Quantonomics

QUANTITATIVE ECONOMICS

Final Report:

Icon Water Expenditure Benchmarking

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1 Introduction

1.1 Scope and purpose

This report presents the outcomes of the Icon Water benchmarking study undertaken on behalf of Icon Water. It has the purpose of informing some aspects of Icon Water's regulatory proposal for prices in the period 1 July 2023 to 30 June 2028. This study:

(a) uses econometric analysis to assess the efficiency of Icon Water's opex relative to Australian urban water businesses;

(b) undertakes analysis of Icon Water's total factor productivity (TFP) levels and growth rates relative to those of other urban water businesses;

(c) identifies key cost drivers (ie, outputs and operating environment factors) and estimates output weights relevant to forecasting efficient opex.

The methodologies for benchmarking urban water businesses to be implemented here include:

(1) Partial productivity indicators to compare urban water businesses using cost indicators relative to individual outputs. For example, total cost per customer, per kilometre of main, or per litre of water supplied;

(2) Econometric stochastic frontier analysis (SFA) of the variable cost function for the purpose of measuring comparative cost efficiency levels of utilities and productivity trends; and

(3) Multilateral total factor productivity (MTFP) and partial factor productivity (MPFP) indexes.

Finally, conclusions are reached on output weights that can be used in forecasting aggregate output, and the forecast rate of change of partial factor productivity (PFP) for non-capital inputs ('opex') which can be supported by the benchmarking results.

1.2 Outline

Section 2 describes the methodologies used in this study, the data sources and sample characteristics. It also presents a brief outline of relevant literature. Section 2 also documents the definitions and calculation of the variables used in the study. Appendix A provides more detailed information on data sources.

Section 3 presents descriptive information on the urban water businesses included in this study. It presents information on key characteristics of Icon Water and other utilities and provides a summary comparison of partial performance indicators relating to costs per customer.

In section 4, an econometric analysis of the variable (opex) cost function for Australian urban water businesses is presented. This is used to measure cost efficiency subject to the constraint of quasi-fixed capital inputs. It is also used to derive output weights and for forecasting opex partial factor productivity (PFP). The results of an econometric analysis of the total cost function are shown in Appendix B; which is only used for deriving output weights for the Multilateral Total Factor Productivity (MTFP) analysis in section 5.

Section 5 presents MTFP indexes, which allow the comparison of TFP levels between utilities and also to estimate rates of change in TFP. Alongside the MTFP index results are PFP results for real opex and capital inputs.

Lastly, section 6 includes a summary of the main results.

1.3 Quantonomics' experience

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

2 Approach to the Study

2.1 Methodologies

In economics, production is a process of transforming inputs into outputs, and productivity is the overall level of output produced per unit of input. Total factor productivity (TFP) is the ratio of an index of all outputs to and index of all inputs, whereas partial productivity is the ratio of total output to a single input. TFP is the most meaningful measure of productivity, because partial factor productivity (PFP) measures do not take account of factor substitution. But PFP measures can be useful in identifying the patterns of use of specific inputs relative to total output, for the purpose of diagnosing the specific drivers of changes in TFP.

The production process is represented in economics by a production set which represents all of the outputs that can be produced with different combinations of inputs, given the available technologies in the industry. The productive efficiency of a firm can be measured by estimating the shape of the frontier (or boundary) of the production set, and measuring either:

- how far the firm's outputs fall short (if at all) from the maximum outputs that can be produced with the same inputs used by the firm; or
- how far the firm's inputs exceed (if at all) the minimum inputs that can produce the same outputs as produced by the firm.

Analogously, the cost efficiency of the firm (which is a broader concept of efficiency which takes into account allocative efficiency in the use of inputs, given relative input prices) can be estimated by identifying the minimum cost frontier and the departures (cost inefficiencies) of individual firms.

