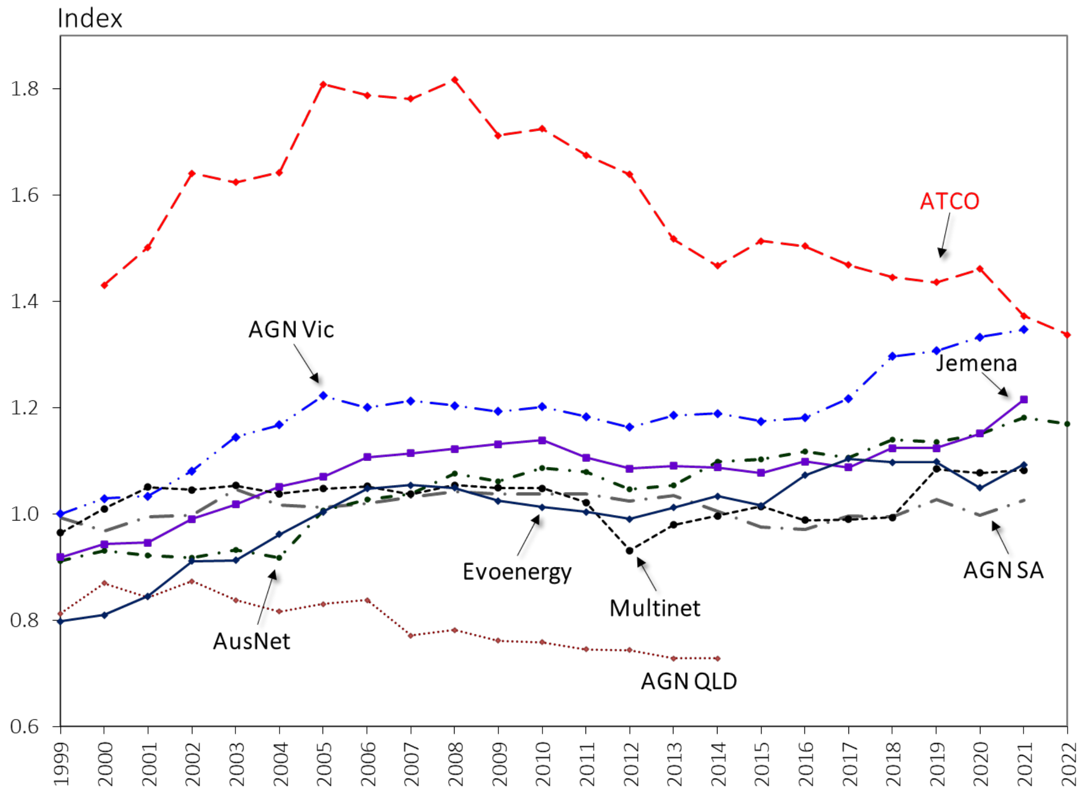
Table 3.9: (cont.)

Year	*AGN Vic*	*Multinet*	*AusNet*	*JGN*	*AGN SA*	*AGN Qld*	*ATCO*	*Evoenergy*
2018	1.296	0.993	1.140	1.124	0.994		1.445	1.097
2019	1.306	1.085	1.135	1.124	1.027		1.436	1.098
2020	1.333	1.077	1.150	1.151	0.998		1.461	1.049
2021	1.347	1.082	1.181	1.215	1.025		1.373	1.093
2022			1.169				1.337	
Average Annual Change								
1999–2007	2.4%	0.9%	1.6%	2.4%	0.5%	-0.7%	3.2%	3.6%
2007–2014	-0.3%	-0.6%	0.8%	-0.3%	-0.4%	-0.8%	-2.7%	-0.3%
*2014-2022**	1.8%	0.0%	0.8%	1.6%	0.3%	.	-0.3%	0.8%
*1999–2022**	1.4%	0.1%	1.1%	1.3%	0.1%	-0.7%	0.0%	1.4%

*Or latest year. Source: Calculations using Quantonomics GDB database.

The MTFP results indicate that in the latest years available, ATCO is found to have second highest TFP level—an MTFP index of 1.34 in, followed by AGN Vic (1.35), Jemena (1.21) and AusNet (1.17). Those with TFP lowest levels include AGN SA (1.03), Multinet (1.08) and Evoenergy (1.09), whereas AGN Qld has a much lower TFP level (0.73 in 2014).

Figure 3.9: GDB multilateral TFP indexes, 1999–2022



Source: Quantonomics GDB database

ATCO had a significant increase in TFP over the period 2000-2007 (3.2 per cent) however it faced a decline from 2007 onwards, causing average growth from 2000 to 2022 to be 0.0 per cent per year. Aside from AGN Qld, which had declining productivity, the other GDBs in the sample enjoyed a significant gain in productivity over the sample period.

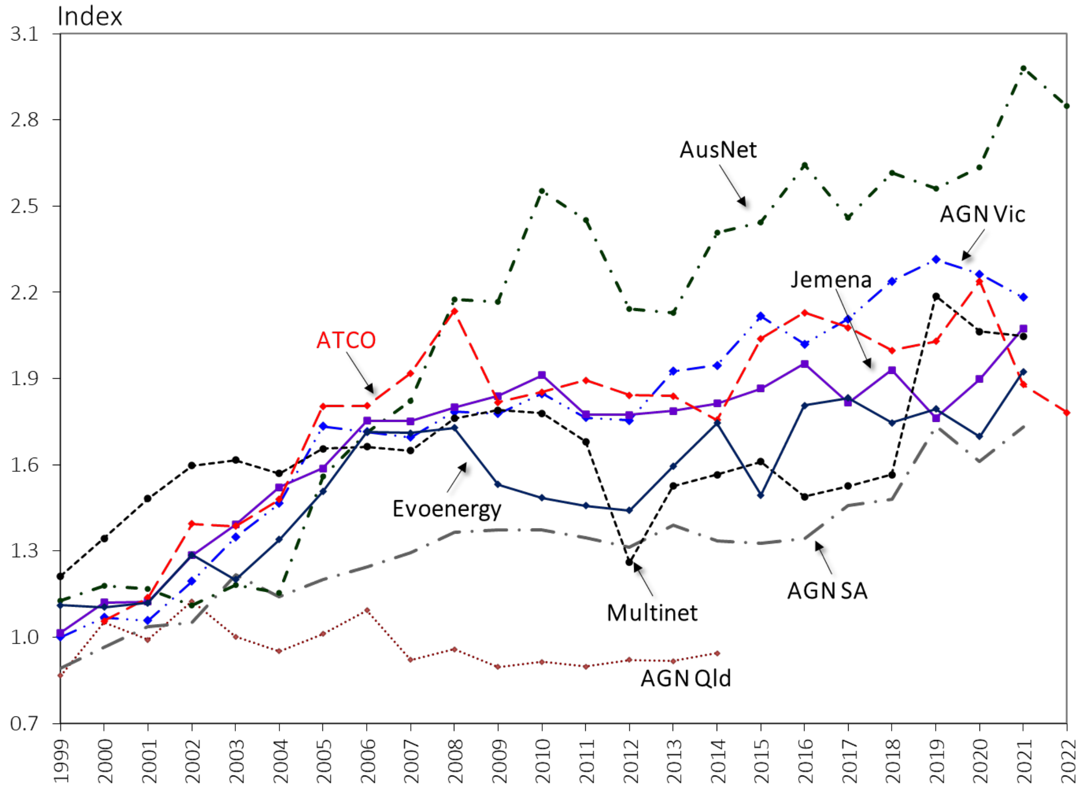
Table 3.10 and Figure 3.10 compare the levels of Opex PFP using multilateral Opex PFP indexes for the eight GDBs. In the last year available, ATCO had the sixth highest Opex PFP level (1.78). In comparison to ATCO's Opex PFP level in 2000 (1.06), it indicates a strong growth in Opex PFP over the sample period. Most of the GDBs had similarly strong growth in Opex PFP over the sample period, with the only exceptions being Multinet and AGN Qld, which had more modest gains. The GDBs with strongest growth in Opex PFP were AGN Vic and AusNet, and they also had the highest levels of Opex PFP at the end of the period (2.18 and 2.85 respectively). ATCO's Opex PFP level at the end of the sample period was most comparable to AGN SA (1.73).

