Attachment 7.4

Economic Insights

The productivity performance of Australian Gas Networks' SA gas distribution system

SA Final Plan July 2021 – June 2026

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Australian Gas Networks

The Productivity Performance of Australian Gas Networks' South Australian Gas Distribution System

Report prepared for

Australian Gas Networks (AGN)

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CONTENTS

EXECUTIVE SUMMARY

Australian Gas Networks Limited ('AGN') has commissioned Economic Insights Pty Ltd ('Economic Insights') to provide advice on productivity measurement and benchmarking of its South Australian gas distribution network operations. The advice provided in this report details analysis of AGN South Australia's (AGN SA) 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 AGN SA's productivity levels against other Australian GDBs using multilateral TFP.

The primary data source for this study is information supplied by eight Australia GDBs, including AGN SA. The other GDBs are AGN's Victorian and Queensland gas networks, Multinet Gas and AusNet in Victoria, Jemena Gas Networks (JGN) in New South Wales (NSW), ATCO Gas Australia in Western Australia, and Evoenergy in the Australian Capital Territory. The data was provided in response to common detailed data surveys, covering key output and input value, price and quantity information. For AGN SA this data is available for 2000 to 2019 and for the other GDBs is generally available for the period from 1999 or 2000 to 2018 or 2019 (with the exception of AGN Queensland which is only available to 2014).

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

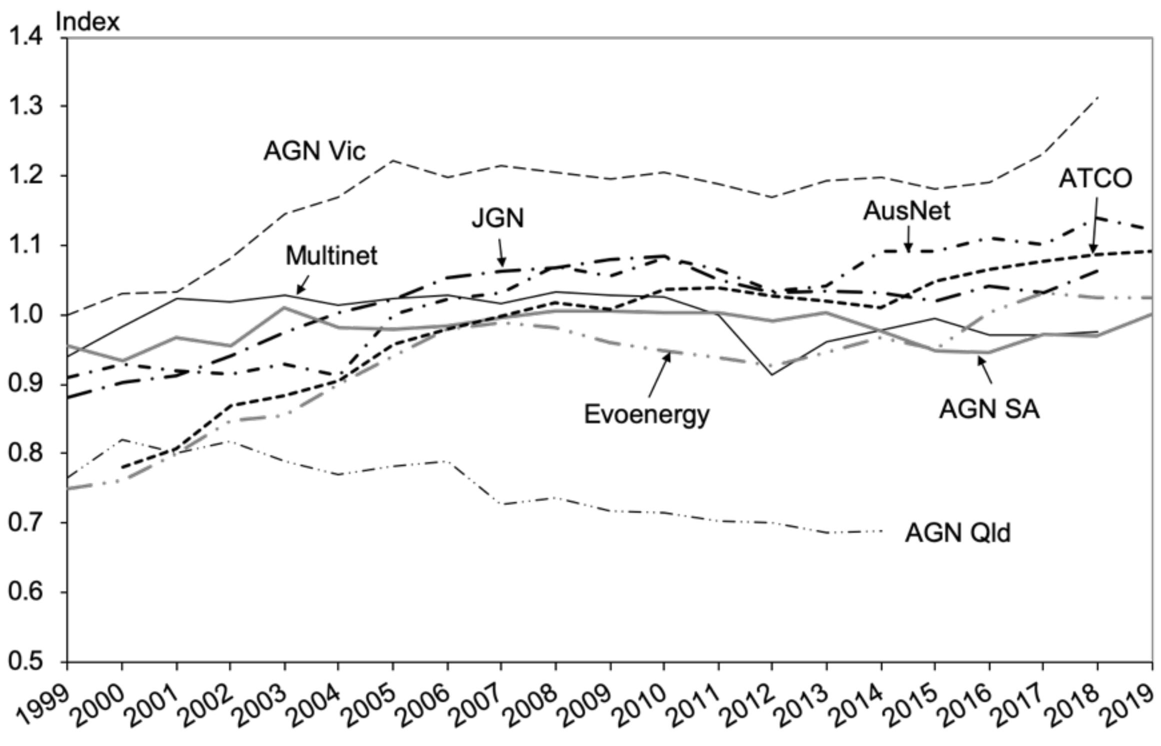
Fisher indexes are used to measure TFP trends. The time series TFP results for AGN SA are as follows:

1. AGN SA's TFP increased at an average annual rate of 0.8 per cent from 1999 to 2019. As is common among the Australian GDB, TFP growth was weaker in the period 2007 to 2014, and somewhat stronger in the periods before and since.
2. AGN SA's Opex partial factor productivity (PFP) increased at an average annual rate of 3.4 per cent from 1999 to 2019. Capital PFP *decreased* at an average annual rate of 0.5 per cent over the same period. Opex PFP growth was strong in the periods 1999 to 2007 (4.8 per cent) and 2014 to 2019 (5.4 per cent), but there was little growth in the intervening period. The decline in AGN SA's Capital PFP mainly occurred in the period up to 2007 (-1.3 per cent), with little or no change thereafter.
3. Comparing the average rates of TFP growth of GDBs, AGN SA's TFP growth over the full sample period was similar to JGN (0.7 per cent) and Multinet (0.6 per cent). Evoenergy had a lower rate of TFP growth (0.4 per cent), whereas ATCO, AGN Vic and AusNet had higher rates of TFP growth (1.4, 1.5 and 1.3 per cent respectively). Most GDBs had strong rates of growth in Opex PFP, comparable to AGN SA. However, AGN SA's decline in Capital PFP (-0.5 per cent per year) was slightly greater than for most other GDBs.
4. Over the most recent period from 2014 to 2019, AGN SA's average annual rate of TFP growth of 1.4 per cent was higher than for most GDBs. Only AGN Vic had a

comparable rate of productivity growth in this period. Among the other GDBs, and over the same period, Evoenergy's TFP declined by 0.7 per cent per year, JGN had no TFP growth, and AusNet, Multinet and ATCO all had an average rate of TFP growth of 0.4 per cent per year.

5. AGN SA had a below-average output growth averaging 1.5 per cent per year between 1999 and 2019, compared to the average for all GDBs of 1.9 per cent over the same period. The average rate of increase in inputs for AGN SA over the period 1999 to 2019 was 0.7 per cent per year, which was below the average for all GDBs (1.1 per cent). Over the full period from 1999 to 2019, AGN SA's average rate of change of opex inputs was −1.8 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 AGN SA over the period 1999 to 2019 was 2.0 per cent per year, which was close to the average for all GDBs (2.1 per cent).

Figure A: **GDB multilateral TFP indexes, 1999–2019**



Source: Economic Insights GDB database.

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, AGN SA is found to have the sixth highest TFP level in the last year of the sample—an MTFP index of 1.00 in 2019 (i.e. equivalent to AGN Vic in 1999, which is used as the index base). This TFP level is comparable to Multinet (0.98) and Evoenergy (1.02). This can be compared to

the following MTFP indexes for the other GDBs: AGN Vic (1.37), AusNet (1.13), ATCO (1.09), and JGN (1.06). AGN Qld has a much lower TFP level.

2. AGN SA also had the sixth highest Opex PFP level (1.75) in the last year of the sample. The Opex PFPs of the other GDBs are: AGN Vic (2.24), AusNet (2.56), JGN (2.07), ATCO (1.90), Evoenergy (1.80), Multinet (1.57), and AGN Qld (0.95).

3. In the latest year, AGN SA's Capital PFP index was 0.80, which is very close to a number of other GDBs, who appear to have converged to the same Capital PFP level over the sample period. The GDBs with essentially the same level of Capital PFP as AGN SA include; Multinet, AusNet, JGN, AGN SA, ATCO and Evoenergy. AGN Vic had a higher level of Capital PFP (1.08) and AGN Qld a lower level (0.61).

1 INTRODUCTION

1.1 Terms of Reference

Australian Gas Networks Limited ('AGN') commissioned Economic Insights Pty Ltd ('Economic Insights') to provide advice on productivity measurement and benchmarking of its South Australian gas distribution network operations. The advice provided in this report details analysis of AGN South Australia's (AGN SA) 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 AGN SA's productivity levels against other Australian GDBs using multilateral TFP.

This study entails updating and extending analysis that Economic Insights has carried out previously in relation to the South Australian gas distribution network (Economic Insights 2010; 2015c) and similar analysis carried out for other Australian GDBs, including in relation to the three Victorian gas networks (Economic Insights 2012c; 2016a); and in relation to the New South Wales (NSW) network (Economic Insights 2009a; 2015a).

1.2 Approach to this Study

The study concentrates on the performance of AGN SA's gas network in the period from 1999 to 2019. The primary data source for this study is information supplied by AGN SA in relation to its South Australian gas distribution business. The data was provided in response to a detailed data survey, covering key output and input value, price and quantity information for calendar years 2000 to 2019. Similar data was provided for this study by AGN in relation to its Victorian gas network ('AGN Vic'), by Multinet Gas[1] and AusNet Services in relation to their Victorian gas networks; by Jemena Gas Networks (JGN) in relation to its NSW gas distribution network; ATCO Gas Australia in Western Australia; and Evoenergy in the Australian Capital Territory.

The surveys completed by AGN SA, AusNet and Evoenergy cover the years 1999 to 2019, and ATCO's data covers 2000 to 2019. (In each case, data for 2019 are year-end estimates.) The surveys completed by Multinet, AGN Vic and JGN cover the years 1999 to 2018. A previously completed survey by AGN for its Queensland gas network ('AGN Qld') covers the period 1999 to 2014.

Measures of TFP and PFP are formed in this report using time series and multilateral indexes. These are used to compare AGN SA's productivity growth rates and productivity levels with those of other GDBs in Victoria, NSW, the ACT, Western Australia and Queensland. The time series TFP analysis involves forming indexes of outputs and inputs using the Fisher index method. The analysis includes three outputs (throughput, customer numbers and system capacity) and eight inputs (opex, lengths of transmission pipelines, high pressure pipelines, medium pressure pipelines, low pressure pipelines, and services, numbers of meters and other capital). This specification is broadly consistent with the analogous preferred electricity distribution output and input specification presented in AER (2013). The time series TFP indexes use the first year of data (typically 1999) as the base–year for each individual GDB,

[1] AGN and Multinet are both owned by the Australian Gas Infrastructure Group.

and the analysis provides estimates of TFP growth over the period 1999 to 2019 (or latest year) as well as PFP growth for the GDBs. This analysis is presented in section 3.

Multilateral TFP analysis is used in this study for productivity level comparisons. Multilateral TFP is a method of measuring the TFP levels of all the GDBs in the sample using a common base, so their TFP levels can be compared. In this part of the analysis, transmission pipelines are excluded to allow like–with–like comparisons across GDBs. This analysis is presented in section 4.

1.3 Relevant Previous Studies

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

In 2004 Denis Lawrence undertook a comparative benchmarking study of Australian and New Zealand gas transmission and distribution pipeline businesses, and a trend analysis of New Zealand gas businesses' TFP, for the New Zealand Commerce Commission using data sourced from New Zealand and Australian regulatory decisions (Denis Lawrence 2004a; 2004b). That study used the multilateral TFP index method. It found New Zealand GDBs to be around 21 per cent behind the productivity of a sample of Australian GDBs. The three Victorian GDBs were among the most efficient performers after allowing for operating environment differences.

In 2007, Lawrence undertook a study of the TFP performance of the Victorian gas distribution industry on behalf of the three Victorian GDBs (Denis Lawrence 2007). The study contained a number of advances for gas distribution TFP measurement. In conjunction with the GDBs' engineers Lawrence developed a measure of system capacity to supplement the standard output measures of throughput and customer numbers. He also included 7 capital input components and presented a range of sensitivity analyses of alternative output and input specifications to assess the influence of specification changes on the results. Subsequently, PEG (2008) carried out a study of TFP trends for Victoria's GDBs on behalf of the Essential Service Commission.

Economic Insights has since carried out a number of productivity and benchmarking studies on behalf of gas distribution businesses, including for JGN (Economic Insights 2009a; 2015a; 2019); for Envestra South Australia and Queensland (Economic Insights 2010); AGN South Australia (Economic Insights 2015b; 2015c); for the Victorian GDBs (Economic Insights 2012b; 2012c; 2016a); and for ATCO (Economic Insights 2018). Economic Insights has also carried out econometric analyses of gas distribution opex cost functions, for the Victorian gas distribution businesses (Economic Insights 2012a); for JGN (Economic Insights 2015a; 2019);

and for Multinet Gas (Economic Insights 2016b). These models have been used to make projections of gas network business operating costs.

1.4 Outline of the Report

Chapter 2 briefly explains productivity measurement and its applications in the context of the economic regulation of natural monopolies. This chapter also discusses measurement issues, data sources and the definitions of outputs and inputs used in the study. The comparator gas distribution businesses included in the analysis are introduced.

Chapter 3 presents an analysis of TFP and PFP *trends* for AGN SA over the period 1999 to 2019 and provides comparative information for other GDBs.

Chapter 4 presents a comparative analysis of the TFP *levels* of AGN SA and the other major Australian GDBs in other states using multilateral TFP analysis. The multilateral TFP method is explained and the results of the analysis of multilateral TFP are reported.

Finally, chapter 5 summarises the main conclusions of this study.

1.5 Economic Insights' experience and consultants' qualifications

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

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

This report was prepared by Michael Cunningham, who is an Associate of Economic Insights. His summary CV is presented in Attachment A. Michael Cunningham has read the Federal Court Guidelines for Expert Witnesses and this report has been prepared in accordance with the Guidelines. A declaration to this effect is presented in Attachment B to the report.

2 PRODUCTIVITY BENCHMARKING

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

2.1 Productivity Measurement and Benchmarking

Productivity is a measure of the physical output produced from the use of a given quantity of inputs. All enterprises use a range of inputs including labour, capital, land, fuel, materials and services. If the enterprise is not using its inputs as efficiently as possible then there is scope to lower costs through productivity improvements 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):

(1) $$TFP = Q/I$$

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

(2) $$T\dot{F}P = \dot{Q} - \dot{I}$$

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:

(3) $$PFP_i = Q/I_i$$

[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).