Two popular methods of identifying production or cost frontiers are:

- *Stochastic frontier analysis* (SFA): a regression-based (parametric) method which relies on choosing a functional form for the transformation function (eg, in the form of a 'distance function') or the cost function, and estimating this frontier and the firms-specific inefficiencies jointly. The distribution of firm-specific inefficiencies must also be specified, and either a truncated normal or a half-normal distribution is often used.
- *Data envelopment analysis* (DEA): a non-parametric method using linear programming to find the tightest fitting piecewise linear hull encompassing the data. Different assumptions may be made in regard to returns-to-scale (e.g., constant, non-increasing, variable). DEA is applied to data on multiple outputs and inputs for a set of comparable businesses and fewer assumptions.

Although assumptions relating to the functional form of cost or production functions are not required in DEA, unlike econometric methods such as SFA, the latter better accommodates random errors in data, so that outliers or anomalous observations will be less overly influential than is the case in DEA. This is a particularly important consideration in this study, given the lack of quality in some of the data and the broad heterogeneity of urban utilities in the sample. Hence, SFA is the preferred method in this study.

2.2 Relevant Literature

This section briefly discusses some of the water benchmarking literature. Among the Australian studies, Byrnes et al (2010) examined 52 regional water utilities in NSW and Victoria from 2001 to 2004, looking only at the water supply functions. Benchmarking used DEA, with customer satisfaction and water supplied as the outputs, and opex excluding labour costs used as the single input (which is an unusual definition of variable costs). A study by Worthington (2011) also applied DEA to a four-year sample, 2006 to 2009, and also excluded sewerage services. Outputs included customer satisfaction, water quality, water losses and the inverse of mains breaks. There was a single input, real operating costs. Both these studies use variable cost as the only input, but do not control for fixed capital inputs.

Coelli and Walding (2006) used DEA on 18 water utilities from 1996 to 2003. Sewerage services were excluded, and customer numbers and water delivered were the outputs. Inputs include real opex and the length of water mains (as a measure of capital inputs). Productivity was estimated to have *decreased* at 1.1 per cent per year over the sample period. The Essential Services Commission of Victoria (ESC 2012a; 2012b) used SFA to benchmark 54 Australian urban water utilities, including both water supply and sewerage functions, using an unbalanced panel from 1998 to 2010. An input-oriented distance function was estimated. The outputs were the number of customers supplied, water supplied (adjusted for drinking water quality), and the quantity of sewage treated (adjusted for treatment level). The inputs were: (a) non-capital inputs: a composite index of bulk water purchased and all other non-capital inputs; and (b) capital inputs, measured in two ways: an accounting-based measure of fixed asset written-down replacement cost; and a physical measure based on the length of water supply and sewerage mains, and other factors. This study found an overall average rate of *decline* in TFP for all utilities in the sample of 0.5 per cent per year over the period 2006 to 2010. The ESC and the Coelli and Walding studied were broadly consistent in finding a trend towards decreased urban water productivity over periods analysed.[1]

The wider international literature on urban water benchmarking and cost analysis has been surveyed by Abbott and Cohen (2009), Saal *et al* (2013) and Worthington (2014). Many of the productivity studies have been directed at identifying whether privatisation yields efficiency benefits. Cost studies are often directed at informing policies of restructuring water industries.

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[1] Additionally, a Productivity Commission staff working paper (Topp and Kulys 2012) studied of productivity trends in the electricity, gas and water sectors. Although separate results were provided for the water industry, this was defined broadly to include urban water supply and sewerage services providers, rural water authorities, bulk water suppliers, catchment authorities and schemes for supplying water to farms for irrigation.