Table 3.10: GDB multilateral Opex PFP indexes, 1999–2019

Year	*AGN Vic*	*Multinet*	*AusNet*	*JGN*	*AGN SA*	*AGN Qld*	*ATCO*	*Evoenergy*
1999	1.000	1.213	1.127	1.016	0.891	0.867		1.111
2000	1.068	1.344	1.178	1.121	0.965	1.052	1.056	1.104
2001	1.058	1.482	1.167	1.124	1.036	0.991	1.137	1.119
2002	1.194	1.596	1.110	1.286	1.050	1.125	1.394	1.287
2003	1.348	1.616	1.181	1.391	1.217	1.002	1.387	1.200
2004	1.465	1.569	1.154	1.521	1.140	0.951	1.480	1.339
2005	1.733	1.656	1.558	1.588	1.202	1.012	1.803	1.507
2006	1.715	1.662	1.713	1.752	1.245	1.094	1.805	1.715
2007	1.695	1.649	1.823	1.751	1.295	0.921	1.918	1.711
2008	1.785	1.761	2.175	1.799	1.365	0.959	2.135	1.728
2009	1.777	1.790	2.168	1.840	1.374	0.897	1.817	1.531
2010	1.847	1.780	2.553	1.911	1.372	0.914	1.852	1.485
2011	1.763	1.680	2.451	1.775	1.346	0.897	1.894	1.458
2012	1.755	1.261	2.142	1.774	1.314	0.922	1.842	1.441
2013	1.925	1.525	2.128	1.788	1.388	0.917	1.838	1.594
2014	1.946	1.566	2.408	1.813	1.336	0.945	1.755	1.745
2015	2.117	1.610	2.444	1.866	1.327		2.039	1.494
2016	2.020	1.489	2.644	1.952	1.344		2.129	1.807
2017	2.108	1.527	2.459	1.815	1.459		2.077	1.832
2018	2.239	1.566	2.615	1.929	1.480		1.999	1.746
2019	2.314	2.187	2.560	1.763	1.735		2.029	1.794
2020	2.264	2.064	2.636	1.898	1.613		2.239	1.699
2021	2.183	2.047	2.980	2.074	1.730		1.879	1.924
2022			2.848				1.782	
Average Annual Change								
1999–2007	6.8%	3.9%	6.2%	7.0%	4.8%	0.8%	8.9%	5.5%
2007–2014	2.0%	-0.7%	4.1%	0.5%	0.4%	0.4%	-1.3%	0.3%
*2014-2022**	1.7%	0.0%	2.1%	1.9%	3.8%	.	0.2%	1.4%
*1999–2022**	3.6%	1.2%	4.1%	3.3%	3.1%	0.6%	2.4%	2.5%

Source: Calculations using Quantonomics GDB database.

Figure 3.10: GDB multilateral Opex PFP indexes, 1999–2019



Source: Quantonomics GDB database.

Table 3.11 and Figure 3.11 compare Capital PFP levels using multilateral Capital PFP indexes.

Table 3.11: GDB multilateral Capital PFP indexes, 1999–2022

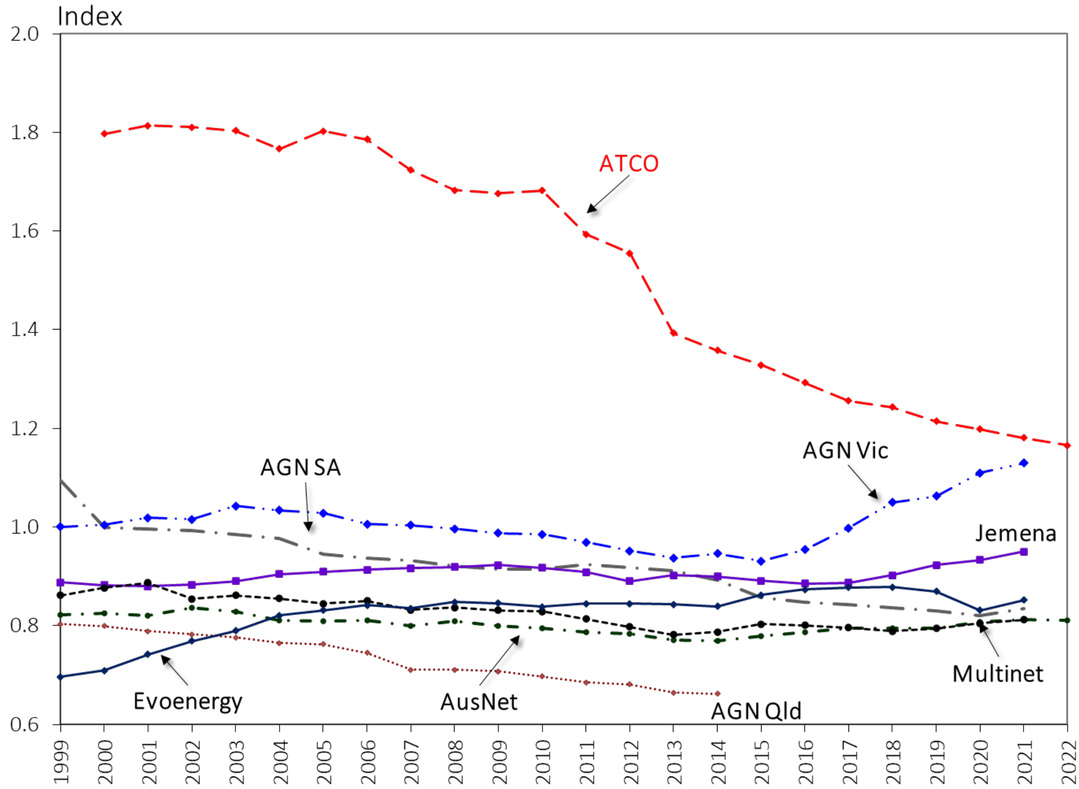
Year	*AGN Vic*	*Multinet*	*AusNet*	*Jemena*	*AGN SA*	*AGN Qld*	*ATCO*	*Evoenergy*
1999	1.000	0.861	0.822	0.888	1.095	0.803		0.696
2000	1.005	0.876	0.825	0.882	1.000	0.799	1.797	0.709
2001	1.019	0.887	0.820	0.880	0.995	0.789	1.814	0.742
2002	1.016	0.854	0.837	0.883	0.993	0.782	1.811	0.769
2003	1.043	0.862	0.828	0.890	0.984	0.776	1.803	0.789
2004	1.034	0.855	0.811	0.905	0.977	0.765	1.767	0.821
2005	1.028	0.845	0.810	0.909	0.944	0.762	1.802	0.831
2006	1.006	0.850	0.810	0.913	0.937	0.745	1.786	0.841
2007	1.003	0.832	0.800	0.916	0.933	0.711	1.723	0.835
2008	0.997	0.837	0.809	0.919	0.922	0.710	1.683	0.848
2009	0.987	0.831	0.799	0.923	0.915	0.707	1.677	0.846
2010	0.985	0.829	0.794	0.918	0.914	0.697	1.682	0.839
2011	0.969	0.813	0.787	0.909	0.924	0.685	1.594	0.845
2012	0.952	0.798	0.783	0.891	0.918	0.681	1.555	0.845
2013	0.937	0.782	0.771	0.902	0.912	0.665	1.393	0.843
2014	0.946	0.787	0.769	0.899	0.892	0.662	1.358	0.839

Table 3.11: (cont.)