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

TFP indexes have a number of advantages including:

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

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

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

2.2 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. Although the weights are complex and vary depending on the technique used, for outputs they are derived from the share of each output in total revenue or, alternatively, from output cost shares and for inputs from the share of each input in total costs. To derive the revenue and cost shares we require information on the value of each output and input, i.e. its price times its quantity. Hence, we require either the price and quantity of each output and input or, alternatively, their values and quantities, or their values and prices. To derive output cost shares we require additional information on how cost drivers link to output components. This is usually derived from estimation of econometric cost functions.

In a sense the quantity data are the primary drivers of productivity results while the value or price data are secondary drivers in that they are used to determine the weights for aggregation. Quantity information can be obtained either directly or indirectly. Direct quantity data are physical measures of a particular output or input, e.g. terajoules 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.

2.2.1 Measuring GDB outputs

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

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

2.2.2 Measuring GDB inputs

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

There are a number of different approaches to measuring both the quantity and cost of capital inputs. The quantity of capital inputs can be measured either directly in quantity terms (eg, using pipeline length measures) or indirectly using a constant dollar measure of the value of assets. Similarly, 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 less operating costs.

Some analysts have argued that measuring the quantity of capital by the deflated asset value method provides a better estimate of total input as it better reflects the quality of capital and can include all capital items, not just pipelines. There are two potential problems with this approach. Firstly, it is better suited to more mature systems where the asset valuations are very consistent over time and across organisations. In Victoria and NSW there has been only one full asset valuation done in each state. In the case of Victoria, these asset values were further 'adjusted' before privatisation for political considerations and so, while the adjusted values form the basis of the current regulatory asset base, they are inappropriate for comparing capital input quantities.

The second problem with basing capital quantities on constant price asset value measures is that they usually incorporate some variant of the straight line approach to measuring depreciation. Gas pipeline assets tend to be long lived and produce a relatively constant flow of services over their lifetime. Consequently, their true depreciation profile is more likely to reflect the 'one hoss shay' or 'light bulb' assumption than that of a straight line approach. That is, they produce the same service each year of their life and until the end of their specified life rather than producing a given amount less service every year. In these circumstances it may be better to proxy the quantity of capital input by the physical quantity of the principal assets. This approach is also invariant to different depreciation profiles that may have been used by different pipeline businesses.

The direct approach to measuring capital costs involves explicitly calculating the return of and return on capital to reflect depreciation and the opportunity cost of capital. The indirect approach of allocating a residual or ex post cost to capital of the difference between revenue and operating costs has been favoured by some regulatory agencies, and is the approach used in PEG (2006). Given that the implicit rates of return in the Economic Insights GDB database are relatively stable and broadly similar in magnitude, and the focus of this study is on productivity performance, we use the indirect approach here for simplicity. 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 (2009b) but it will provide a close approximation in this case.

2.2.3 Normalisation for operating environment conditions

Operating environment conditions can have a significant impact on distribution costs and productivity and in many cases are beyond the control of managers. Consequently, to ensure reasonably like-with-like comparisons it is desirable to 'normalise' for at least the most important operating environment differences. Likely candidates for normalisation include: the scale of the business (e.g. as indicated by the total number of customers); customer density (customers per kilometre of main); customer mix; energy density (energy delivered per customer), climatic and geographic conditions; and features of networks such as the proportion of cast iron pipes or the number of discrete cities and towns supplied.

Customer density is generally found to be one of the most important operating environment variables in energy distribution normalisation studies (see: Denis Lawrence 2003) A GDB with lower customer density will require more pipeline length to reach its customers than will a GDB with higher customer density, making the lower density distributor appear less efficient unless the differing densities are allowed for. Other important factors include scale and energy density. Scale can be important because of economies of scale in network engineering. Energy density can be important because 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, or deliver a greater volume for the same investment in pipelines. Normalisation, for instance for differences in customer density, means that distribution businesses that have low customer density receive credit for their longer line lengths per customer. This would not be the case if output was measured by only one output such as throughput. This is why, in this study, as with many other distribution studies, gas throughput, system capacity and the number of customers are all explicitly included as outputs.

2.3 Data used

The primary data source for this study is information supplied by AGN, ATCO, AusNet, Evoenergy, JGN and Multinet in relation to each of their gas distribution networks in response to common detailed data surveys, covering key output and input value, price and quantity information for the period 1999 to 2019 (or to 2018 in some instances). Similar data was provided in previous years by AGN in relation to its Queensland gas network for the period 1999 to 2014. No forecast data are used for any of the included GDBs.

2.3.1 Output quantities and weights

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

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

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

3) **System capacity**: Gas distribution networks have three primary functions: delivery of gas from supply point to demand point; the interim storage of gas to make available sufficient gas during peak periods; and, the performance of these functions safely and efficiently. We include a measure of system capacity to capture the GDB's functional responsibility of making capacity available to meet the needs of customers. The measure we require is somewhat analogous to the MVA–kilometre system capacity measure used in electricity DB TFP studies (see, for example, Lawrence 2003a) but, in this case, it needs to also capture the interim storage function of pipelines.

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

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

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

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

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

2.3.2 Input quantities and weights

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

1) **Opex**: The quantity of the GDB's opex is derived by deflating the value of opex by the opex price deflator originally developed by PEG (2006). As noted above, the opex values supplied by the GDBs were consistent with the GDBs' Regulatory Accounts but the focus has been on ensuring data reflects actual year–to–year operations. A number of accounting adjustments such as allowance for provisions have been excluded as they do not reflect the actual inputs used by the businesses in a particular year which is what we need for TFP purposes. To ensure consistency in functional coverage throughout the period, for those years prior to the introduction of full retail contestability (FRC) each GDB's constant price

opex is increased by the amount of expenses incurred in the early years of FRC. In these early years FRC was expected to have only affected opex (and not capital) requirements.

To ensure consistency with previous 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. Government levies and unaccounted for gas are excluded from opex for all GDBs. Carbon costs are excluded where separately identified.[3]

The PEG (2006) opex price deflator was developed for electricity DBs. It is made up of a 62 per cent weighting on the Electricity, gas and water sector Wages price index with the balance of the weight being spread across five Producer price indexes covering business, computing, secretarial, legal and accounting, and advertising services. Since the functions of electricity and gas distribution are broadly analogous, the PEG deflator is considered the best currently available for GDB opex as well.[4]

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

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

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

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

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

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

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

The starting point for asset values for each GDB is based on the regulatory asset base (RAB) valuation in an initial year (either 1997, 1998 to 1999) for 12 asset categories. Asset life and remaining asset life estimates were provided for each GDB for each of the asset categories, as well as estimated asset lives for capex using the same asset categories. 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

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

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

price depreciation on capital expenditure for each year calculated using straight line depreciation based on asset–specific asset lives.

Following PEG (2006) we use the endogenous rate of return method for forming estimates of the user cost of capital. Using this approach the value of total costs equals total revenue by definition. As noted in Lawrence (2007), when the implicit gross rate of return is relatively stable over stable over time there should be little difference in TFP estimates formed using this approach and the exogenous user cost method. The input weight given to opex is simply the ratio of opex to total revenue. The aggregate capital input weight is simply given by one minus the opex share. It is then necessary to divide this overall capital share among the 7 capital asset inputs. This is done using the share of each of the 7 asset categories' asset values in the total asset value for that year.

2.4 Key characteristics of the included GDBs

The key characteristics of the eight GDBs included in this study are presented in Table 2.1 for 2018 (for AGN Qld, 2014). AGN SA is the 6th largest GDB in the sample in terms of throughput, customer numbers and distribution mains length. Its throughput of 23 PJ, customer numbers of 448,000 and distribution mains length of 8 thousand km are smaller than the averages for the GDBs in the sample (average throughput = 41 PJ; average customer numbers = 615,000 and average distribution mains length = 11 thousand km).

JGN is the largest of the GDBs in terms of throughput (89 PJ), customer numbers (1.4 million), and distribution mains length (24 thousand km). The Victorian GDBs are similar to each other in size and smaller than JGN. In terms of throughput they are on average about two-thirds of the size of JGN, ranging from 57 PJ (Multinet) to 64 PJ (AusNet). In terms of the number of customers they are on average about half of the size of JGN, ranging from about 695,000 (AGN Vic) to 702,000 (Multinet). In terms of distribution network length, they are on average about 45 per cent of the size of JGN, ranging from 10.0 (Multinet) to 12 thousand km (AusNet). ATCO is also larger than AGN SA. It is a little larger than the Victorian GDBs in terms of customer numbers (746,000) and network length (13 thousand km), but its gas throughput (26 PJ) is only about 45 per cent of the average level of gas throughput of the Victorian GDBs.

The remaining two GDBs are smaller than AGN SA and other GDBs on all measures. Evoenergy has throughput of 8 PJ, a customer base of 149,000, and distribution mains length of 5 thousand km. AGN Qld has throughput of 5 PJ, a customer base of 92,000, and distribution mains length of around 3 thousand km.

As noted previously, the two key operating environment characteristics that influence energy distribution productivity levels are energy density (throughput per customer) and customer density (customers per kilometre of mains). Together these determine the energy throughput per kilometre (km) of distribution mains. These measures are also shown in Table 2.1. Energy and customer densities shown in Table 2.1 are overall figures across domestic, commercial and industrial customers.

AGN SA has comparatively low energy density of 17 GJ per customer, compared to the sample average energy density of 28 GJ per customer. Its customer density of 56 customers per km of main is similar to the sample average of 54 customers per km. Consequently, its energy per unit of mains (2.8 TJ per km) is comparatively low compared to the sample average (3.6 TJ per km).

The three Victorian GDBs have relatively high energy densities, ranging from 45 (AGN Vic) to 57 GJ per customer (Multinet). The energy densities of the other GDBs are much lower than for the Victorian GDBs and most are comparable to AGN SA; such as 19 GJ/customer for JGN, 20 GJ/customer for Evoenergy, 14 GJ/customer for ATCO and 8 GJ/customer for AGN Qld.

The customer densities for the Victorian GDBs are also above average, ranging from 60 (AusNet) to 70 customers per km (Multinet). JGN and ATCO have similar customer densities to AGN SA; 57 and 56 customers/km respectively. The two smallest GDBs have relatively low customer densities. AGN Qld has 36 customers/km and Evoenergy has 32 customers/km.

Energy per unit of mains is the product of the energy density and the customer density. The three Victorian GDBs all have similar energy demand per unit of mains, and much higher than the sample average. They range from 5.2 (AGN Vic) to 5.7 TJ per km (Multinet). The energy throughput per km for JGN (3.6 TJ/km) is similar to the sample average, and significantly higher than AGN SA. The remaining GDBs all have levels of energy throughput per km that are lower than AGN SA. These include AGN Qld (2.1 TJ/km), ATCO (2.0 TJ/km) and Evoenergy (1.8 TJ per km).

Table 2.1: **Included GDBs' key characteristics, 2018***

GDB	Throughput	Customers	System capacity	Distribution mains length	Energy density	Customer density	Energy per unit mains
	TJ	*No*	*Sm³*	*kms*	*GJ/cust.*	*Cust./km*	*TJ/km*
AGN-Vic	57,039	694,822	150,055	10,952	44.6	63.4	5.2
Multinet	56,921	702,242	125,889	10,015	56.9	70.1	5.7
AusNet	63,751	698,227	153,559	11,613	46.7	60.1	5.5
Jemena	88,547	1,390,296	302,196	24,368	18.6	57.1	3.6
AGN-SA	22,577	448,205	107,661	8,072	16.9	55.5	2.8
AGN-Qld	5,356	91,783	27,725	2,542	8.2	36.1	2.1
ATCO	26,449	746,339	27,725	13,392	13.8	56.3	2.0
Evoenergy	8,192	149,288	62,109	4,627	20.4	31.7	1.8

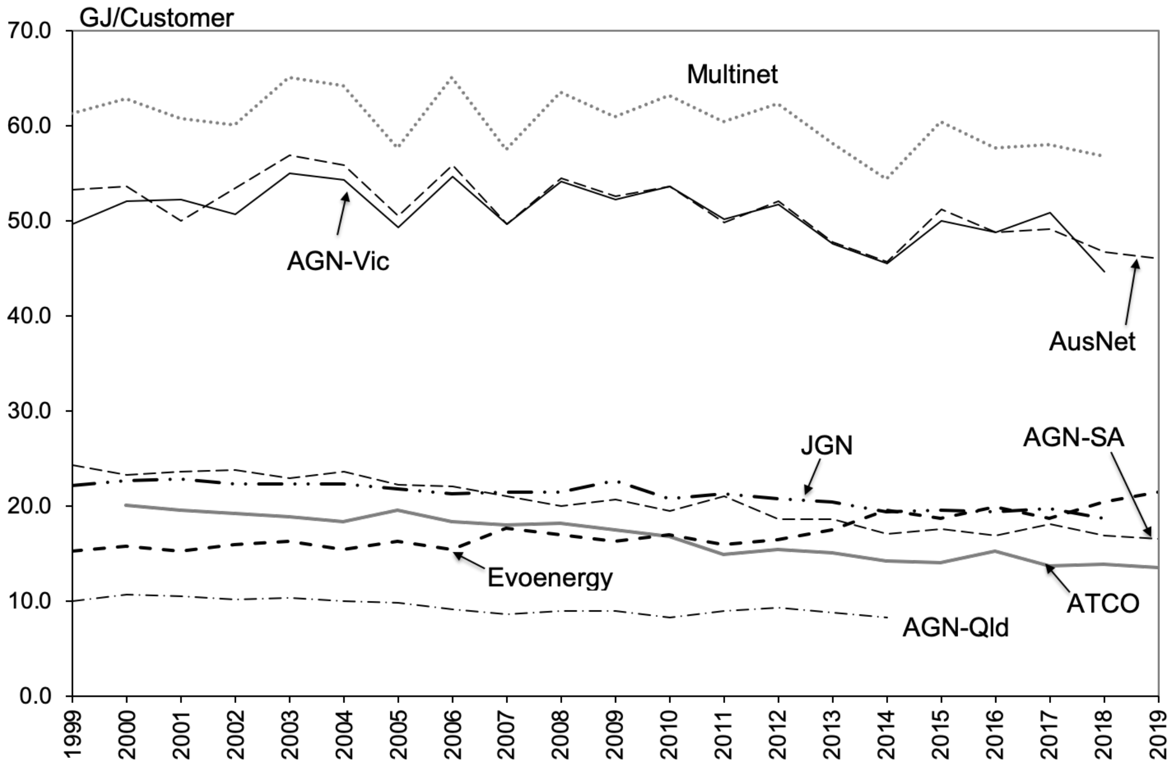
* AGN Qld (2014).