Saal *et al* find there is considerable evidence for the existence of economies of scope between water production and water distribution activities, but the empirical evidence for economies of scope between water and sewerage activities is mixed. Abbott and Cohen suggest that further work is needed to establish economies of scope between water production and water distribution for larger utilities. Lynk (1993) finds economies of scope between water supply and wastewater collection, however the economies of scope between water supply and environmental services are not robust to alternative specifications tested. Most studies find economies of scale for small water utilities, but there are widely different conclusions on the optimal scale. Torres and Morrison-Paul (2006) show that the question of economies of scale is complicated by whether increases in scale are accompanied by spatial expansion or changes customer density, and the effects of these changes on costs. The surveys emphasize that more research is needed.

Benchmarking studies of particular interest are the studies of the English and Welsh water industry by Saal and Parker (2006) and Saal *et al* (2007). These studies both use SFA to estimate input-oriented distance functions. The latter study used a sample of 10 combined water and sewerage businesses over sixteen years. Outputs were the quality-adjusted volumes of water supplied and sewerage collected as well as the number of properties serviced by water supply and sewerage. There were two inputs, non-capital inputs and capital services.

The most prominent regulatory benchmarking in the urban water industry has been by Ofwat in the UK, which began its benchmarking in 1994 (Dassler, Parker, and Saal 2006). The findings have been used in determining each firm’s X-factor in its price cap. Currently, Ofwat uses econometric models to benchmark operating and maintenance costs (‘opex’) for the wholesale and retail water and wastewater sector. The preferred econometric method is the random effects panel data method. Although in the 2014 price review (‘PR14’), Ofwat used a translog variable cost function, in its 2019 price review (‘PR19’), it started with a Cobb-Douglas (CD) specification and only added nonlinear or cross-product terms where there was a clear economic or engineering rationale for doing so, and where statistical tests demonstrated those effects were important (Ofwat 2019). For wholesale water modelling, Ofwat variously uses the following cost drivers: number of connected properties; length of mains; measures of water treatment complexity; number of booster pumping stations per length of main; and weighted average customer density. These variables are intended to reflect the scale, complexity, topography and density of the urban centres served by each utility. For wholesale wastewater modelling, the cost drivers used include: sewer length; wastewater volume; pumping capacity per sewer length; number of properties per sewer length; and number of wastewater treatment works per property served. Data for many of these variables are not available in the Australian context.

2.3 Data Sources

The sources of data used in this study and an overall description of the dataset is provided in Appendix A. The main data source is the National Performance Report (NPR) for urban water utilities produced by the Bureau of Meteorology (BOM). The data collected by BOM and reported in the NPR is supported by data definitions and established data submission procedures (Bureau of Meteorology 2018; 2020). Other data sources are used for:

- Bulk water prices and costs
- Ownership and capacity characteristics of dams and desalination plants
- Weather and temporary water restrictions
- Demographic characteristics of the areas served by utilities, and
- Data used to calculate input prices including published price indexes and interests rates.

Importantly, there are some significant data limitations, which are discussed in section 2.5.

2.4 Defining Variables

This chapter explains the definitions and calculation of outputs and inputs, and of input prices, costs, and operating environment factors (OEFs)

2.4.1 Candidate Outputs

The output measures chosen for urban water businesses in this study are similar to the measures used previously in Cunningham (2013) and Economic Insights' studies for the Essential Services Commission Victoria (Economic Insights 2014; 2018). They are defined as:

- The number of customers;
- The quantity of water supplied to residential and industrial customers and water supplied as bulk water to other water utilities; and
- The quantity of sewage collected and treated, including trade-waste.

Customer numbers

Customer numbers is defined as the maximum of two NPR indicators: the total connected properties for water supply (NPR indicator C4), and for sewerage (C8). Generally, the former is larger.

Water supplied

The quantity of water supplied (ML) is the total of the volume of water supplied to residential customers (W8) and to commercial, municipal and industrial customers (W9), plus the bulk water supplied to other water businesses or operational areas (W14).[2] In previous studies this has been adjusted by an index of water quality, and an adjustment factor for temporary water restrictions (Cunningham 2013). However, in this study they are included separately among the OEFs.