Year	*AGN Vic*	*Multinet*	*AusNet*	*Jemena*	*AGN SA*	*AGN Qld*	*ATCO*	*Evoenergy*
2015	0.931	0.803	0.778	0.891	0.857		1.328	0.862
2016	0.954	0.801	0.787	0.886	0.847		1.292	0.873
2017	0.998	0.796	0.794	0.887	0.843		1.256	0.877
2018	1.050	0.789	0.794	0.902	0.837		1.243	0.878
2019	1.063	0.795	0.795	0.923	0.830		1.214	0.870
2020	1.110	0.804	0.808	0.933	0.821		1.198	0.831
2021	1.130	0.812	0.813	0.950	0.835		1.181	0.852
2022			0.811				1.166	
Average Annual Change								
1999–2007	0.0%	-0.4%	-0.3%	0.4%	-2.0%	-1.5%	-0.6%	2.3%
2007–2014	-0.8%	-0.8%	-0.6%	-0.3%	-0.6%	-1.0%	-3.3%	0.1%
*2014-2022**	2.6%	0.0%	0.7%	0.8%	-0.9%	.	-1.4%	0.2%
*1999–2022**	0.6%	-0.4%	-0.1%	0.3%	-1.2%	-1.3%	-1.8%	0.9%

Source: Calculations using Quantonomics GDB database.

Figure 3.11: GDB multilateral Capital PFP indexes, 1999–2019



Source: Quantonomics GDB database.

In the latest year, ATCO's Capital PFP index was 1.17, which is comparable with AGN Vic's index of 1.13. A number of GDBs converged essentially the same level of Capital PFP as Jemena (0.95), Multinet (0.81), AusNet (0.81), AGN SA (0.84), and Evoenergy (0.85). AGN Vic had a higher level of Capital PFP (1.13) and AGN Qld a lower level (0.66).

In terms of the trend, there was little change in the Multilateral Capital PFP indexes between the beginning and end of the sample period for the AusNet, Multinet and for Jemena. For Evoenergy there was a substantial improvement, in the order of 22.3 per cent. ATCO, AGN SA and AGN Qld showed deterioration in Capital PFP over the sample period, respectively of 35.1, 23.7 and 17.6 per cent decrease.

3.5 Summary Conclusions

Fisher indexes are used to measure TFP trends. The time series TFP results for ATCO are as follows:

1. ATCO's TFP increased at an average annual rate of 0.5 per cent from 2000 to 2022. Productivity growth was stronger in the period up to 2007, and has been declining over the period since then.
2. ATCO's Opex partial factor productivity (PFP) increased at an average annual rate of 2.4 per cent from 2000 to 2022. Capital PFP *decreased* at an average annual rate of 0.4 per cent over the same period. Opex PFP growth was strong in the period 1999 to 2007 (8.9 per cent) but there was decrease in the periods from 2007 to 2014 (-1.3 per cent) and a slightly growth in 2014 to 2019 (0.2 per cent). The decline in ATCO's Capital PFP mainly occurred in the periods from 2007 to 2014 (-2.4 per cent) and from 2014 to 2019 (-0.1 per cent).
3. Comparing the average rates of TFP growth of GDBs, ATCO's TFP growth over the full sample period was below the sample average of 0.7 per cent per year. AusNet had higher rates of TFP growth (1.4 per cent). Most GDBs had strong rates of growth in Opex PFP, comparable to ATCO. However, ATCO's decline in Capital PFP (-0.4 per cent per year) was slightly greater than for most other GDBs.
4. Over the most recent period from 2014 to 2022, ATCO's average annual rate of TFP growth was -0.2 per cent. The other GDBs all had some productivity growth in this period. AGN SA, AGN-Vic and AusNet all had an average rate of TFP growth of around 1.0 per cent per year in the 2014 to 2017 period.
5. ATCO had above-average output growth averaging 2.1 per cent per year between 2000 and 2022, compared to the average for all GDBs of 1.8 per cent over the same period. The average rate of increase in inputs for ATCO over the period 2000 to 2022 was 1.6 per cent per year, which was above the average for all GDBs (1.1 per cent). Over the full period from 2000 to 2022, ATCO's average rate of change of opex inputs was -0.3 per cent per year, compared to the average for all GDBs of –0.9 per cent per year. The average growth rate of capital inputs for ATCO over the period 2000 to 1999 was 2.5 per cent per year, compared to the average for all GDBs (2.1 per cent).

The multilateral total factor productivity (MTFP) index is used to measure comparative productivity *levels*. The results for comparative TFP levels are as follows:

1. The MTFP results indicate that in the latest years available, ATCO is found to have the second highest TFP level in the last year of the sample—an MTFP index of 1.34 in 2022. This TFP level is comparable to AGN Vic (1.35). This can be compared to the following MTFP indexes for the other GDBs: Multinet (1.08), AusNet (1.17), Jemena (1.21), AGN SA (1,03) and Evonergy (1.09). AGN Qld has a much lower TFP level (0.73).
2. ATCO had the sixth highest Opex PFP level (1.78) in the last year of the sample. The Opex PFPs of the other GDBs are: AGN Vic (2.18), AusNet (2.85), Jemena (2.07), Multinet (2.05), Evoenergy (1.92), AGN SA (1.73) and AGN Qld (0.95).
3. In the latest year, ATCO's Capital PFP index was 1.17, which is very close to AGN Vic (1.13).

4 Econometric Cost Functions

This section presents the results of estimating the opex cost function for gas distribution businesses in Australia and New Zealand. The opex (or variable) cost function assumes that, in the short-run, capital inputs are quasi-fixed factors of production, and can be included as explanatory variables in addition to outputs, input prices and other cost drivers.

The principal aims of the analysis are to estimate trends in technical efficiency in the industry and estimate the opex efficiency of ATCO relative to other GDBs. The econometric results are used to establish whether ATCO is efficient in its use of opex inputs, and also to estimate parameters that can be used when forecasting ATCO'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 2021-22 to 2025-26. These parameters include the average historical rate of frontier shift (or technical change) and the appropriate weights for constructing the output index.

The opex cost function is estimated using two different estimation techniques, stochastic frontier analysis (SFA) and feasible generalised least squares (FGLS). SFA is a frontier method which can estimate the minimum cost envelope together with firm-specific cost inefficiencies which cause their costs to exceed the lower bound. FGLS can consider groupwise heterogeneity, where the variance of the stochastic disturbance varies between the GDBs in the sample.

4.1 Literature

Cost function analysis of gas network businesses has a long history in Australia and New Zealand. The Bureau of Industry (BIE 1994) used data envelopment analysis (DEA) to benchmark the technical efficiency of the transmission and distribution activities of five Australian gas utilities against international counterparts in the USA, UK, Canada and Japan. The Independent Pricing and Regulatory Tribunal (IPART 1999) carried out a benchmarking study of nine Australian GDBs with a sample of 50 GDBs in the USA, again using DEA.

Among the studies most relevant to this study, Pacific Economics Group (PEG 2001a; 2001b; 2001c) evaluated the opex performance of the three Victorian GDBs relative to 43 US gas distribution utilities by estimating an econometric cost function model. Lawrence (2004) carried out econometric cost efficiency comparisons for four New Zealand and 10 Australian gas distributors (and separately benchmarked gas transmission). The outputs of GDBs were taken to be throughput and customer numbers, and customer density was controlled for. Economic Insights (2012) used econometric analyses of the total and opex cost functions for GDBs to assess the comparative efficiency of SP AusNet. This analysis was based on a sample of nine Australian GDBs and two New Zealand GDBs. The total cost model accounted for opex/capital trade–offs through price effects and included some operating environment factors (OEFs). The opex cost function was used to produce forecasts of opex partial productivity growth rates.

Economic Insights subsequently carried out a number of econometric studies of gas distributor opex using Australian and New Zealand GDBs. Economic Insights (2015a), produced on behalf of Jemena Gas Networks, utilised both stochastic frontier analysis (SFA) and feasible generalized least squares (FGLS) 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 tested alternatives but preferred the SFA and random effects (RE) methods. Both the Translog and Cobb-Douglas functions were tested, with the latter preferred because the Translog results had excessive degrees of multicollinearity and produced estimated marginal effects inconsistent with expectations of elasticity signs. 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. Similar modelling exercises were undertaken for Jemena in 2019 and Evoenergy in 2020. In the 2019 study for Jemena, more flexible functional forms were tested, but were found to offer no improvement over the simpler Cobb-Douglas specification.