Source: Economic Insights GDB database

Domestic energy density is a key cost driver for GDBs. GDBs operating in a temperate climate will be at an obvious disadvantage relative to GDBs operating in cold climates where there is a much higher demand for gas for space heating. The domestic demand for gas for GDBs operating in temperate climates is likely to be more focused on cooking and hot water heating. The domestic energy densities of the eight included GDBs are plotted in Figure 2.1. From this figure we can see that AGN SA has broadly similar domestic energy density to JGN, Evoenergy and ATCO. For the most part this reflects broadly similar climatic conditions in reticulated areas of NSW, South Australia and Western Australia. Although the ACT does have a colder winter climate due to its higher altitude, there is little or no heavy industry in Evoenergy's supply area.

The three Victorian GDBs have considerably higher domestic energy densities than the non–Victorian GDBs, due to relatively higher domestic space heating demand. Greater variability of the Victorian densities is also associated with heating use, as demand is less in milder winters. The significant differences in domestic energy densities highlight the different operating conditions faced by Australian GDBs.

Figure 2.1: **Domestic energy densities, 1999–2019**



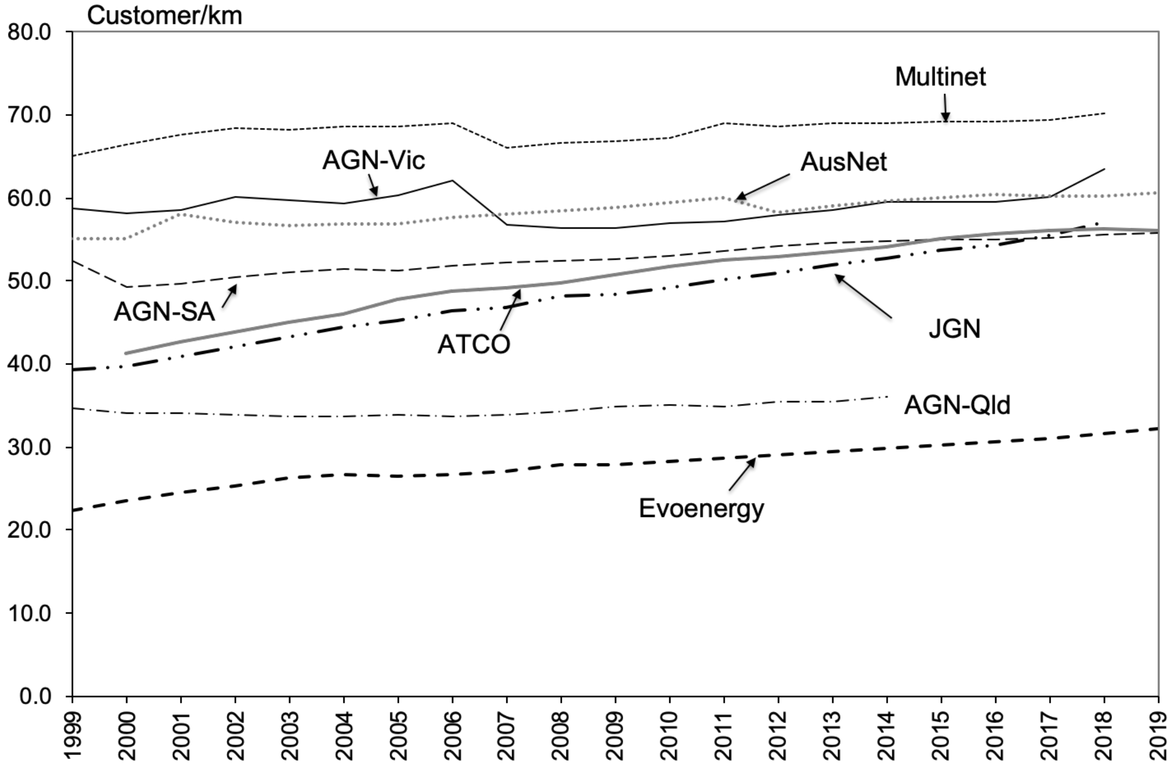
Source: Economic Insights GDB database

Such differences are further highlighted by differences in the share of domestic energy out of total energy throughput between GDBs. In 2018 (for AGN Qld, 2014), domestic throughput accounted for 33 per cent of AGN SA's throughput; 38 per cent of ATCO's throughput; and 29 per cent of JGN's throughput. By contrast domestic demand accounted for only 13 per cent of AGN Qld's throughput, and as much as 85 per cent of Evoenergy's throughput. In the cases of AGN Vic, AusNet and Multinet, domestic demand accounted for 52 per cent, 50 per cent and 69 per cent of total throughput, respectively.

Differences in climatic conditions and the geographic characteristics of the areas served also effect customer density. Domestic customer penetration rates are typically much lower for GDBs operating in warmer climates, meaning that those GDBs have to lay relatively more length of pipeline to reach each domestic customer. Customer densities will also be lower for those GDBs whose geography dictates a relatively 'dendritic' system rather than a more compact, meshed system. A dendritic system will arise where a number of spread out pockets of consumption have to be served. Customer densities for the included GDBs are plotted in Figure 2.2.

AGN SA's customer density is towards the average for Australian GDBs, and similar to ATCO and JGN. Multinet has the highest customer density of the included GDBs reflecting its coverage of Melbourne's densely populated inner southeast. AGN Vic and AusNet also have higher customer densities than AGN SA. AGN Qld and Evoenergy have lower customer densities than AGN SA.

Figure 2.2: **Customer densities, 1999–2017**



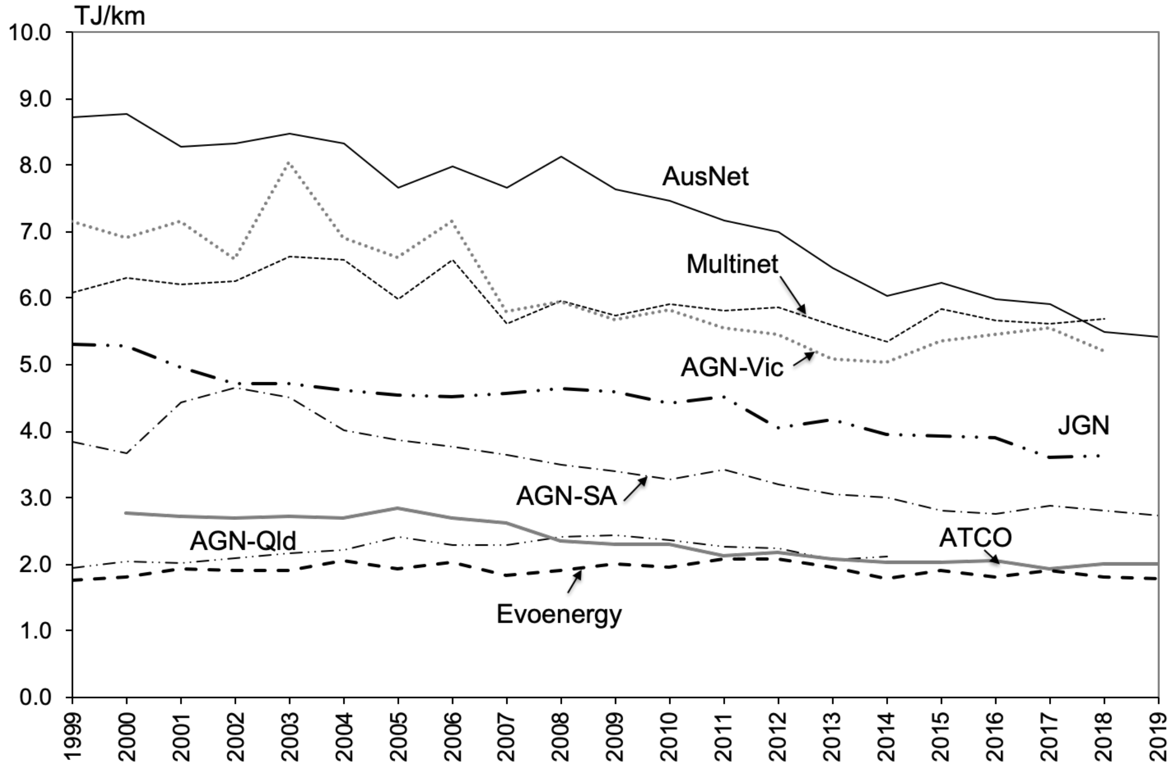
Source: Economic Insights GDB database

Figure 2.3 summarises the differences between the GDBs in terms of energy throughput per km of main. This is based on both domestic and non-domestic energy use. AGN SA has a below-average level of energy deliveries per km, which reflects its comparatively low energy density and average customer density. Three GDBs have lower energy throughput per km of main, namely ATCO, AGN Qld and Evoenergy. These GDBs have both low energy densities per customer and low customer densities. The Victorian GDBs have the highest energy throughput per km among the GDBs in the sample, which reflects a combination of the high energy densities and high customer densities previously discussed. JGN has a higher energy throughput per km of main, a combination of similar customer density and higher energy density compared to AGN SA.

There is a general trend, across all the GDBs (except AGN Qld and Evoenergy), of declining energy throughput per km, which is quite a pronounced shift over the whole of the sample period. Over the period full sample period (for each GDB) the cumulative *decline* in energy throughput per km was: AGN SA, 29 per cent; ATCO, 27 per cent; AGN Vic, 27 per cent; Multinet, 6 per cent; AusNet, 38 per cent; and JGN, 32 per cent. AGN Qld's energy throughput per km *increased* by 8 per cent and Evoenergy's was unchanged. An important factor in these declines has been reductions in demand by major industrial ('Tariff D' or 'contract') customers. The average cumulative decline in energy throughput per km over the whole sample period, for all GDBs, was 19 per cent.

To summarise, the review of operating environment conditions has shown that AGN SA has relatively low overall energy density, and domestic energy density. Its customer density is around average for the Australian GDBs. Consequently, it has a relatively low energy throughput per km of distribution mains, although not the lowest in the sample. This could be expected to give AGN SA at least some disadvantage when comparing productivity levels against some of the other GDBs.

Figure 2.3: **Energy throughput per km main, 1999–2017**



Source: Economic Insights GDB database

3 PRODUCTIVITY GROWTH RESULTS

3.1 TFP indexes

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

To operationalise TFP measurement 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. The four most popular index formulations are:

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

Diewert (1993) reviewed alternate index number formulations to determine which index was best suited to TFP calculations. Indexing methods were tested for consistency with a number of axioms which an ideal index number should always satisfy.[5] Diewert found that only the Fisher ideal index passed all of the axiomatic tests.[6] On the basis of his analysis, Diewert recommended the Fisher ideal index be used for TFP work although he indicated that the Törnqvist index could also be used as it closely approximates Fisher's ideal index. For this study the Fisher ideal index was therefore chosen as the preferred index formulation for the TFP time series analysis. It is also increasingly the index of choice of leading national statistical agencies.

Mathematically, the Fisher ideal output index is given by:

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

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

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

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

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

Y_i^t	is the quantity of the *i*th output for observation *t*;
P_i^t	is the price of the *i*th output for observation *t*; and
Y_j^B	is the quantity of the *j*th output for the base observation.

Similarly, the Fisher ideal input index is given by:

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

where:

I_F^t	is the Fisher ideal input index for observation *t*;
W_i^B	is the price of the *i*th input for the base observation;
X_i^t	is the quantity of the *i*th input for observation *t*;
W_i^t	is the price of the *i*th input for observation *t*; and
X_j^B	is the quantity of the *j*th input for the base observation.

The Fisher ideal TFP index is then given by:

(6) $$TFP_F^t = Q_F^t / I_F^t .$$

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

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

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

The inputs are listed in section 2.3.2. Real opex is one of the inputs and there are seven asset categories that are treated as separate inputs. The index of opex inputs, I_O^t, is merely the rebased quantity of opex inputs (X_O^t). Equation (5) is also used to construct a Fisher index for capital inputs only. The Fisher index of capital inputs is denoted as $I_{F,K}^t$. The partial factor productivity index for opex inputs is defined as:

(8) $$PFP_{F,O}^t = Q_F^t / I_O^t$$

The partial factor productivity index for capital inputs is defined as:

(9) $$PFP_{F,K}^t = Q_F^t / I_{F,K}^t$$

3.2 AGN-SA's productivity growth results, 2000 to 2019

In this section we present the key productivity results for AGN SA's South Australian gas distribution business for the 21-year period to 2019. Results are derived using the output index specification outlined in section 2.2 (throughput, customer numbers and system capacity) and with two broad inputs (real opex and capital). The capital index is based on seven components (lengths of transmission pipelines, high pressure pipelines, medium pressure pipelines, low pressure pipelines and services, number of meters, and the real value of other capital inputs), again as described in section 2.2. Table 3.1 shows the total factor and partial factor productivity index results for AGN SA.