Alternative approaches to measuring water quality using NPR indicators have been tested, with similar results in the SFA analysis. The chosen index of water quality is the geometric average of two indexes, one for microbiological compliance and the other for chemical compliance. These indexes are defined such that at full compliance they equal 1.0, and otherwise <1.0. The microbiological quality index is defined as $(H3/100)^2$ where H3 is the percent of the population where microbiological compliance is achieved. The squared value is used because H3 is an estimate of the proportion of population affected rather than a raw measurement, and appears to have low variation relative to other comparable measures.[3] The chemical compliance index is H4, the proportion of zones where chemical compliance is achieved. For both these indexes a floor of 0.25 is imposed, to avoid zero values, and to reduce undue impact of outliers.

Temporary water restrictions (TWRs) are used to restrict outdoor water use during severe drought conditions. Restrictions are imposed by government and hence outside the control of the water utility. We adjust for their effects to obtain an estimate of the quantity of water which would otherwise have been demanded. This depends on the level of the TWR and the proportion of water used outdoors. The TWR adjustment factor use here is defined as: $twradj = 1 - \omega(twr/maxtwr)$, where ω is the proportion of water used outdoors, twr is the actual temporary water restriction stage (eg, stage 2) and $maxtwr$ is the maximum water restriction stage for the relevant state or region (eg, 4 or 7). At the maximum restriction all outdoor use of water is prohibited. It is assumed here that outdoor water use represents 33 per cent of residential water use on average, and 11 per cent of the water use of non-residential customers, and ω is the weighted average calculated at each observation. This formulation assumes that the constraining effect of the water restriction on water use is proportionate to the ratio of the actual water restriction stage to the maximum restriction stage. Permanent water saving measures are not treated as TWRs. They are considered equivalent to long-term changes in demand patterns and therefore do not cause a temporary mismatch between inputs and outputs.

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[2] So defined, water supplied does not include non-revenue water (W10.1)—ie, water losses—which is implicitly assumed to have no value, and hence neither a good nor a bad. By implication, the cost of producing non-revenue water will contribute to inefficiency.

[3] Eg, past values of H3 can be compared to the now discontinued H2 measure of the proportion of zones with microbiological compliance, which was an objective measure.

Wastewater collected and treated

The quantity of sewage treated is the total volumes collected of residential sewage, non-residential sewage and non-trade waste (W16) and of trade waste (W17). This is used as an output, and in this study a measure of the quality of wastewater treatment services is included separately as an OEF. The wastewater treatment quality index is defined as: $squal = a_1\text{E1} + a_2\text{E2} + a_3\text{E3}$. We have assumed: $a_1 = 0.333$, $a_2 = 0.666$ and $a_3 = 1.0$. This formulation, while approximate, is supported by some cost studies (Ong and Adams 1987).

2.4.2 Candidate Inputs

The main types of inputs are:

(a) The quantity of bulk water purchased;

(b) Real opex (excluding bulk water purchases) of water supply and of sewerage services; and

(c) Capital inputs of water supply services and wastewater services.

As with previous studies, the capital and non-capital inputs have each been aggregated across water supply and sewerage services. In part this is because there would be a high degree of correlation between costs for water and sewerage services given the very high rates of sewerage provision per household supplied with water. Further, empirical studies appear to support a conclusion that there are economies of scope between water and wastewater services. This would suggest there are common costs to be allocated between them, which may not be allocated consistently between utilities.

Bulk water purchases pose a problem because some utilities have their own sources of water and have zero water purchases. Zeros cannot be accommodated in a log-log econometric model, so in these applications the quantity of bulk water purchased is aggregated with real opex using an index method.

Capital Input

Measures of capital inputs assume that the productive services provided by the capital stock of a business are proportionate to the quantity of capital employed. Two broad approaches to measuring the quantity of capital employed are:

(a) physical measures which enumerate the different types of capital employed and aggregate them using appropriate weights; and

(b) financial measures which use a financial valuation of the capital employed and deflate that value using an appropriate deflator that reflects the market price movements for the kinds of capital employed.