In a study prepared for three Victorian GDBs, ACIL Allen (2022) estimated an econometric opex cost function and used it for estimating opex partial productivity growth, which was decomposed into the effects of technology change, returns-to-scale and OEFs. A sample of Australian GDBs was used, and a Cobb-Douglas functional specification was chosen. Two alternative estimation techniques were used, FGLS and SFA, and two alternative output specifications, one using customer numbers and energy throughput and the other using customer numbers and mains length. Fixed capital input was included as an explanatory variable, and customer density was used as an OEF.

4.2 Methodology

4.2.1 Economic concepts of cost functions

The opex cost function used in economic benchmarking is usually a short-run variable cost function, in which capital input is fixed, and hence appears as an explanatory variable. Although the short-run variable cost function has the price of non-capital inputs as an explanatory variable, all cost functions have the property of homogeneity of degree zero in input prices, which constrains the coefficient applying to the non-capital input price index. In a log-log functional form the coefficient on the non-capital input price index equals 1. This constraint can be conveniently imposed by subtracting the log input price index from both sides, thereby changing the dependent variable from the log of nominal opex to the log of real opex (i.e., nominal opex deflated by the price index of non-capital inputs). Hence, the dependent variable is a measure of the quantity of non-capital inputs.

It is also possible to use a long-run demand function for non-capital inputs. In this case, instead of using fixed capital stock as an explanatory variable, the ratio of capital and non-capital input prices should be used. This price ratio captures the long-run substitutability between capital and non-capital inputs when capital is not fixed. Given the long-lived nature of the assets comprising gas network infrastructure, a short-run opex cost function is generally preferred.

Developing a model for a variable cost function involves:

- 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.
- 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.

The following three sections discuss the functional specification, stochastic specification and the variables used in the variables used in the analysis respectively.

4.2.2 Functional specification

In this study we adopt the Cobb-Douglas cost functional form, consistent with general and recent practice in Australian gas distribution benchmarking. Coelli *et al* (2005, 211) list several commonly used functional forms for production or cost functions. Among them, the Cobb-Douglas and Translog specifications are popular. Both are log-log forms (which are typically used in SFA) that are regular and linear in parameters. The Translog function is a second-order flexible function, whereas Cobb-Douglas is a first-order flexible function. Coelli *et al* (2005) observe:

> "All other things being equal, we usually prefer functional forms that are second-order

> flexible. However, increased flexibility comes at a cost – there are more parameters to estimate, and this may give rise to econometric difficulties (eg., multicollinearity). … The principle of parsimony says we should choose the simplest functional form that 'gets the job done adequately'." (Coelli et al. 2005, pp.211–2)

The Translog function has the advantage of being more flexible, but the Cobb-Douglas function is more parsimonious and easier to implement. In the small data sample used here, the Cobb-Douglas specification is expected to yield the most reliable results. This observation is consistent with the findings from past studies of Australian and New Zealand gas distribution opex cost functions discussed in section 4.1, including Economic Insights (2019; 2020a) and ACIL Allen (2022). For these reasons, the Cobb-Douglas form is used in this study.

The Cobb-Douglas real opex cost (*vc*) function in the short-run has the following form:

$$\ln vc = \alpha_0 + \beta_K \ln K + \beta_t t + \sum_j \theta_j \ln y_j + \sum_h \alpha_h \ln z_h + \varpi \qquad (4.1)$$

where:

- K is a service flow measure of fixed capital;[3]
- t is a measure of time and reflects the principle that, all else unchanged, costs decrease marginally each year due to technical change;
- y_j is the quantity of output j; where $j, k = 1, 2, \dots J$;
- z_h are operating environment factors h; where $h = 1, 2, \dots H$;
- ϖ is a stochastic term that reflects the combined influence of all other influences on variable cost, including inefficiency.

4.2.3 Stochastic specification

The stochastic specification is another important aspect of the theoretical model underlying the econometric specification. The two estimation methods used in this study, stochastic frontier analysis (SFA) and feasible generalized least squares (FGLS), differ in terms of how the stochastic component of the model is specified. SFA models seek to identify an efficient frontier, based on best practice among the firms in the sample. The stochastic term includes two components. Firstly, an additive white noise component which randomly varies over all observations, causing the efficiency frontier to be random. Secondly, a one-sided stochastic

[3] 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).

effect which varies only across firms. This latter component is interpreted as measuring firm-specific inefficiency. The FGLS model has only one stochastic error term, but the variance of this term can vary between GDBs, thereby taking account of groupwise heterogeneity of the stochastic term. It can also account for serial correlation of the disturbance within panels (i.e., observations pertaining to an individual firm), although that capability is not needed in this study.

The use of both SFA and FGLs models is consistent with previous recent studies, such as Economic Insights (2019; 2020a) and ACIL Allen (2022). However, in those studies the FGLS model was not used to estimate firm-specific inefficiency effects. In this study we also test an FGLS model with firm-specific dummy variables that are interpreted as measuring the relative efficiency of firms.

The stochastic specifications of the most commonly used SFA models can be expressed as:

$$\varpi_{it} = u_{it} + \varepsilon_{it}$$

$$u_{it} = u_i G(t) \qquad \text{with} \quad u_i \sim N^+(\mu, \sigma_v^2) \tag{4.2}$$

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

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 (i.e., 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.

The FGLS estimator allows for heteroscedastic panels, but does not provide estimates of the comparative efficiency of the GDBs within the stochastic term. As used here the stochastic specification is:

$$\varpi_{it} = \varepsilon_{it}$$

$$\varepsilon_{it} \sim N(0, \sigma_{\varepsilon i}^2) \tag{4.3}$$

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:

$$\mathrm{E}[\boldsymbol{\varepsilon} \cdot \boldsymbol{\varepsilon}'] = \begin{bmatrix} \sigma_1^2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_n^2 \end{bmatrix} \tag{4.4}$$

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 are 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.

4.2.4 Outputs and OEFs

The dependent variable used in all models tested in this study is constant price opex (in 2020-21 prices). This section discusses the choice of explanatory variables. All the models examined here are short-run variable cost functions, and include a measure of 'quasi-fixed' capital inputs, as proxied by the constant price asset value; the regulatory asset base (RAB) in 2020-21 prices. All models also include a measure time in years, the coefficient on which measures the annual rate of technological change.

It remains to discuss the choice of output variables and operating environment variables. Table 4.1 shows the outputs and OEFs used in several studies of Australian GDBs' opex cost function. Our general approach to choosing the variables is to begin with those variables used in the recent econometric studies of gas opex costs, especially the most recent carried out by Economic Insights (2020a) and ACIL Allen (2022). The strategy is then to consider variations, and determine those that improve the modelling, given the current dataset. The variables considered are generally consistent with other benchmarking studies of energy networks.

The Economic Insights studies in 2015 and 2016 used several OEFs, but in the 2020 study, it was found that with the data sample used in that study, the OEFs were not jointly significant in one of the models tested. Hence a specification was test with no OEFs included. In this study we have used fewer OEFs, retaining the proportion of mains that are not. Made of cast iron or unprotected steel, but not including the number of city gates or the proportion of tariff class gas throughput in total throughput. We also include customer density as an OEF which is used in ACIL Allen's (2022) study and in Economic Insights (2015).