Table 3.1: **AGN-SA productivity indexes, 1999–2019**

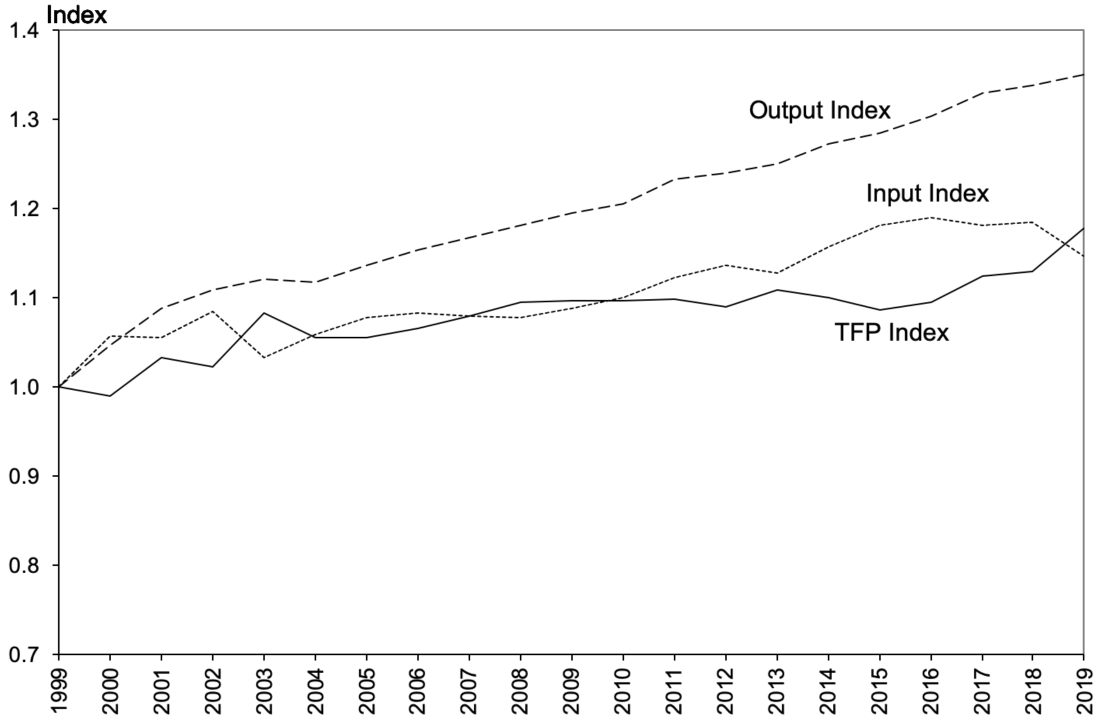
Year	*Output*	*Input*	*Opex*	*Capital*	*PP Opex*	*PP Capital*	*TFP*
1999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000	1.047	1.057	0.967	1.123	1.082	0.932	0.990
2001	1.089	1.055	0.915	1.158	1.190	0.940	1.032
2002	1.109	1.084	0.962	1.175	1.153	0.944	1.023
2003	1.120	1.034	0.819	1.193	1.367	0.939	1.084
2004	1.118	1.059	0.873	1.196	1.281	0.934	1.055
2005	1.137	1.078	0.842	1.255	1.350	0.906	1.055
2006	1.153	1.083	0.830	1.275	1.390	0.905	1.065
2007	1.167	1.080	0.803	1.292	1.452	0.903	1.080
2008	1.181	1.078	0.773	1.316	1.527	0.897	1.095
2009	1.194	1.089	0.771	1.337	1.550	0.893	1.097
2010	1.206	1.100	0.782	1.348	1.541	0.895	1.097
2011	1.234	1.123	0.816	1.361	1.511	0.906	1.099
2012	1.240	1.137	0.839	1.370	1.479	0.905	1.090
2013	1.251	1.128	0.801	1.379	1.562	0.907	1.109
2014	1.273	1.158	0.844	1.403	1.507	0.907	1.099
2015	1.284	1.181	0.855	1.435	1.502	0.895	1.087
2016	1.303	1.190	0.856	1.448	1.522	0.900	1.095
2017	1.329	1.182	0.805	1.466	1.651	0.907	1.125
2018	1.338	1.184	0.802	1.474	1.670	0.908	1.130
2019	1.351	1.146	0.690	1.486	1.958	0.909	1.178
Average Annual Change							
1999–2007	1.9%	1.0%	-2.7%	3.3%	4.8%	-1.3%	1.0%
2007–2014	1.3%	1.0%	0.7%	1.2%	0.5%	0.1%	0.3%
2014-2019	1.2%	-0.2%	-4.0%	1.2%	5.4%	0.0%	1.4%
1999–2019	1.5%	0.7%	-1.8%	2.0%	3.4%	-0.5%	0.8%

Source: Calculations using Economic Insights GDB database

AGN SA had an average rate of growth in output over the period 1999 to 2007 of 1.9 per cent per year. Its input growth averaged 1.0 per cent per year over the same period, resulting in annual TFP growth of 1.0 per cent in that period. Output grew at a lower rate in subsequent periods. From 2007 to 2014, output growth was 1.3 per cent per year, whereas input growth continued to increase at an average rate of 1.0 per year over this period, resulting in TFP growth averaging 0.3 per cent per year from 2007 to 2014. Output growth averaged 1.2 per cent per year from 2014 to 2019. During this period inputs decreased by 0.2 per cent per year on average, and consequently TFP growth improved to average 1.4 per cent annually in the latest period. Over the whole period from 1999 to 2019, annual output growth averaged 1.5 per cent per year and input growth averaged 0.7 per cent, with TFP averaging 0.8 per cent annually.

These trends are depicted in Figure 3.1, which plots AGN SA'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. Data for the last year (2019) are estimates and any inaccuracies may affect the trends described.

Figure 3.1: **AGN-SA output, input and TFP indexes, 1999–2019**

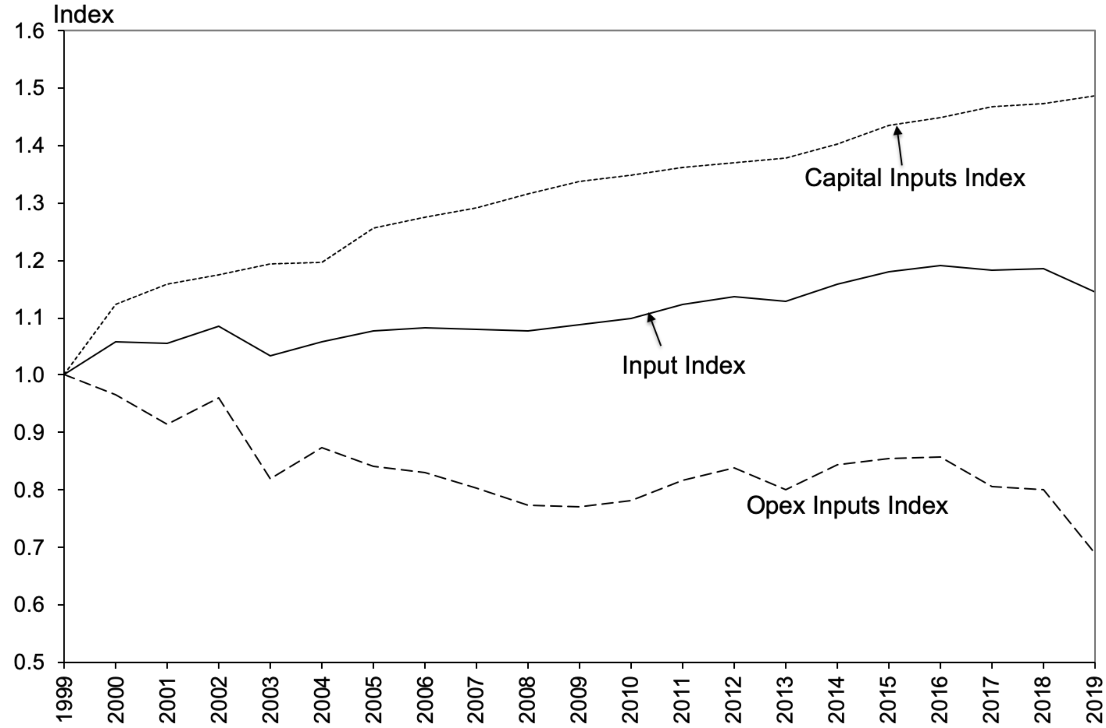


Source: Economic Insights GDB database

Figure 3.2 shows the divergent trends in the use of real opex inputs and capital inputs. On average, over the period from 1999 to 2019, opex inputs decreased at an average annual rate of 1.8 per cent. These reductions were concentrated in the period before 2007 and in the latest five-year period, whereas in the intervening period from 2007 to 2014, opex inputs increased. In contrast, the capital inputs index increased over the whole period from 1999 to 2019, averaging an annual increase of 2.0 per cent. The movements in the input index are the aggregate effect of the increases in capital inputs, and the decline on average in real opex inputs.

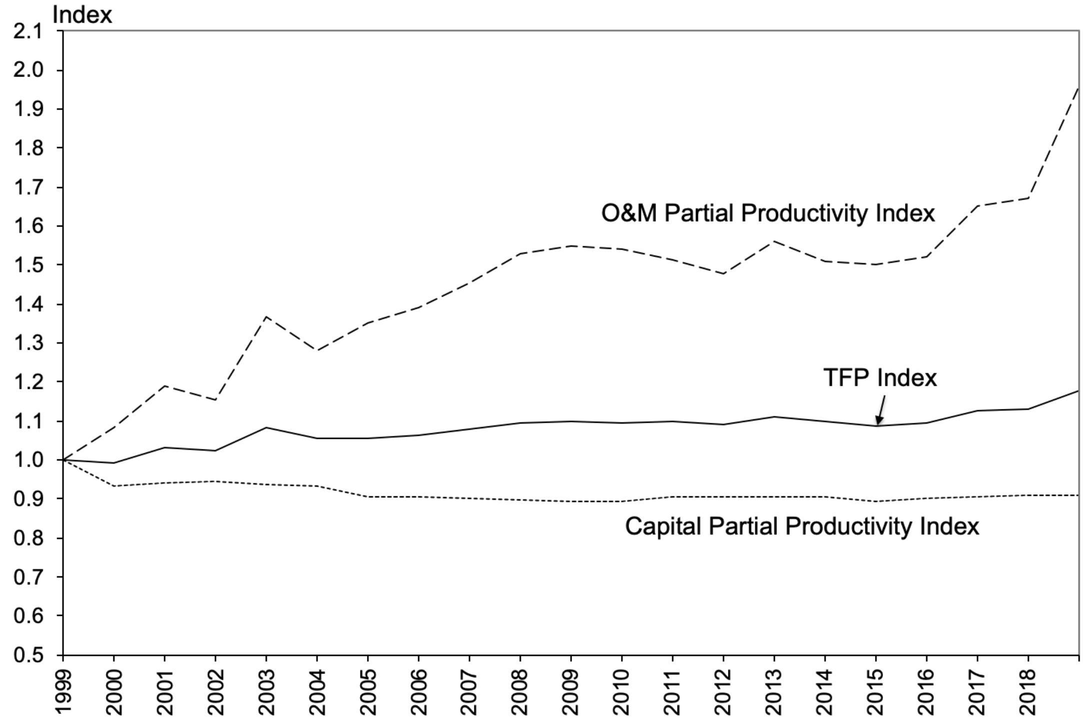
Figure 3.3 shows the movements in opex partial productivity and capex partial productivity indexes. These indexes represent the ratios of the output index shown in Figure 3.1, to each individual input index shown in Figure 3.2. Because of the combined effect of the growth of output and the decline in real opex inputs, in the period from 1999 to 2007 opex partial productivity increased at an average annual rate of 4.8 per cent. In the period from 2007 to 2014, output growth was slower and opex inputs increased, resulting in a much weaker 0.5 per cent annual growth of opex partial productivity. From 2014 to 2019, output growth continued at a similar rate to the preceding period whereas opex inputs declined significantly, leading to opex partial productivity increasing at an average annual rate of 5.4 per cent.

Figure 3.2: **AGN-SA inputs indexes, 1999–2019**



Source: Economic Insights GDB database

Figure 3.3: **AGN-SA partial productivity indexes, 1999–2019**



Source: Economic Insights GDB database

As mentioned, opex data for 2019 are estimates and any revisions to that data may affect the trends described. Capital partial productivity decreased in the period up to 2007 and was constant thereafter; averaging a decline of 0.5 per cent per year over the whole period from 1999 to 2019. This results from similar rates of growth in output and capital inputs.

3.3 Comparison with Interstate GDB Productivity Growth

This section compares AGN SA'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. Three GDBs, had stronger rates of TFP growth than the other GDBs over the period 1999 to 2019, namely AGN-Vic (whose TFP growth rate of averaged 1.5 per cent per year), ATCO (1.4 per cent) and AusNet (1.3 per cent).

AGN SA's TFP growth over the same period of 0.8 per cent per year, was equal to the sample average, and broadly similar to those of JGN (with average growth of 0.7 per cent) and Multinet (0.6 per cent), and higher than Evoenergy (0.4 per cent). Less data is available for AGN Qld, however the trend for the period up to 2014 suggests an ongoing decline in TFP. Although these average TFP growth rates are similar, the time-patterns are quite different. For AGN SA, TFP growth was positive in each of the three sub-periods for which TFP growth rates are calculated in Table 3.2. In contrast, JGN, Multinet and Evoenergy all had stronger TFP growth in the period from 1999 to 2007, and declines in TFP in the period from 2007 to 2014. From 2014 to 2019 (or latest year), JGN's TFP did not grow, Multinet's increased slowly, and Evoenergy's continued to decrease, whereas AGN SA's TFP increased at an average annual rate of 1.4 per cent per year in the latest period.