Both of these approaches are used, and we also develop a mixed measure. An index of physical capital is constructed using the following physical capital measures:[4]

- A1, number of water treatment plants providing full treatment
- A2, length of water mains (km)
- A4, number of wastewater treatment plants
- A5, length of sewer mains & channels (km)
- *rescap*, total reservoir capacity of dams associated with each urban water utility,[5] and
- *desalcap*, capacity of marine water desalination plants owned by the utility.

Fixed unit values are applied to each of the above quantities, and these aggregated to form the index of physical capital.

$$kapi = \vartheta_1 \mathrm{A1} + \vartheta_2 \mathrm{A2} + \vartheta_3 \mathrm{A4} + \vartheta_4 \mathrm{A5} + \vartheta_5 rescap + \vartheta_1 desalcap \tag{2.1}$$

For the financial measure of capital inputs, this study uses the NPR series for the written down replacement cost of fixed assets in 2020 dollars, given by the sum of F9 (assets used in water supply) and F10 (wastewater services assets). Some difficulties with this series are that utilities do not necessarily use the same asset valuation methods. This is implied by the BOM when it states:

> *It is recognised that not all urban water utilities will be able to report on the basis of the written-down replacement cost. In this case the utility should record in the indicator footnote the approach used to value assets.* (Bureau of Meteorology 2018, 89)

Unfortunately, information on different valuation methods used is not available. Further, some utilities revalue their assets periodically, causing jumps in reported asset value series. Lastly, new accounting standards have been introduced within the sample period, and more widely adopted by utilities, resulting in changes to asset valuation methods over time. For these reasons we use: $rwdv = \mathrm{F9} + \mathrm{F10}$, as a measure of financial asset value only for the last year of the data sample for each utility (generally 2020). For all earlier years, the real financial asset value is calculated using the formula:

$$rwdv_{t-1} = (rwdv_t - \mathrm{F16}_t + \mathrm{F26}_t + \mathrm{F27}_t)/(1 - dep) \qquad \text{for } t \leq 2020 \tag{2.2}$$

where subscript t refers to the period, and dep is the average declining balance depreciation rate, here assumed to be 2.0 per cent per year. NPR indicator F16 is total capital expenditure

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[4] The 2007 NPR, and some earlier publications, also included the numbers of water and sewerage pumping stations (National Water Commission and Water Services Association of Australia, 2007). We investigated whether this could be used as cross-sectional data (eg, expressed in proportion to other assets). However, even in the earlier report, this data was not available for all utilities, and hence is too incomplete to be useable.

[5] From Dams Australia database.

(water and wastewater services) in real 2020 dollars; and F26 and F27 are government grants for capital works for water and wastewater services respectively, also in 2020 dollars.

Non-capital input & input price

Non-capital inputs are, broadly speaking, a measure of real opex, using an appropriate deflator. This is a simple calculation for utilities that are not bulk water buyers. However, for utilities that buy bulk water the purchase cost is included in opex and calculating a meaningful quantity index for non-capital inputs index is more complex. Bulk water and other non-capital inputs cannot be treated as two separate inputs because purchased bulk water inputs are zero for some utilities, and log values are used in the econometric analysis. Hence purchased bulk water and other non-capital inputs need to be aggregated as an index. This involves developing a measure of real opex as a weighted average of:

(a) an index of the real operating expenses excluding expenditure on bulk water (or 'real net operating expenses').

(b) an index of the quantity of bulk water purchases.