Table 4.1: Outputs and OEFs used in selected studies of the gas distribution opex cost function

Category	*Economic Insights (2015a)*	*Economic Insights (2016c)*	*Economic Insights (2020a)*		*ACIL-Allen (2022)*	
			Specification 1	*Specification 2*	*Specification 1*	*Specification 2*
Outputs	Gas throughput (TJ) Customer numbers	Customer numbers Network length	Customer numbers Network length	Customer numbers Network length	Gas throughput (TJ) Customer numbers	Gas throughput (TJ) Network length
OEFs	Customer density (customers/km mains) Proportion of total mains length not made of cast iron or unprotected steel* Number of city gates**	Load factor Proportion of total mains length not made of cast iron or unprotected steel* Proportion of tariff class gas throughput in total throughput	Proportion of total mains length not made of cast iron or unprotected steel* Proportion of tariff class gas throughput in total throughput Number of city gates**		Customer density (customers/km mains)	

Notes: *Proxy for network age; ** Proxy for service area dispersion.

This study uses as outputs, customer numbers and gas throughput. Network length is not used as an output in this study, but by using customer density as an OEF, the effect is equivalent to including mains length as an output in some models.[4] The output specifications we test are:

- Customer numbers only;
- Gas throughput only; and
- Customer numbers and gas throughput.

It is important to recognise a difficult modelling problem in econometric studies which seek to estimate the relative cost efficiencies of the firms in the sample. 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 controlled for (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.

4.2.5 Using the Model to Forecast Trends in productivity

The trend in partial productivity of opex can be obtained through a number of steps, the first of which is to differentiate equation (4.1) with respect to *t*. A dot over a variable is used here to denote its growth rate: i.e., $\dot{y} = \partial \ln y / \partial t$.

$$\dot{VC} = \varepsilon_K . \dot{K} + \sum_{m=1}^{M} \varepsilon_{Y_m} . \dot{y}_m + \sum_{n=1}^{N} \varepsilon_{Z_n} \dot{z}_n + \beta_t + \frac{\partial u}{\partial t} \quad (4.5)$$

where the following changes in notation are used to emphasise that the coefficients of log variables are elasticities: $\varepsilon_K = \beta_K$ (from 4.1) is the elasticity of variable cost with respect to the capital input; and $\varepsilon_{Y_m} = \theta_m$ (from 4.1) is the elasticity of variable cost with respect to the output m. Next define the rate of change in an aggregate output index using elasticities as weights. Table 4.3 shows the calculation of these weights from the elasticities of cost with respect to the outputs.

$$\dot{Y} = \sum_{m=1}^{M} \left(\frac{\varepsilon_{y_m}}{\sum_{m=1}^{M} \varepsilon_{y_m}} \right) \dot{y}_m \quad (4.6)$$

The sum of the elasticities of cost with respect to the outputs (i.e., the numerator of the term in brackets in equation (4.3)) is usually called the elasticity of scale: $\varepsilon_Y \equiv \sum_{m=1}^{M} \varepsilon_{y_m}$. Recall that

[4] Because the outputs and OEFs are in logs, the expression: $\ln vc = \beta_1 \ln Cust + \beta_2 \ln TJ - \gamma \ln(Cust/Mains)$ is equivalent to: $\ln vc = (\beta_1 - \gamma) \ln Cust + \beta_2 \ln TJ + \gamma \ln(Mains)$.

$\dot{VC}$ represents the rate of change in real opex inputs and hence the rate of opex partial factor productivity growth for non-capital inputs is: $P\dot{F}P_o = \dot{Q} - \dot{VC}$. Expanding this using (4.4) and (4.5), and the definition of the elasticity of scale, gives:

$$P\dot{F}P_o = (1 - \varepsilon_Y)\dot{Y} - \varepsilon_K.\dot{K} - \sum_{n=1}^{N} \varepsilon_{Z_n}\dot{z}_n - \left(\beta_t + \frac{\partial u}{\partial t}\right) \tag{4.7}$$

In the case where a time-invariant inefficient model is used, $\partial u/\partial t = 0$. Equation (4.6) can be used to forecast the rate of opex partial factor productivity growth over the forthcoming access period if forecasts are available for the growth rates of the real RAB, and the outputs.

4.3 Modelling and Results

This section presents the results of the econometric estimation of the gas distribution opex cost function using both the stochastic frontier analysis (SFA) and feasible generalised least squares (FGLS) estimation. The different model specifications were tested, as detailed in Appendix C.

4.3.1 Preferred model

In the preferred specification, opex is a function of:

- two outputs, customer numbers (*Cust*) and gas throughput (*TJ*);
- the 'quasi-fixed' capital input measured by the constant price asset value (*RAV*)
- two operating environment variables, namely:
  - customer density (*CustDens*) defined as customers per km main;
  - the proportion of mains not made of cast-iron or unprotected steel (*NCI*).
- a time trend variable (*t*) to capture the effects of technical change.

The two methods of estimation are:

- SFA with time-invariant inefficiencies which are assumed to have a half-normal distribution;
- FGLS allowing for heteroscedastic errors between panel groups, but do not allow for serial correlation within panels. These assumptions are supported by statistical tests reported in Appendix C.

Table 4.2 presents the estimation results for the preferred opex cost function specification. Both the SFA and FGLS models are shown.

Table 4.2: Models with output measured by customer numbers and gas throughput

	SFA model			FGLS model		
	coeff	*se*	*t-stat*	*coeff*	*se*	*t-stat*
Const	-3.9417	0.5930	-6.65	-4.3265	0.2174	-19.9
ln*Cust*	0.0125	0.1004	0.12	0.2868	0.0695	4.13
ln*TJ*	0.2972	0.0951	3.13	0.1051	0.0385	2.73
ln*RAV*	0.7133	0.0930	7.67	0.5314	0.0384	13.83
ln*CustDens*	-0.1981	0.1432	-1.38	-0.0343	0.0493	-0.70
ln*NCI*	-0.9762	0.2093	-4.66	-0.2185	0.1004	-2.18
t	0.0018	0.0024	0.78	-0.0095	0.0020	-4.84
N (sample size)	276			276		
Pseudo-R-sq.(1)	0.9768			0.9542		
RMSE(2)	0.1701			0.2423		
VIF(3)	14.32			14.32		

(1) Squared correlation coefficient between predicted and actual values of the dependent variable.
(2) Root-mean-square error of stochastic disturbance (not including estimated inefficiency effects).
(3) Variance inflation factor.

The models in Table 4.2 satisfy the requirement that the coefficients all have the expected or necessary signs. The elasticities of variable cost with respect to each of the outputs (*Cust* and *TJ*) are positive. The elasticity of variable cost with respect to the capital stock (*RAV*) is positive. And the elasticity of variable cost with respect to each OEF (*CustDens* and *NCI*) are negative as expected.

Most coefficients are statistically significant, at least in one of the two models. The measures of the first of the model indicate that a large proportion of the variation of log real opex in the sample is explained by the regressors. The variance inflation factor (VIF) statistic of 14.3, suggests there is some degree of multicollinearity, but not so high as to cause concern about the reliability of the coefficient estimates, especially when averaged between the models.

4.3.2 Output weights and technical efficiency trends

Table 4.3 reproduces the parameter estimates of the two models in Table 4.2, and calculates the average of each parameter. The coefficients applying to the two outputs are short-run elasticities of opex with respect to each output. The elasticity of opex with respect to customer numbers is 0.15, and the elasticity of opex with respect to gas throughput is 0.20. The total of these two elasticities is the short-run elasticity of opex with respect to scale.

The coefficient on the time variable can be interpreted as the rate of change in opex due to technical change. This is estimated to be –0.4 per cent per year. This means that the industry average rate of change in opex-related technical change is 0.4 per cent per year.

Table 4.3: Average coefficients and output weights

	SFA	*FGLS*	*Average*
Const	-3.942	-4.327	-4.134
ln*Cust*	0.013	0.287	0.150
ln*TJ*	0.297	0.105	0.201
ln*RAV*	0.713	0.531	0.622
ln*CustDens*	-0.198	-0.034	-0.116
ln*NCI*	-0.976	-0.219	-0.597
t	0.002	-0.009	-0.004
Output weights:			
- *Cust*			0.427
- *TJ*			0.573
- *Total*			1.000

The output elasticities can be used to calculate weights for calculating an aggregate output index. The weights are defined as: $w_i = \epsilon_i/\sum \epsilon$ (where ϵ is the cost-elasticity with respect to output i).[5] The output index is then calculated by: $\dot{Q} = \sum w_i \dot{q}_i$, where the dot above a variable indicates the rate of change.