Figure 3.5 plots the Opex PFP indexes and Table 3.3 shows the Opex PFP index numbers and the growth rates. AGN SA's Opex PFP growth over the full period from 1999 to 2019 was 3.4 per cent per year; which was close to the average for all the GDBs (2.9 per cent), and similar to JGN (3.5 per cent), ATCO (3.1 per cent) and somewhat higher than Evoenergy (2.5 per cent). AGN Vic and AusNet had higher rates of Opex PFP growth over the same period (4.3 per cent and 4,2 per cent respectively) whilst Multinet had a lower Opex PFP growth rate (1.4 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 2019, Opex PFP growth increased (averaging 2.0 per cent per year for all GDBs). In this period AGN SA's Opex PFP growth was particularly high (averaging a 5.4 per cent increase 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, no change, or small decreases. Examples of the first are AGN Vic (0.4 per cent per year from 1999 to 2019) and ATCO (0.6 per cent). Examples of no change are Multinet (0.1 per cent per year over the same period) and AusNet (–0.1 per cent). Examples of small declines include AGN SA (–0.5 per cent per year), JGN (–0.4 per cent) and Evoenergy (–0.5 per cent).

Figure 3.4: **Comparative TFP indexes, 1999–2019**

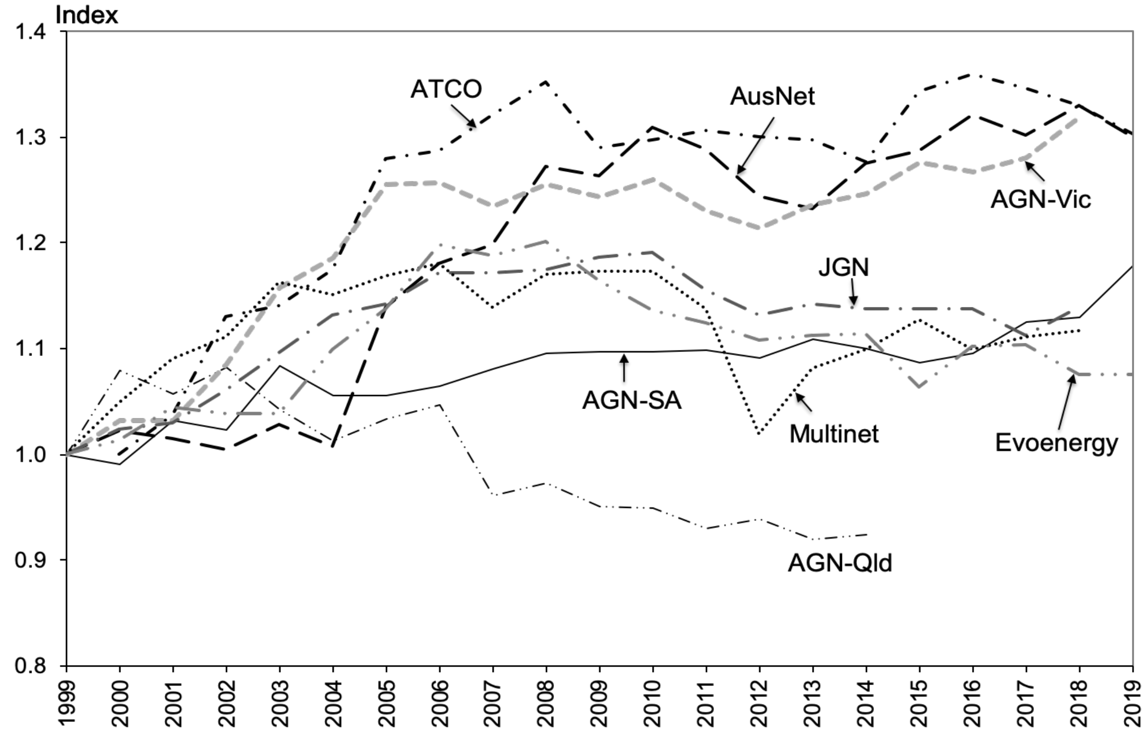


Table 3.2: **TFP indexes comparison, 2000–2019***

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	0.990	1.032	1.022	1.024	1.049	1.000	1.013
2001	1.056	1.032	1.032	1.014	1.029	1.090	1.037	1.045
2002	1.082	1.023	1.085	1.004	1.061	1.111	1.130	1.039
2003	1.042	1.084	1.157	1.029	1.097	1.163	1.141	1.039
2004	1.013	1.055	1.186	1.008	1.131	1.151	1.175	1.099
2005	1.034	1.055	1.256	1.140	1.142	1.169	1.280	1.138
2006	1.047	1.065	1.257	1.181	1.172	1.181	1.287	1.198
2007	0.960	1.080	1.235	1.199	1.172	1.139	1.321	1.188
2008	0.973	1.095	1.255	1.273	1.175	1.171	1.353	1.202
2009	0.950	1.097	1.244	1.264	1.187	1.173	1.290	1.164
2010	0.949	1.097	1.259	1.309	1.191	1.173	1.298	1.136
2011	0.930	1.099	1.229	1.289	1.155	1.137	1.306	1.124
2012	0.938	1.090	1.213	1.245	1.132	1.019	1.300	1.107
2013	0.919	1.109	1.237	1.232	1.142	1.082	1.298	1.113
2014	0.924	1.099	1.247	1.275	1.138	1.099	1.277	1.113
2015	.	1.087	1.276	1.288	1.137	1.127	1.343	1.063
2016	.	1.095	1.267	1.321	1.137	1.100	1.360	1.102
2017	.	1.125	1.280	1.303	1.113	1.111	1.346	1.103
2018	.	1.130	1.319	1.330	1.139	1.118	1.331	1.075
2019	.	1.178	.	1.300	.	.	1.303	1.075
Average Annual Change								
1999–2007	-0.5%	1.0%	2.7%	2.3%	2.0%	1.6%	4.1%	2.2%
2007–2014	-0.6%	0.3%	0.1%	0.9%	-0.4%	-0.5%	-0.5%	-0.9%
2014–2019*	.	1.4%	1.4%	0.4%	0.0%	0.4%	0.4%	-0.7%
1999–2019*	-0.5%	0.8%	1.5%	1.3%	0.7%	0.6%	1.4%	0.4%

* Or latest year.

Source: Calculations using Economic Insights GDB database

Figure 3.5: **Comparative Opex PFP indexes, 1999 – 2019**

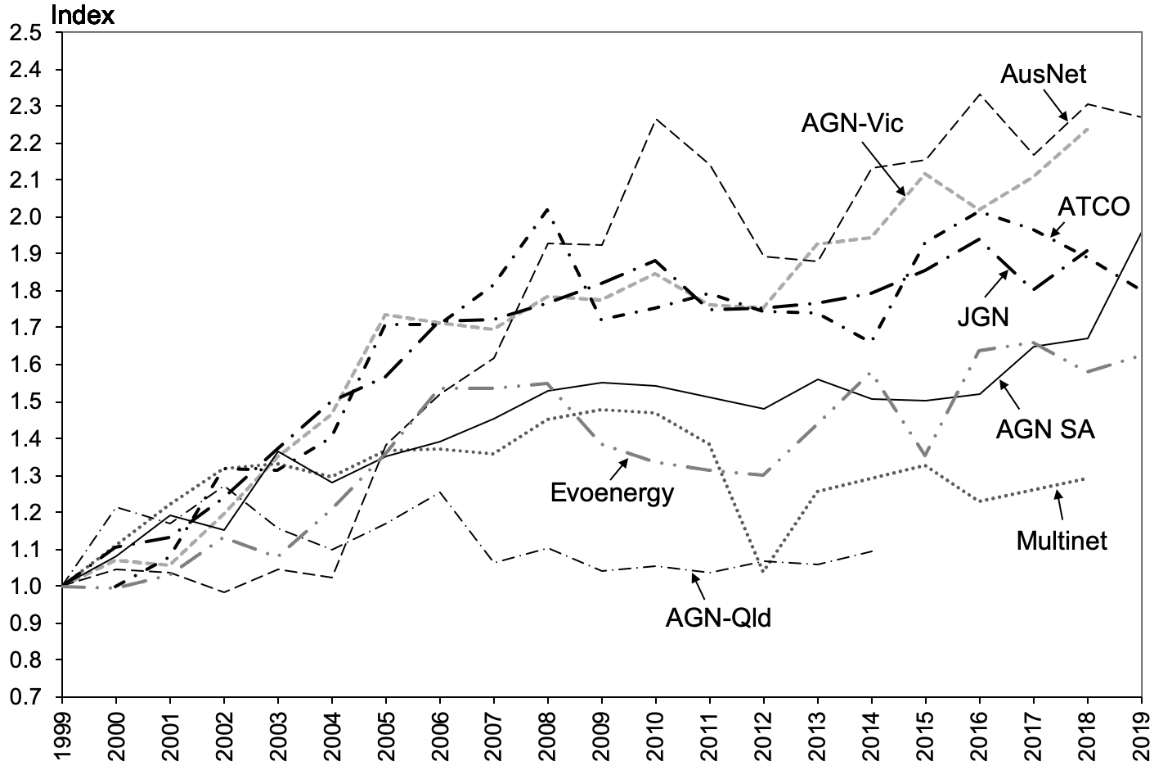


Table 3.3: **Opex PFP indexes comparison, 2000–2019***

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	1.213	1.082	1.068	1.045	1.103	1.108	1.000	0.993
2001	1.169	1.190	1.058	1.035	1.132	1.222	1.077	1.029
2002	1.270	1.153	1.194	0.984	1.239	1.316	1.320	1.133
2003	1.156	1.367	1.348	1.047	1.371	1.333	1.313	1.080
2004	1.098	1.281	1.465	1.024	1.498	1.294	1.401	1.205
2005	1.168	1.350	1.733	1.382	1.565	1.365	1.708	1.357
2006	1.255	1.390	1.715	1.520	1.716	1.370	1.709	1.535
2007	1.062	1.452	1.696	1.617	1.723	1.359	1.816	1.538
2008	1.102	1.527	1.785	1.930	1.765	1.452	2.021	1.549
2009	1.039	1.550	1.777	1.923	1.820	1.476	1.720	1.384
2010	1.056	1.541	1.847	2.264	1.883	1.467	1.754	1.337
2011	1.035	1.511	1.763	2.140	1.748	1.385	1.793	1.312
2012	1.066	1.479	1.755	1.891	1.751	1.040	1.744	1.300
2013	1.060	1.562	1.925	1.879	1.765	1.257	1.741	1.438
2014	1.096	1.507	1.946	2.132	1.794	1.291	1.662	1.578
2015	.	1.502	2.117	2.153	1.853	1.328	1.931	1.356
2016	.	1.522	2.020	2.331	1.939	1.228	2.016	1.640
2017	.	1.651	2.108	2.169	1.802	1.259	1.967	1.662
2018	.	1.670	2.237	2.307	1.908	1.291	1.891	1.579
2019	.	1.958	.	2.268	.	.	1.802	1.623
Average Annual Change								
1999–2007	0.7%	4.8%	6.8%	6.2%	7.0%	3.9%	8.9%	5.5%
2007–2014	0.5%	0.5%	2.0%	4.0%	0.6%	-0.7%	-1.3%	0.4%
2014–2019*	.	5.4%	3.6%	1.3%	1.6%	0.0%	1.6%	0.6%
1999–2019*	0.6%	3.4%	4.3%	4.2%	3.5%	1.4%	3.1%	2.5%

* Or latest year.