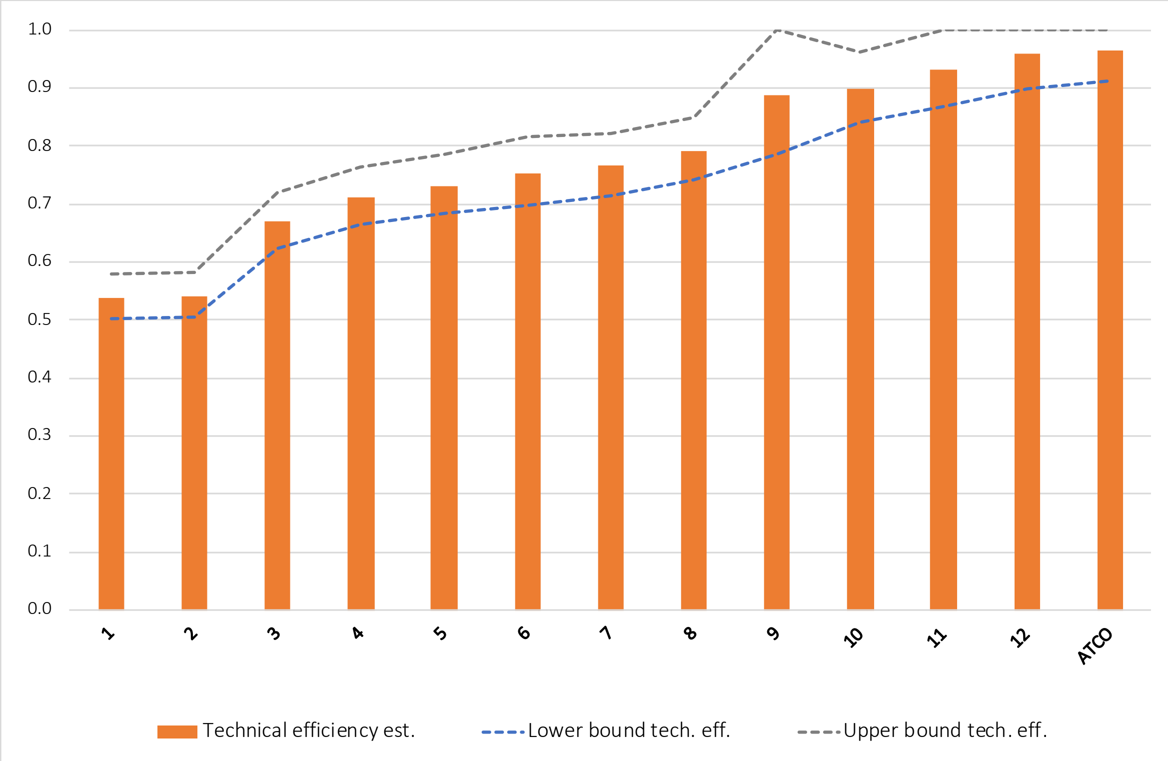
4.3.3 Technical efficiency estimates

As Appendix C shows, in all of the SFA models we estimated, ATCO was found to have the highest comparative technical efficiency among the GDBs in the sample. Figure 4.1 shows the comparative technical efficiency scores in the preferred model (which has both customer numbers and energy throughput as outputs). The technical efficiencies of GDBs are ranked and only ATCO is identified. ATCO is ranked highest in term of technical efficiency. It is one of four GDBs in the sample whose technical efficiency scores are not significantly different from 1.0, which indicates full efficiency.

This finding is particularly relevant to forecasting efficient opex because it indicates that ATCO's base-year opex is consistent with that of an efficient operator.

[5] Noting: $\epsilon_i = (\partial C/\partial q_i)(q_i/C)$, where C is cost, q_i is the quantity of output i and $\partial C/\partial q_i$ is the marginal cost of producing output i, which serves as the shadow price of output i. Hence, the calculation of output weights in proportion to output elasticities is equivalent to output value shares calculated using these shadow prices.

Figure 4.1: Technical efficiency with output measured by customer numbers



4.4 Summary Conclusions

The main findings of the econometric analysis are as follows:

1. In the preferred specification, opex is a function of two outputs, customer numbers and gas throughput; the 'quasi-fixed' capital input measured by the constant price asset value; two operating environment variables, customer density and the proportion of mains not made of cast-iron or unprotected steel, and finally a time trend variable to capture the effects of technical change.
2. The two methods of estimation used are Stochastic Frontier Analysis (SFA) with time-invariant inefficiencies and Feasible Generalized Least Squares (FGLS) allowing for heteroscedastic errors between panel groups, but do not allow for serial correlation within panels.
3. The elasticity of opex with respect to customer numbers is 0.15, and the elasticity of opex with respect to gas throughput is 0.20. The total of these two elasticities is the short-run elasticity of opex with respect to scale.
4. The rate of change in opex due to technical change is estimated to be –0.4 per cent per year from 1999 to 2022. This means that the industry average rate of change in opex-related technical change is 0.4 per cent per year over the same period.

5. ATCO's average technical efficiency scores of all SFA models estimated is the highest of the sample and it is equal to 1.0, indicating full efficiency. ATCO is one of four GDBs in the sample whose technical efficiency score are not significantly different from 1.0.
6. The last finding indicates that ATCO's base-year opex is consistent with that of an efficient operator.

Appendix A: Gas Distribution Businesses Included in the Study

The database formed for the study includes 9 Australian GDBs and four New Zealand GDBs (although the New Zealand GDBs are only used in Chapter 2). A brief summary of the operations of the included GDBs follows.

A.1 Australian GDBs

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 2.2 million in 2021), Busselton and Bunbury (together a population of 229,114), Geraldton, Kalgoorlie and the Albany region (each with a population of approximately 35,000). Each of these urban areas has a separate gas distribution network (Albany is supplied with reticulated LPG). In 2022, ATCO supplied approximately 772,085 customers with 26,767 TJ of gas from a distribution network of 14,310 kilometres of mains.

AGN Victoria & AGN Albury (NSW) combined as 'AGN Vic'

AGN[6] Victoria serves parts of the greater Melbourne metropolitan area (population of 4.9 million in 2021) 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.

[6] 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 Vic & Albury, Multinet, AGN SA and AGN Qld all belong to the AGN group.

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 2021 had a population of approximately 67,000. There is a small number of large industrial customers which represent over half of its gas deliveries. In 2017 AGN Albury supplied its 22,000 customers with around 2,800 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. For this reason, this study combines AGN Victoria and AGN Albury into AGN Vic. Together, in 2022, AGN Vic supplied its 740,00 customers with around 56,400 TJ of gas from a distribution network of 12,400 kilometres of mains.

Multinet Gas, Victoria

Multinet Gas is, since 2017, part of the Australian Gas Infrastructure Group (AGIG), 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 2022, Multinet supplied 718,200 customers with 53,900 TJ of gas from a distribution network of 9,940 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 2022, AusNet supplied its 786,600 customers with 67,300 TJ of gas from a distribution network of 12,725 kilometres of mains.

AGN SA, South Australia

AGN SA's distribution network services greater Adelaide and: 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 2021 was approximately 1.4 million. As with Melbourne, Adelaide's winter climate is conducive to relatively high residential gas demand for heating.

In 2021, AGN SA supplied 463,700 customers with 21,000 TJ of gas from a distribution network of 8,500 kilometres of mains. The Adelaide network makes up 93 per cent of the total network length.

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 2021 southeast Queensland's population was around 3.8 million. Approximately 70 per cent of Allgas' gas demand is from around 150 large demand class customers. In 2022 Allgas supplied approximately 119,000 customers with 10,500 TJ of gas from a distribution network of 3,900 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.

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 2021 there were approximately 107,000 customers consuming 5,900 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.

Jemena Gas Network, NSW

Jemena 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 Jemena 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. Jemena has the largest distribution network and customer base of the Australian GDBs. In 2021 it supplied 1,464,200 customers with 89,600 TJ of gas from a distribution network of 26,000 kilometres of mains.

Evoenergy, Australian Capital Territory

Evoenergy (the energy networks part of Evoenergy[7]) is the distribution business supplying gas and electricity in the Australian Capital Territory (ACT). The total population of the ACT in 2022 was 456,700. 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 2021 Evo supplied 156,132 customers with 9,900 TJ of gas from a distribution network of around 4,716 kilometres of mains.

A.2 New Zealand GDBs

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

Powerco Limited

Powerco is based in New Plymouth (population 87,700 in 2022) 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 81,200 in 2022), and Hawkes Bay networks (including Napier-Hastings, population 50,400 in 2022). In the lower North Island it supplies Wellington City (population of 419,000 in 2022), Hutt Valley (estimated population 112,500 in 2022) and Porirua (district population of 61,600 in 2022). Powerco acquired part of UnitedNetworks' gas operations in 2002 comprising the Hawkes Bay, Wellington, Horowhenua and Manawatu networks. In 2017, Powerco supplied 112,200 customers with 8,970 TJ of gas from a distribution network of 4,000 kilometres of mains.

[7] 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.

Vector Ltd

Vector Ltd operates the gas distribution network in Auckland (estimated population of 1,652,000 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 2022, Vector supplied 117,425 gas distribution customers with 13,000 TJ of gas from a distribution network of 4,280 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 2021, GasNet had 10,100 customers and supplied 1,260 TJ, and its networks were approximately 400 km in length. In terms of customer numbers it is approximately half the size of AGN Albury. In terms of mains length it is similar in size to AGN Albury.

Firstgas

Firstgas is part of the wider Firstgas Group and operates, across the regions of Northland, Waikato, Central Plateau, Bay of Plenty, Gisborne, and Kapiti Coast (population around 670,000 in 2022). Firstgas is New Zealand's largest gas network and in 2022 supplied 66,883 customers with 9,431 TJ from 4,980 km in length.

Appendix B: Data

The analysis makes use of the Quantonomics datasets for Australian and New Zealand gas distribution businesses. The periods for which data is available are shown in Table B.1. There are two datasets.

The first one is from confidential survey data provided by several Australian GDBs for the purposes of productivity analysis. It includes eight Australian GDBs: AGN Qld, AGN SA, AGN Vic, AusNet Services, Jemena, Multinet, ATCO and Evoenergy. The data surveys are in a common format, covering key output and input value, price and quantity information. The survey data obtained for this and previous studies, is supplemented by information gathered and reported by the Australian Energy Regulator (AER) through Regulatory Information Notices (RINs).[8] In some cases, survey data extends from 1999 to 2022, and for AGN Qld it extends only to 2014. Where survey data has been supplemented with RIN data, this generally extends up to 2021. This database is used to provide the analysis in chapter 3.

The analysis in chapters 2 and 4 uses a dataset that includes 13 GDBs, including nine Australian and four New Zealand GDBs. Here the survey data (used in chapter 3) is supplemented by data which has been sourced from documents in the public domain, 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 NZ GDBs is the Information Disclosure Data filings required by the *Gas (Information Disclosure) Regulations 1997*. In addition to the eight previously listed, this dataset includes data for another five GDBs: (i) Allgas Energy in Australia, and (ii) in New Zealand, Powerco, Vector, Firstgas and GasNet. The periods for which data is available varies as shown in Table B.1.

Data used includes throughput, customer numbers, distribution pipeline length, opex, capex and regulatory asset value.

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 2021 dollars using the same price indexes. The New Zealand data were then converted to Australian dollars using the OECD purchasing power parity for 2021.[9] Purchasing power parities are the rates of currency conversion that eliminate differences in

[8] https://www.aer.gov.au/taxonomy/term/1495.

[9] https://stats.oecd.org/Index.aspx?DataSetCode=PPPGDP.

international price levels and are commonly used to make comparisons of real variables between countries.

Table B.1: Summary of data sample

GDB	*Data period*	*Years ending*	*# obs*
AGN Vic	1999–2022	Dec	24
Multinet	1998–2022	Dec	25
AusNet	1998–2022	Dec	25
AGN SA	1999–2021	Jun	23
AGN Qld	1999–2020#	Jun	23*
Allgas Energy	2001–2022#	Jun	22
Jemena	1999–2021	Jun	23
Evoenergy	1999–2021	Jun	23
ATCO	2000–2022	Dec	23
Powerco (NZ)	2004–2021	Sep	19*
Vector (NZ)	2006–2022	Dec	17
GasNet (NZ)	2000–2021	Jun	22
Firstgas (NZ)	2016–2022	Sep	7
Total			276

Notes: # Regulatory forecasts used for part of the period; * After changing reporting year, a 6-month period has been annualised.

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 2021 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 2021.

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 is beyond the scope and timeframe of this study.

Furthermore, GDBs included in the sample are not all comparable as they operate in different operating environments, with different types of organisational integration, and with differing regulatory obligations applying businesses. Not all operating environment factors can practically and quantitatively be accounted for in benchmarking analysis, including different regulatory obligations, government environmental policies, asset age, mains distances and trajectory, and other input costs beyond the control of businesses.

Appendix C: Econometric Results Detail

This appendix presents the results of estimating the gas distribution opex cost function using three alternative specifications, in each case using both stochastic frontier analysis (SFA) and feasible generalised least squares (FGLS) estimation. The three specifications differ in the output variables. The first two have only a single output, the first using only customer numbers and the second using only gas throughput. The third specification uses both customer numbers and gas throughput as outputs. All three specifications include capital input as an explanatory variable and include the same operating environment factors (OEFs), namely customer density and the proportion of mains no made of cast-iron or unprotected steel. All three models also include a time trend to capture the effect of technical change on real opex.

C.1 Selected hypothesis tests

The following tests have been applied to each model specification to determine the appropriate FGLS stochastic specification.

- *Serial correlation in panels*: We use a portmanteau test for serial correlation in the errors of a linear panel model as implemented by Jochmans and Viradi (2019).[10] For each of the candidate model specifications, this test provides strong evidence for the absence of serial correlation in the errors.
- *Groupwise heteroskedasticity*: A modified Wald statistic is used to test for groupwise heteroskedasticity in the errors, as implemented by Baum.[11] For each of the candidate model specifications, this test provides strong evidence for the presence of groupwise heteroscedasticity.

C.2 Econometric Results

This section explains the choice of the preferred opex cost function model. Tables 4.2 to 4.4 compare three alternative specifications. In these tables, *Cust* refers to the number of customers; *TJ* refers to the gas throughput (in TJ); *RAV* refers to real asset value (based on the RAB); *CustDens* is the ratio of customers to mains length (in km); *NCI* is the proportion of mains not cast iron or unprotected steel; and *t* is a time variable.

All of the SFA models presented in this section have time-invariant inefficiencies which are assumed to have a half-normal distribution. All FGLS models presented in this section allow

[10] In the user-contributed Stata command *xtserialpm*. The null hypothesis is of no correlation at any order. If "Prob > Chi-sq" < 0.05 this provides strong evidence for the presence of serial correlation in the errors.

[11] In the user-contributed Stata command *xttest3*. The null hypothesis is of no groupwise heteroscedasticity. If "Prob > Chi-sq" < 0.05 this provides strong evidence for the presence of heteroskedastic panels.

for heteroscedastic errors between panel groups, but do not allow for serial correlation within panels.

In table C.1, customer numbers (*Cust*) is the only output. Both the SFA and FGLS models are shown.