Source: Calculations using Economic Insights GDB database

Figure 3.6: Comparative Capital PFP indexes, 1999–2017

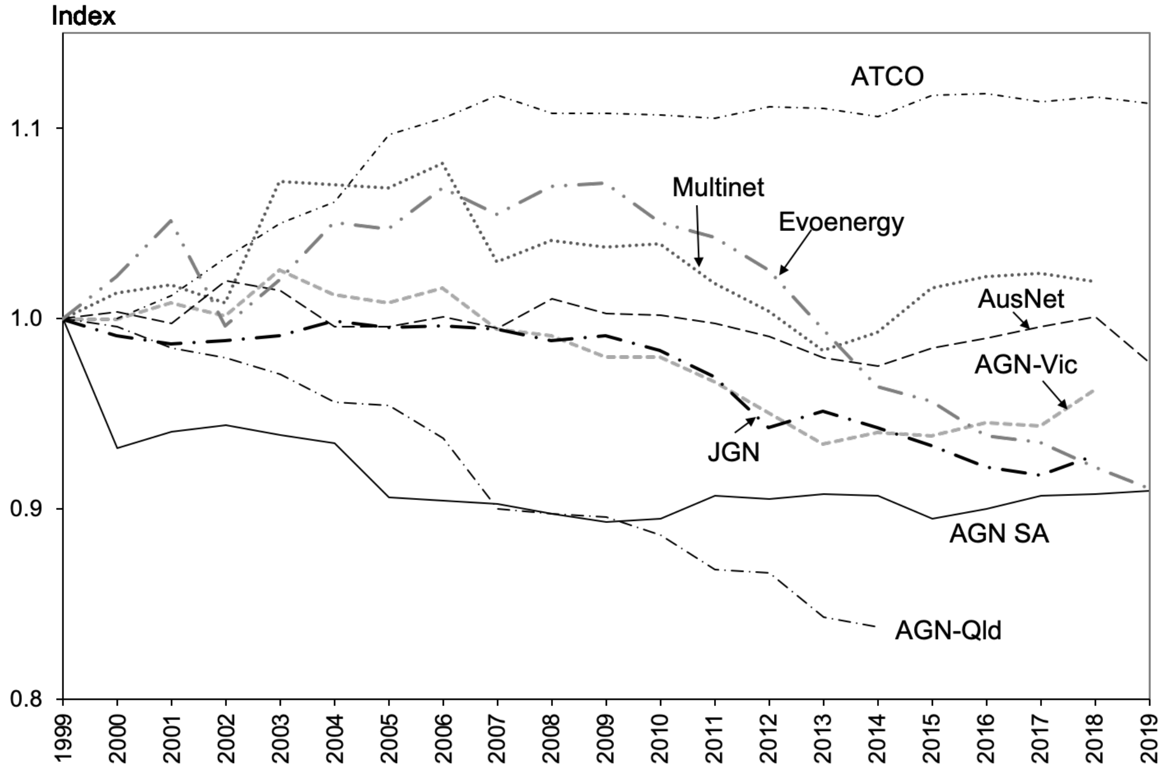


Table 3.4: **Capital PFP indexes comparison, 2000–2019***

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	1.004	0.991	1.014	1.000	1.022
2001	0.984	0.940	1.008	0.998	0.986	1.018	1.012	1.052
2002	0.979	0.944	1.002	1.020	0.988	1.008	1.032	0.996
2003	0.971	0.939	1.025	1.014	0.991	1.072	1.050	1.020
2004	0.956	0.934	1.013	0.995	0.999	1.070	1.061	1.051
2005	0.954	0.906	1.009	0.996	0.995	1.069	1.097	1.047
2006	0.937	0.905	1.016	1.001	0.996	1.082	1.105	1.069
2007	0.900	0.903	0.994	0.995	0.995	1.030	1.117	1.054
2008	0.897	0.897	0.991	1.011	0.988	1.041	1.108	1.069
2009	0.896	0.893	0.980	1.002	0.991	1.037	1.108	1.071
2010	0.886	0.895	0.980	1.002	0.983	1.039	1.107	1.051
2011	0.868	0.906	0.967	0.997	0.969	1.019	1.105	1.043
2012	0.866	0.905	0.950	0.991	0.943	1.004	1.112	1.026
2013	0.843	0.907	0.934	0.979	0.952	0.983	1.110	0.994
2014	0.837	0.907	0.940	0.975	0.943	0.992	1.106	0.964
2015	.	0.895	0.939	0.984	0.933	1.016	1.117	0.957
2016	.	0.900	0.946	0.990	0.922	1.022	1.118	0.938
2017	.	0.907	0.944	0.996	0.917	1.024	1.114	0.935
2018	.	0.908	0.962	1.001	0.928	1.019	1.117	0.922
2019	.	0.909	.	0.977	.	.	1.113	0.910
Average Annual Change								
1999–2007	-1.3%	-1.3%	-0.1%	-0.1%	-0.1%	0.4%	1.6%	0.7%
2007–2014	-1.0%	0.1%	-0.8%	-0.3%	-0.8%	-0.5%	-0.1%	-1.3%
2014–2019*	.	0.0%	0.6%	0.0%	-0.4%	0.7%	0.1%	-1.1%
1999–2019*	-1.2%	-0.5%	-0.2%	-0.1%	-0.4%	0.1%	0.6%	-0.5%

* Or latest year.

Source: Calculations using Economic Insights GDB database

Figure 3.7 shows the comparative output indexes, which are also presented in Table 3.5. AGN SA had a below-average output growth averaging 1.5 per cent per year between 1999 and 2019, compared to the average for all GDBs of 1.9 per cent over the same period. GDBs with the highest output growth were Evoenergy, AGN Vic and AusNet, averaging 2.7, 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.

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 AGN SA followed a similar pattern. 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 0.9 per cent per year. In the period 2014 to 2019 (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 –0.2 per cent per year. Over the full period from 1999 to 2019, the average rate of change of opex inputs was –0.9 per cent per year.

AGN SA's trend was similar to the average for all GDBs, except in the latest period, when it has much stronger decrease in opex inputs compared to the average GDB. In the period 1999 to 2007, its opex inputs *decreased* at the average rate of 2.7 per cent per year; from 2007 to 2014, opex inputs increased at an average rate of 0.7 per cent per year; and from 2014 to 2019, opex inputs decreased at 4.0 per cent per year. Over the full period from 1999 to 2019, AGN SA's average rate of change of opex inputs was –1.8 per cent per year. This average rate of reduction of opex inputs is comparable to AGN Vic, AusNet and JGN, for whom the average rate of change of opex inputs over the period from 1999 to 2019 was –1.9 per cent, –1.9 per cent, and –1.6 per cent per year, respectively. Smaller reductions in opex were achieved by ATCO and Multinet, with average rates of change of opex inputs over the same period of –0.8 per cent and –0.5 per cent per year, respectively. Opex inputs increased slightly for Evoenergy and AGN Qld.

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 AGN SA over the period 1999 to 2019 was 2.0 per cent per year, which was close the average for all GDBs (2.1 per cent). Most GDBs had a similar trend, with the exceptions of Multinet, which had lower growth of capital inputs, and Evoenergy which had higher growth, and these differences may be due to differences in customer growth.

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 AGN SA over the period 1999 to 2019 was 0.7 per cent per year, which was below the average for all GDBs (1.1 per cent). The main reason for this was AGN SA's large reductions in opex inputs in the latest period 2014 to 2019, as previously discussed.

Figure 3.7: **Comparative Output indexes, 1999–2019***

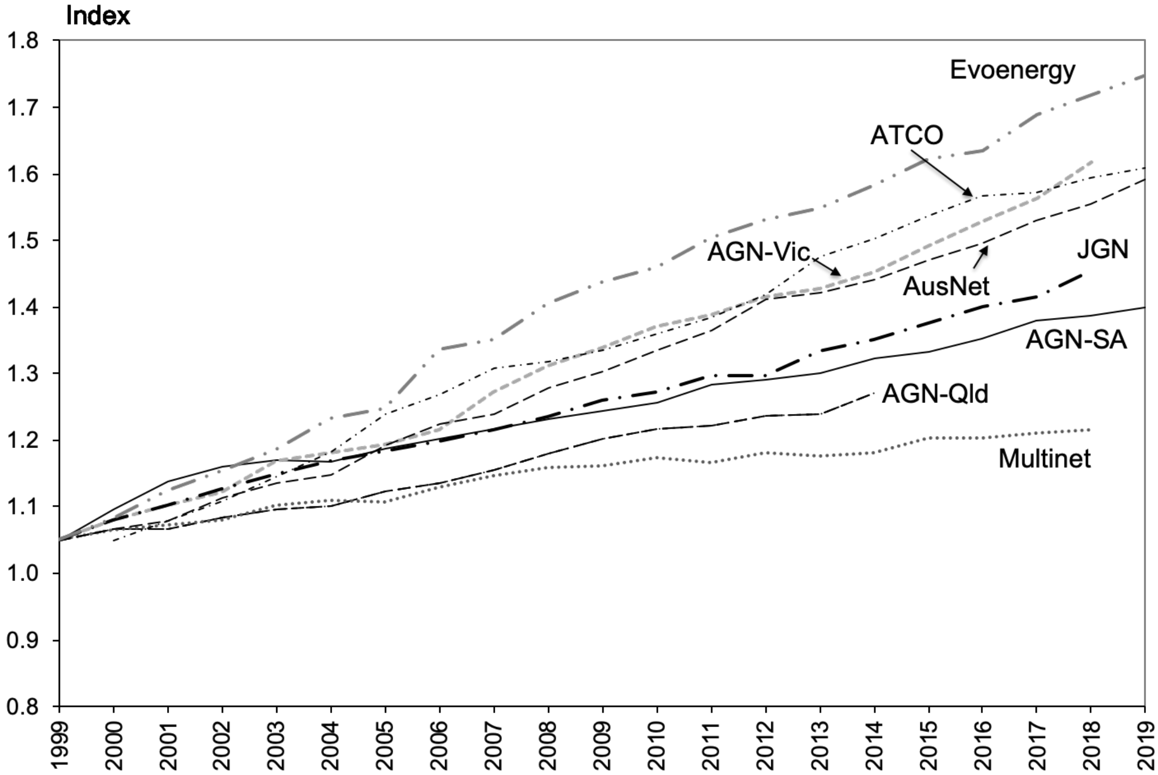


Table 3.5: **Output indexes comparison, 2000–2019***

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	1.314	1.247	1.116	1.334	1.455
2012	1.188	1.240	1.366	1.361	1.248	1.130	1.368	1.481
2013	1.190	1.251	1.378	1.371	1.285	1.127	1.425	1.498
2014	1.220	1.273	1.403	1.390	1.302	1.131	1.453	1.534
2015	.	1.284	1.441	1.421	1.326	1.152	1.488	1.573
2016	.	1.303	1.479	1.446	1.351	1.154	1.517	1.584
2017	.	1.329	1.513	1.480	1.366	1.160	1.523	1.640
2018	.	1.338	1.567	1.505	1.405	1.166	1.545	1.668
2019	.	1.351	.	1.541	.	.	1.558	1.698
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%
2014–2019*	.	1.2%	2.8%	2.1%	1.9%	0.8%	1.4%	2.1%
1999–2019*	1.3%	1.5%	2.4%	2.2%	1.8%	0.8%	2.4%	2.7%

* Or latest year.

Source: Calculations using Economic Insights GDB database

Figure 3.8: Comparative Opex indexes, 1999–2019*

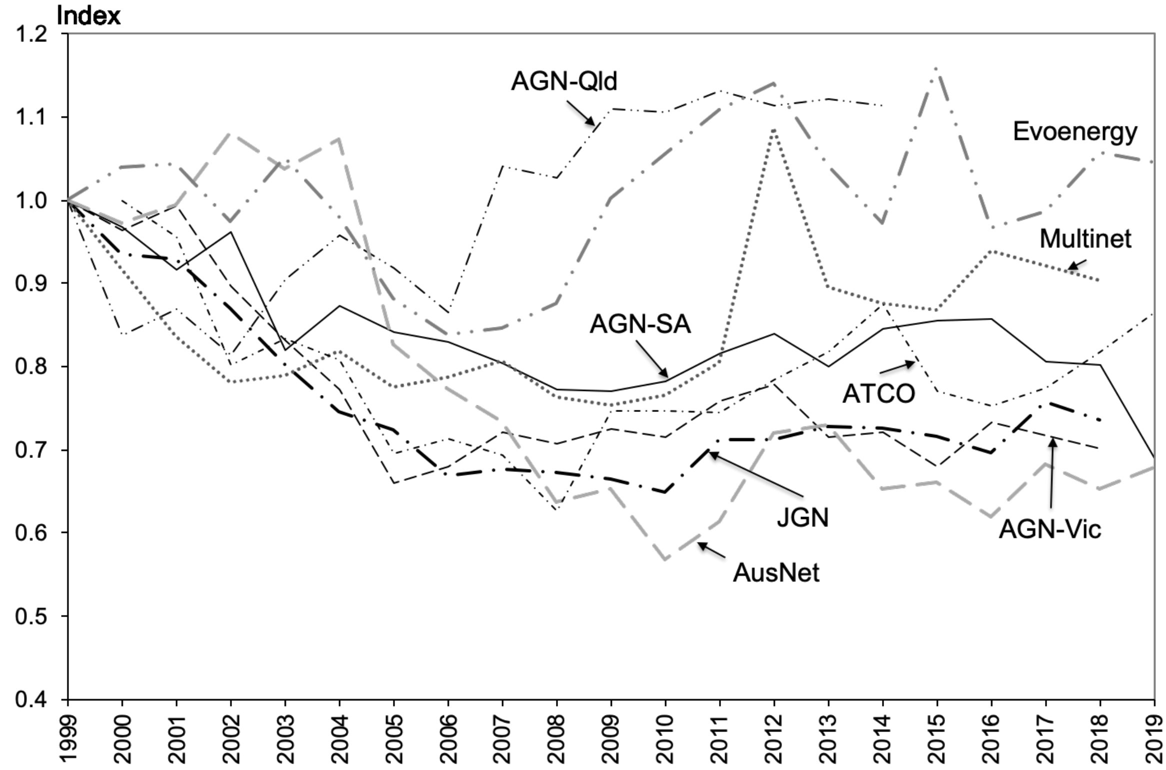


Table 3.6: **Opex input indexes comparison, 2000–2019***

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	0.838	0.967	0.963	0.974	0.934	0.917	1.000	1.039
2001	0.870	0.915	0.994	0.994	0.930	0.837	0.955	1.043
2002	0.814	0.962	0.897	1.081	0.870	0.782	0.803	0.975
2003	0.905	0.819	0.831	1.037	0.802	0.789	0.833	1.051
2004	0.957	0.873	0.772	1.073	0.746	0.819	0.808	0.981
2005	0.919	0.842	0.660	0.826	0.725	0.775	0.696	0.883
2006	0.866	0.830	0.681	0.773	0.669	0.787	0.713	0.839
2007	1.041	0.803	0.721	0.735	0.677	0.807	0.693	0.847
2008	1.026	0.773	0.707	0.637	0.672	0.764	0.627	0.875
2009	1.110	0.771	0.725	0.652	0.665	0.753	0.747	1.002
2010	1.106	0.782	0.715	0.568	0.650	0.766	0.747	1.055
2011	1.132	0.816	0.759	0.614	0.713	0.806	0.744	1.109
2012	1.114	0.839	0.778	0.720	0.713	1.087	0.784	1.139
2013	1.122	0.801	0.716	0.729	0.728	0.896	0.819	1.042
2014	1.113	0.844	0.721	0.652	0.726	0.876	0.874	0.972
2015	.	0.855	0.681	0.660	0.716	0.868	0.771	1.160
2016	.	0.856	0.732	0.620	0.697	0.939	0.752	0.966
2017	.	0.805	0.718	0.682	0.758	0.921	0.774	0.987
2018	.	0.802	0.700	0.652	0.736	0.903	0.817	1.056
2019	.	0.690	.	0.679	.	.	0.865	1.046
Average Annual Change								
1999–2007	0.5%	-2.7%	-4.0%	-3.8%	-4.8%	-2.6%	-5.1%	-2.1%
2007–2014	1.0%	0.7%	0.0%	-1.7%	1.0%	1.2%	3.4%	2.0%
2014–2019*	.	-4.0%	-0.7%	0.8%	0.4%	0.8%	-0.2%	1.5%
1999–2019*	0.7%	-1.8%	-1.9%	-1.9%	-1.6%	-0.5%	-0.8%	0.2%

* Or latest year.