Table C.1: Models with output measured by customer numbers

	*SFA model**			*FGLS model***		
	coeff	*se*	*t-stat*	*coeff*	*se*	*t-stat*
Const	-2.9391	0.4773	-6.16	-4.7214	0.1785	-26.45
ln*Cust*	0.1970	0.0824	2.39	0.4728	0.0380	12.45
ln*RAV*	0.7671	0.0897	8.55	0.4605	0.0353	13.03
ln*CustDens*	-0.3902	0.1282	-3.04	-0.1362	0.0474	-2.88
ln*NCI*	-0.9836	0.2118	-4.64	-0.2871	0.1044	-2.75
t	-0.0013	0.0022	-0.59	-0.0117	0.0018	-6.38
N (sample size)	276			276		
Pseudo-R-sq.(1)	0.9763			0.9501		
RMSE(2)	0.1721			0.2532		
VIF(3)	11.30			11.30		

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

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

(1) Squared correlation coefficient between predicted and actual values of the dependent variable.

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

(3) Variance inflation factor.

Each model in Table C.1 satisfies the following requirements:

- the elasticity of variable cost with respect to output (*Cust*) are positive and significant;
- the elasticity of variable cost with respect to the capital stock (*RAV*) is positive and significant;
- the elasticity of variable cost with respect to each OEF (*CustDens* and *NCI*) are negative as expected, and significant. The elasticity of variable cost with respect *CustDens* should be negative because, for a given number of customers, higher customer density will be associated with lower cost. The elasticity of variable cost with respect *NCI* should be negative because older mains require higher maintenance.

The pseudo-R^2 is defined here as the squared correlation coefficient between predicted and actual values of the dependent variable. Both models explain a high proportion of the variation in the sample. The root-mean-square error (RMSE) measured the average absolute size of the residuals. It is smaller for the SFA model which attributes a part of the unexplained variation to inefficiency effects.

In Table C.1, the variance inflation factor (VIF) indicates whether multicollinearity is likely to be a problem. Although a value of 10 is sometimes suggested as a criterion, we consider the value of 11.3 to be sufficient to indicate that multicollinearity is not a problem in this model.

In table C.2, gas throughput (*TJ*) is the only output. Both the SFA and FGLS models are shown.

Table C.2: Models with output measured by gas throughput

	*SFA model**			*FGLS model***		
	coeff	*se*	*t-stat*	*coeff*	*se*	*t-stat*
Const.	-3.9281	0.5641	-6.96	-3.5222	0.0998	-35.29
ln*TJ*	0.3037	0.0775	3.92	0.2418	0.0196	12.36
ln*RAV*	0.7186	0.0830	8.66	0.6652	0.0209	31.87
ln*CustDens*	-0.1861	0.1055	-1.76	0.0920	0.0380	2.42
ln*NCI*	-0.9709	0.2045	-4.75	-0.2151	0.1009	-2.13
t	0.0019	0.0022	0.86	-0.0064	0.0018	-3.61
N (sample size)	276			276		
Pseudo-R-sq.(1)	0.9768			0.9563		
RMSE(2)	0.1701			0.2345		
VIF(3)	4.59			4.59		

See notes to Table C.1.

Each model in Table C.2 satisfies the following requirements:

- the elasticity of variable cost with respect to gas throughput (*TJ*) are positive and significant;
- the elasticity of variable cost with respect to the capital stock (*RAV*) is positive and significant; and
- the elasticity of variable cost with respect to *NCI* is negative as expected and significant.

However:

- the elasticity of variable cost with respect to *CustDens* is not negative in the FGLS model. It is negative in the SFA model but and only statistically significant at a 90 per cent degree of confidence, rather than the usual 95 per cent standard; and
- the coefficient on the time variable which indicates technical change is positive in the SFA model and negative in the FGLS model.

The fit of the models in Table C.2 is similar to the models in Table C.1. However, because some of the coefficients do not have the correct signs, the models in Table C.1 are preferable.

In table C.3, there are two outputs, gas throughput (*TJ*) and customer numbers (*Cust*). Both the SFA and FGLS models are shown.

Table C.3: Models with output measured by customer numbers and gas throughput

	*SFA HN model**			*FGLS model***		
	coeff	*se*	*t-stat*	*coeff*	*se*	*t-stat*
Const	-3.9417	0.5930	-6.65	-4.3265	0.2174	-19.9
ln*Cust*	0.0125	0.1004	0.12	0.2868	0.0695	4.13
ln*TJ*	0.2972	0.0951	3.13	0.1051	0.0385	2.73
ln*RAV*	0.7133	0.0930	7.67	0.5314	0.0384	13.83
ln*CustDens*	-0.1981	0.1432	-1.38	-0.0343	0.0493	-0.70
ln*NCI*	-0.9762	0.2093	-4.66	-0.2185	0.1004	-2.18
t	0.0018	0.0024	0.78	-0.0095	0.0020	-4.84
N (sample size)	276			276		
Pseudo-R-sq.[(1)]	0.9768			0.9542		
RMSE[(2)]	0.1701			0.2423		
VIF[(3)]	14.32			14.32		

See notes to Table 2.

The models in Table C.3 satisfy the following requirements:

- the elasticities of variable cost with respect to each of the outputs (*Cust* and *TJ*) are positive;
- the elasticity of variable cost with respect to the capital stock (*RAV*) is positive and significant; and
- the elasticity of variable cost with respect to each OEF (*CustDens* and *NCI*) are negative as expected.

However, some coefficients are not statistically significant:

- although the elasticity of variable cost with respect to *TJ* is statistically significant in both models, the elasticity of *Cust* is only significant in the FGLS model;
- although the elasticity of variable cost with respect to *NCI* is statistically significant in both models, the elasticity of *CustDens* is not significant in either model.

We do not consider these instances in insignificant coefficients to be problematic, because all of the coefficients are significant in at least one of the two models presented.

The fit of the models in Table C.3 is similar to the models in Table C.1. The VIF statistic is slightly larger at 14.3, but remains acceptable.

An advantage of the models in Table C.3 over those in C.1 is that the specification is more general, incorporating both customer numbers and gas throughput. It also includes mains length indirectly via the customer density variable.

C.3 Technical efficiency estimates

The three SFA models shown in Tables C.1 to C.3 produce broadly similar estimates for ATCO's comparative technical efficiency, as shown in Table C.4. Given our general preference for the third specification, which has two outputs, the technical efficiency scores for that model are reported.

Table C.4: Technical efficiency scores

	Specification 1			*Specification 2*			*Specification 3*		
GDB	te_lb	te_est	te_ub	te_lb	te_est	te_ub	te_lb	te_est	te_ub
A	0.53	0.57	0.61	0.67	0.72	0.77	0.67	0.72	0.77
B	0.58	0.63	0.67	0.75	0.80	0.86	0.74	0.79	0.85
C	0.63	0.68	0.73	0.85	0.91	0.97	0.84	0.90	0.97
D	0.69	0.74	0.80	0.72	0.77	0.83	0.72	0.77	0.83
E	0.80	0.85	0.92	0.69	0.74	0.79	0.69	0.73	0.79
F	0.87	0.93	1.00	0.88	0.94	1.00	0.87	0.93	1.00
G	0.52	0.56	0.61	0.63	0.67	0.72	0.63	0.67	0.72
H	0.58	0.62	0.66	0.51	0.54	0.58	0.51	0.54	0.58
ATCO	0.92	0.97	1.00	0.91	0.96	1.00	0.91	0.97	1.00
I	0.75	0.81	0.88	0.70	0.76	0.82	0.70	0.75	0.82
J	0.85	0.92	1.00	0.90	0.96	1.00	0.90	0.96	1.00
K	0.56	0.61	0.65	0.50	0.54	0.58	0.50	0.54	0.58
L	0.81	0.91	1.00	0.78	0.88	1.00	0.79	0.89	1.00

Notes: "te_lb" means technical efficiency lower bound estimate; "te_est" means technical efficiency best estimate; and "te_ub" means technical efficiency upper bound estimate.

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