Source: Calculations using Economic Insights GDB database

Table 3.7: Capital input indexes comparison, 2000–2019*

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	1.014	1.040	1.002	1.000	1.010
2001	1.032	1.158	1.043	1.031	1.067	1.005	1.016	1.021
2002	1.056	1.175	1.070	1.044	1.090	1.021	1.027	1.109
2003	1.077	1.193	1.092	1.071	1.110	0.981	1.042	1.113
2004	1.099	1.196	1.118	1.103	1.120	0.990	1.067	1.125
2005	1.125	1.255	1.134	1.147	1.140	0.990	1.083	1.144
2006	1.159	1.275	1.149	1.174	1.153	0.997	1.103	1.205
2007	1.228	1.292	1.230	1.194	1.173	1.065	1.127	1.235
2008	1.260	1.316	1.273	1.217	1.200	1.066	1.144	1.268
2009	1.287	1.337	1.315	1.251	1.221	1.071	1.160	1.295
2010	1.317	1.348	1.348	1.283	1.245	1.081	1.183	1.343
2011	1.350	1.361	1.385	1.318	1.286	1.095	1.207	1.395
2012	1.371	1.370	1.437	1.374	1.323	1.125	1.231	1.444
2013	1.412	1.379	1.476	1.400	1.351	1.146	1.284	1.507
2014	1.457	1.403	1.493	1.426	1.381	1.140	1.314	1.591
2015	.	1.435	1.535	1.444	1.421	1.134	1.332	1.644
2016	.	1.448	1.564	1.460	1.465	1.128	1.357	1.688
2017	.	1.466	1.603	1.486	1.489	1.132	1.367	1.754
2018	.	1.474	1.628	1.504	1.514	1.144	1.383	1.809
2019	.	1.486	.	1.578	.	.	1.400	1.865
Average Annual Change								
1999–2007	2.6%	3.3%	2.6%	2.2%	2.0%	0.8%	1.7%	2.7%
2007–2014	2.5%	1.2%	2.8%	2.6%	2.4%	1.0%	2.2%	3.7%
2014–2019*	.	1.2%	2.2%	2.0%	2.3%	0.1%	1.3%	3.2%
1999–2019*	2.5%	2.0%	2.6%	2.3%	2.2%	0.7%	1.8%	3.2%

Table 3.8: Input indexes comparison, 2000–2019*

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	0.996	1.007	0.968	1.000	1.019
2001	0.962	1.055	1.019	1.014	1.022	0.938	0.991	1.028
2002	0.956	1.084	0.987	1.060	1.016	0.926	0.937	1.063
2003	1.004	1.034	0.968	1.055	1.003	0.904	0.959	1.093
2004	1.038	1.059	0.954	1.090	0.989	0.921	0.964	1.075
2005	1.038	1.078	0.911	1.002	0.994	0.905	0.929	1.052
2006	1.038	1.083	0.928	0.996	0.980	0.914	0.948	1.075
2007	1.150	1.080	0.990	0.991	0.995	0.963	0.953	1.096
2008	1.162	1.078	1.005	0.966	1.010	0.948	0.937	1.128
2009	1.214	1.089	1.036	0.993	1.019	0.947	0.996	1.191
2010	1.229	1.100	1.049	0.982	1.028	0.958	1.009	1.242
2011	1.260	1.123	1.089	1.020	1.079	0.981	1.022	1.295
2012	1.266	1.137	1.126	1.093	1.102	1.108	1.053	1.338
2013	1.294	1.128	1.115	1.112	1.125	1.041	1.098	1.347
2014	1.321	1.158	1.126	1.090	1.143	1.029	1.138	1.378
2015	.	1.181	1.129	1.104	1.166	1.022	1.108	1.480
2016	.	1.190	1.167	1.094	1.188	1.049	1.116	1.438
2017	.	1.182	1.182	1.136	1.227	1.044	1.131	1.487
2018	.	1.184	1.189	1.132	1.233	1.044	1.161	1.552
2019	.	1.146	.	1.185	.	.	1.196	1.579
Average Annual Change								
1999–2007	1.8%	1.0%	-0.1%	-0.1%	-0.1%	-0.5%	-0.7%	1.2%
2007–2014	2.0%	1.0%	1.9%	1.4%	2.0%	1.0%	2.6%	3.3%
2014–2019*	.	-0.2%	1.4%	1.7%	1.9%	0.3%	1.0%	2.8%
1999–2019*	1.9%	0.7%	0.9%	0.9%	1.1%	0.2%	0.9%	2.3%

4 PRODUCTIVITY LEVEL RESULTS

4.1 Multilateral TFP indexes

Traditional measures of TFP such as those discussed in section 3 have enabled comparisons to be made of rates of change of productivity between GDBs but have not enabled comparisons to be made of differences in the absolute levels of productivity in combined time series, cross section GDB data. This is due to the failure of conventional TFP measures to satisfy the important technical property of transitivity. This property states that direct comparisons between observations *m* and *n* should be the same as indirect comparisons of *m* and *n* via any intermediate observation *k*.

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

The multilateral translog index is given by:

$$(8) \qquad \log (TFP_m/TFP_n) = \sum_i (R_{im}+R_i^*) (\log Y_{im} - \log Y_i^*)/2 - \sum_i (R_{in}+R_i^*) (\log Y_{in} - \log Y_i^*)/2 - \sum_j (S_{jm}+S_j^*) (\log X_{jm} - \log X_j^*)/2 + \sum_j (S_{jn}+S_j^*) (\log X_{jn} - \log X_j^*)/2$$

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

The formula in (8) gives the proportional change in MTFP between two adjacent observations (denoted *m* and *n*). An index is formed by setting some observation (usually the first in the database) equal to one and then multiplying through by the proportional changes between all subsequent observations in the database to form a full set of indexes. The index for any observation then expresses its productivity level relative to the observation that was set equal to one. However, this is merely an expositional convenience as, given the invariant nature of the comparisons, the result of a comparison between any two observations will be independent of which observation in the database was set equal to one.

This means that when using equation (8), comparisons between any two observations *m* and *n* will be both base–distributor and base–year independent. Transitivity is satisfied since comparisons between the two GDBs for 1999 will be the same regardless of whether they are compared directly or via, say, one of the GDBs in 2002. An alternative interpretation of this index is that it compares each observation to a hypothetical average distributor with output vector $log\ Y_i*$, input vector $log\ X_j*$, revenue shares R_i* and cost shares S_j*.

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

4.2 Productivity levels comparisons

The multilateral TFP indexes for eight GDBs are presented in table 4.1 and figure 4.1. 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 4.1: **GDB multilateral TFP indexes, 1999–2019**

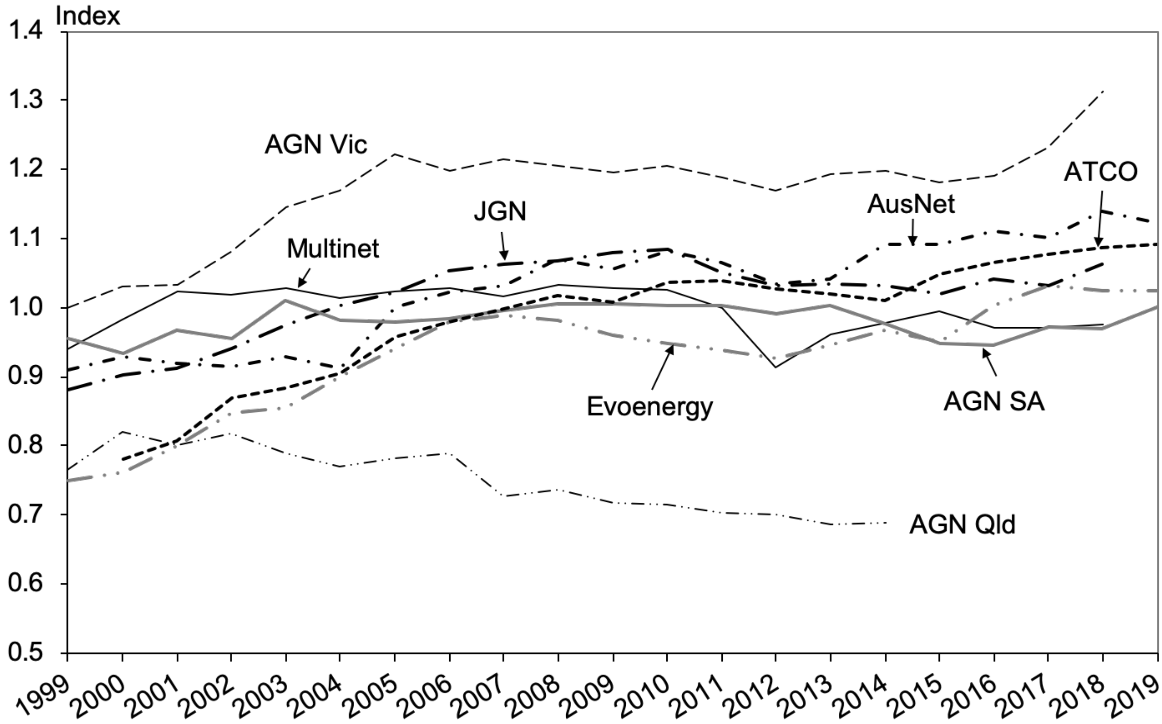
	AGN Vic	Multinet	AusNet	JGN	AGN SA	AGN Qld	ATCO	Evoenergy
1999	1.000	0.940	0.909	0.882	0.956	0.766	.	0.750
2000	1.029	0.983	0.928	0.903	0.933	0.820	0.781	0.760
2001	1.033	1.023	0.918	0.913	0.968	0.801	0.808	0.799
2002	1.081	1.019	0.916	0.941	0.955	0.818	0.869	0.848
2003	1.145	1.028	0.928	0.975	1.011	0.790	0.884	0.855
2004	1.168	1.013	0.913	1.004	0.982	0.769	0.906	0.900
2005	1.223	1.024	1.000	1.021	0.979	0.783	0.958	0.940
2006	1.197	1.028	1.022	1.054	0.984	0.788	0.978	0.980
2007	1.214	1.016	1.032	1.063	0.996	0.727	0.998	0.988
2008	1.206	1.033	1.070	1.068	1.006	0.735	1.018	0.981
2009	1.196	1.027	1.055	1.079	1.005	0.718	1.009	0.961
2010	1.205	1.026	1.081	1.084	1.004	0.715	1.037	0.948
2011	1.188	1.001	1.065	1.052	1.003	0.702	1.038	0.939
2012	1.168	0.912	1.033	1.031	0.991	0.701	1.028	0.926
2013	1.193	0.960	1.042	1.035	1.002	0.686	1.019	0.946
2014	1.197	0.978	1.091	1.032	0.976	0.688	1.010	0.967
2015	1.181	0.995	1.092	1.021	0.948	.	1.048	0.949
2016	1.190	0.970	1.111	1.041	0.946	.	1.065	1.002
2017	1.230	0.972	1.100	1.031	0.972	.	1.077	1.032
2018	1.313	0.976	1.140	1.064	0.969	.	1.086	1.023
2019	.	.	1.124	.	1.001	.	1.091	1.024

Source: Calculations using Economic Insights GDB database.

The MTFP results indicate that in the latest years available, AGN SA is found to have the sixth highest TFP level—an MTFP index of 1.00 in 2019. The highest TFP level is AGN Vic 1.37, AusNet (1.13), ATCO (1.09) and JGN (1.06). AGN SA's TFP level is similar to Evoenergy (1.02) and Multinet (0.98), whereas AGN Qld has a much lower TFP level.

The trends in MTFP shown in Figure 4.1 suggest that AGN SA and Multinet were both more highly ranked in terms of productivity levels at the commencement of the sample period, but both had lower ranking by the end of the period. Their productivity did not grow as strongly in the first half of the sample period as did some of the other GDBs, and was relatively flat in the second half of the period. Aside from AGN Qld, which had declining productivity, the other GDBs in the sample enjoyed a significant gain in productivity over the sample period.

Figure 4.1: **GDB multilateral TFP indexes, 1999–2019**



Source: Economic Insights GDB database

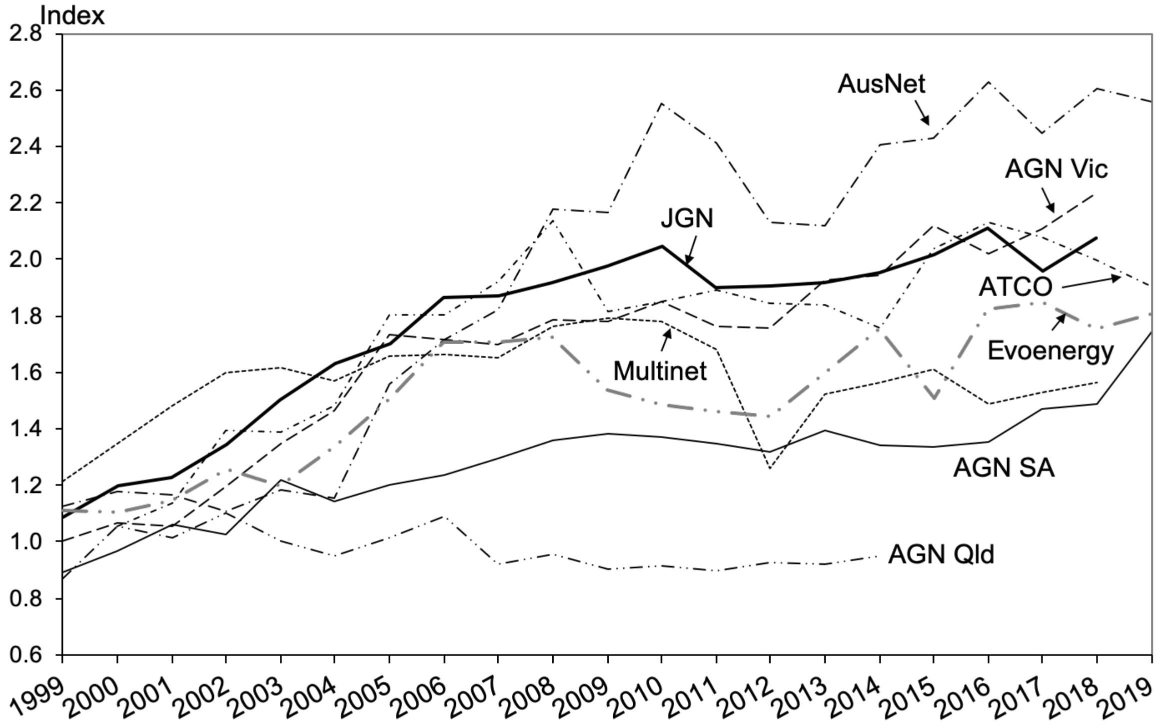
Table 4.2 and Figure 4.2 compare the levels of Opex PFP using multilateral Opex PFP indexes for the eight GDBs. In the last year available, AGN SA had the sixth highest Opex PFP level (1.75). In comparison to AGN SA's Opex PFP level in 1999 (0.89), it indicates a strong growth in Opex PFP of almost 100 per cent 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 (2.24 and 2.56 respectively).

Table 4.2: **GDB multilateral Opex PFP indexes, 1999–2019**

	AGN Vic	Multinet	AusNet	JGN	AGN SA	AGN Qld	ATCO	Evoenergy
1999	1.000	1.213	1.127	1.087	0.891	0.868	.	1.111
2000	1.068	1.344	1.178	1.199	0.965	1.052	1.056	1.104
2001	1.058	1.482	1.167	1.230	1.060	1.014	1.137	1.144
2002	1.194	1.596	1.110	1.346	1.028	1.101	1.394	1.259
2003	1.348	1.616	1.181	1.500	1.218	1.003	1.387	1.201
2004	1.465	1.569	1.154	1.629	1.141	0.952	1.480	1.340
2005	1.733	1.656	1.558	1.701	1.203	1.013	1.803	1.508
2006	1.715	1.662	1.713	1.866	1.238	1.088	1.805	1.706
2007	1.695	1.649	1.823	1.873	1.294	0.921	1.918	1.709
2008	1.785	1.761	2.175	1.919	1.360	0.956	2.135	1.722
2009	1.777	1.790	2.168	1.979	1.381	0.901	1.817	1.538
2010	1.847	1.780	2.553	2.047	1.373	0.916	1.852	1.486
2011	1.763	1.680	2.412	1.900	1.346	0.898	1.894	1.458
2012	1.755	1.261	2.132	1.904	1.318	0.924	1.842	1.445
2013	1.925	1.525	2.119	1.918	1.392	0.920	1.838	1.598
2014	1.946	1.566	2.403	1.950	1.343	0.951	1.755	1.754
2015	2.117	1.610	2.427	2.014	1.338	.	2.039	1.507
2016	2.020	1.489	2.629	2.108	1.356	.	2.129	1.823
2017	2.108	1.527	2.445	1.959	1.471	.	2.077	1.847
2018	2.237	1.566	2.601	2.074	1.488	.	1.997	1.755
2019	.	.	2.557	.	1.745	.	1.903	1.804

Source: Calculations using Economic Insights GDB database.

Figure 4.2: **GDB multilateral Opex PFP indexes, 1999–2019**



Source: Economic Insights GDB database.

Table 4.3 and Figure 4.3 compare Capital PFP levels using multilateral Capital PFP indexes. In the latest year, AGN SA's Capital PFP index was 0.80, which is very close to a number of other GDBs, who appear to have converged to the same Capital PFP level over the sample period. The GDBs with essentially the same level of Capital PFP as AGN SA include; Multinet, AusNet, JGN, AGN SA, ATCO and Evoenergy. AGN Vic had a higher level of Capital PFP (1.08) and AGN Qld a lower level (0.61).

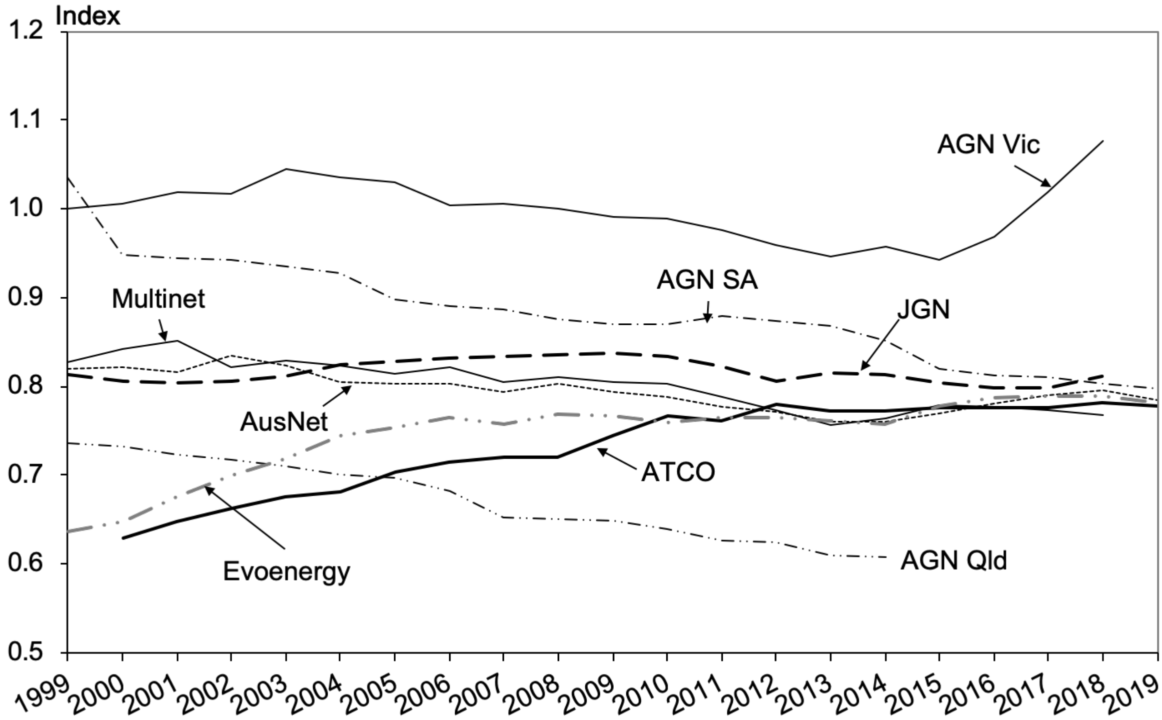
In terms of the trend, there was little change in the Multilateral Capital PFP indexes between the beginning and end of the sample period for the three Victorian GDBs and for Jemena. For ATCO and Evoenergy there was a substantial improvement, in the order of 20 per cent. Only AGN SA and AGN Qld showed deterioration in Capital PFP over the sample period, both in the order of 20 per cent decrease.

Table 4.3: **GDB multilateral Capital PFP indexes, 1999–2019**

	AGN Vic	Multinet	AusNet	JGN	AGN SA	AGN Qld	ATCO	Evoenergy
1999	1.000	0.827	0.819	0.812	1.036	0.736	.	0.636
2000	1.005	0.841	0.822	0.806	0.948	0.733	0.629	0.647
2001	1.019	0.851	0.816	0.803	0.944	0.722	0.647	0.676
2002	1.016	0.821	0.834	0.806	0.943	0.716	0.662	0.700
2003	1.044	0.829	0.824	0.812	0.935	0.710	0.675	0.717
2004	1.036	0.823	0.806	0.824	0.927	0.700	0.681	0.745
2005	1.030	0.815	0.803	0.828	0.897	0.697	0.704	0.754
2006	1.003	0.821	0.804	0.831	0.890	0.682	0.714	0.764
2007	1.005	0.805	0.794	0.833	0.886	0.651	0.720	0.758
2008	1.000	0.810	0.802	0.835	0.876	0.651	0.721	0.769
2009	0.992	0.804	0.793	0.838	0.869	0.648	0.745	0.767
2010	0.989	0.802	0.788	0.833	0.869	0.638	0.767	0.760
2011	0.975	0.788	0.778	0.823	0.878	0.627	0.762	0.765
2012	0.959	0.773	0.771	0.806	0.873	0.623	0.779	0.764
2013	0.947	0.757	0.761	0.816	0.869	0.609	0.772	0.762
2014	0.957	0.764	0.760	0.813	0.852	0.607	0.772	0.758
2015	0.942	0.779	0.769	0.804	0.820	.	0.776	0.777
2016	0.968	0.778	0.781	0.798	0.813	.	0.776	0.786
2017	1.018	0.773	0.790	0.799	0.810	.	0.776	0.790
2018	1.076	0.767	0.796	0.812	0.803	.	0.781	0.789
2019	.	.	0.785	.	0.797	.	0.778	0.781

Source: Calculations using Economic Insights GDB database

Figure 4.3: **GDB multilateral Capital PFP indexes, 1999–2019**



Source: Economic Insights GDB database

5 CONCLUSIONS

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

1. AGN SA's TFP increased at an average annual rate of 0.8 per cent from 1999 to 2019. As is common among the Australian GDB, TFP growth was weaker in the period 2007 to 2014, and somewhat stronger in the periods before and since.
2. AGN SA's Opex partial factor productivity (PFP) increased at an average annual rate of 3.4 per cent from 1999 to 2019. Capital PFP *decreased* at an average annual rate of 0.5 per cent over the same period. Opex PFP growth was strong in the periods 1999 to 2007 (4.8 per cent) and 2014 to 2019 (5.4 per cent), but there was little growth in the intervening period. The decline in AGN SA's Capital PFP mainly occurred in the period up to 2007 (-1.3 per cent), with little or no change thereafter.
3. Comparing the average rates of TFP growth of GDBs, AGN SA's TFP growth over the full sample period was similar to JGN (0.7 per cent) and Multinet (0.6 per cent). Evoenergy had a lower rate of TFP growth (0.4 per cent), whereas ATCO, AGN Vic and AusNet had higher rates of TFP growth (1.4, 1.5 and 1.3 per cent respectively). Most GDBs had strong rates of growth in Opex PFP, comparable to AGN SA. However, AGN SA's decline in Capital PFP (-0.5 per cent per year) was slightly greater than for most other GDBs.
4. Over the most recent period from 2014 to 2019, AGN SA's average annual rate of TFP growth of 1.4 per cent was higher than for most GDBs. Only AGN Vic had a

comparable rate of productivity growth in this period. Among the other GDBs, and over the same period, Evoenergy's TFP declined by 0.7 per cent per year, JGN had no TFP growth, and AusNet, Multinet and ATCO all had an average rate of TFP growth of 0.4 per cent per year.

5. AGN SA had a below-average output growth averaging 1.5 per cent per year between 1999 and 2019, compared to the average for all GDBs of 1.9 per cent over the same period. The average rate of increase in inputs for AGN SA over the period 1999 to 2019 was 0.7 per cent per year, which was below the average for all GDBs (1.1 per cent). Over the full period from 1999 to 2019, AGN SA's average rate of change of opex inputs was −1.8 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 AGN SA over the period 1999 to 2019 was 2.0 per cent per year, which was close 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, AGN SA is found to have the sixth highest TFP level in the last year of the sample—an MTFP index of 1.00 in 2019 (i.e. equivalent to AGN Vic in 1999, which is used as the index base). This TFP level is comparable to Multinet (0.98) and Evoenergy (1.02). This can be compared to the following MTFP indexes for the other GDBs: AGN Vic (1.37), AusNet (1.13), ATCO (1.09), and JGN (1.06). AGN Qld has a much lower TFP level.
2. AGN SA also had the sixth highest Opex PFP level (1.75) in the last year of the sample. The Opex PFPs of the other GDBs are: AGN Vic (2.24), AusNet (2.56), JGN (2.07), ATCO (1.90), Evoenergy (1.80), Multinet (1.57), and AGN Qld (0.95).
3. In the latest year, AGN SA's Capital PFP index was 0.80, which is very close to a number of other GDBs, who appear to have converged to the same Capital PFP level over the sample period. The GDBs with essentially the same level of Capital PFP as AGN SA include; Multinet, AusNet, JGN, ATCO and Evoenergy. AGN Vic had a higher level of Capital PFP (1.08) and AGN Qld a lower level (0.61).

APPENDIX A: DERIVING OUTPUT COST SHARE WEIGHTS

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

$$C(y^t, w^t, t) = \sum_{i=1}^{M} w_i^t \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^t (1 + b_i t)\right] \quad \text{(A1)}$$

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

The estimating equations were the M input demand equations:

$$x_i^t = \sum_{j=1}^{N} (a_{ij})^2 y_j^t (1 + b_i t) \quad \text{(A2)}$$

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

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

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

$$h_j^t = \left\{\sum_{i=1}^{M} w_i^t \left[(a_{ij})^2 y_j^t (1 + b_i t)\right]\right\} / \left\{\sum_{i=1}^{M} w_i^t \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^t (1 + b_i t)\right]\right\}. \quad \text{(A3)}$$

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

$$s_b^t = C(b, y_b^t, w_b^t, t) / \sum_{b,t} C(b, y_b^t, w_b^t, t). \quad \text{(A4)}$$

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