Total opex is given by the sum of indicators IF11 and IF12. Nominal non-capital costs is given by: $nopex_t = (\mathrm{IF11}_t + \mathrm{IF12}_t).(CPI_t/CPI_{2020})$. The quantity of bulk water purchases in ML (*bwquant*) is given by indicator W5, and $bw\_totcost$ is the nominal cost of bulk water purchases. The real cost of net opex (*rnetopex*; ie, opex net of bulk water purchases) in 2020 prices is:

$$rnetopex_t = (nopex_t - bw\_totcost_t).(CPI_{2020}/CPI_t) \qquad (2.3)$$

where *CPI* is the average CPI in each financial year.[6] Each measure (ie, *bwquant* and *rnetopex*) is expressed as an index relative to the base of Sydney Water in 2020 = 1.0, for the purpose of combining them into a quantity index of non-capital inputs. Weights are based on the per utility average cost share of bulk water in total opex; which is constant for each utility but varies between utilities.

$$ropexi_t = \overline{CS}_{bw}.bwquant_t + (1 - \overline{CS}_{bw}).rnetopex_t \qquad (2.4)$$

where: $\overline{CS}_{bw} = bw\_totcost/nopex$ is the cost share of bulk water in total opex, and represents the mean share per utility. The implied input price for non-capital inputs is given by:

$$opr_t = nopex_t/ropexi_t \qquad (2.5)$$

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[6] Australian All Groups CPI, average of four quarters in each financial year.

Capital Costs and Input Prices

Here we use a real pre-tax WACC to account for tax and imputation credits within the rate of return using a pre-tax WACC defined as:

$$(2.5) \qquad ror_t \;=\; g.(rfr_t + dp) + (1 - g).(rfr_t + \beta * \frac{mrp}{[1 - \tau(1 - \gamma)]})$$

where g in the debt share of funds employed; *rfr* is the real risk free rate; *dp* is the corporate debt premium; *mpr* = market risk premium; τ is the company tax rate; β is the equity beta; and γ is the rate (per dollar) of utilisation of franking credits. The assumed risk-free rate is the yield on inflation indexed Commonwealth Government bonds.[7] An exception is the debt premium which is inferred from Icon Water's current debt cost and the yield on 5-year Commonwealth Government bonds.[8] The other parameters those previously used for Icon Water by the Independent Competition and Regulatory Commission (ICRC): (a) g = 0.6, (b) β = 0.7, (c) *mrp* = 6.5 per cent, (d) τ = 0.3, (e) γ = 0.4.

The nominal cost of fixed asset inputs (ie, return on and of capital) is:

$$(2.6) \qquad nfacost_t = rwdv_t(ror_t + dep).(CPI_t/CPI_{2020})$$

Depending on the measure of capital used therefore, the input price of capital inputs is either:

$$(2.7) \qquad fkpr_t = nfacost_t/rwdv_t = (ror_t + dep).(CPI_t/CPI_{2020})$$

or:

$$(2.8) \qquad pkpr_t = nfacost_t/kapi_t$$

A Fisher Ideal index is used to aggregate the opex input price index and the capital input price index into a composite input price index (CIPI).[9]

2.4.3 Operating Environment Factors (OEFs)

Table 2.1 lists a number of variables that are candidate OEFs.

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[7] Reserve Bank of Australia: FCMYGBAG5. Average of monthly data.

[8] Icon Water reports its cost of debt for 2021/22 as 4.41%, and the average Commonwealth 5-year bond rate from July 2021 to December 2021 was 0.95%; implying a debt premium of 3.46%.

[9] This is defined as: $CIPI = \sqrt{L.P}$, where $L = (p_{1t}.q_{1,t-1} + p_{2t}.q_{2,t-1})/(p_{1,t-1}.q_{1,t-1} + p_{2,t-1}.q_{2,t-1})$ and $P = (p_{1t}.q_{1t} + p_{2t}.q_{2t})/(p_{1,t-1}.q_{1t} + p_{2,t-1}.q_{2t})$.

Table 2.1: Candidate OEFs

Description	*Calculation*
Residential customer share of urban water supplied	W8/(W8+W9)
Trade waste proportion of all wastewater collected	W17/(W16 + W17)
Proportion of water sourced from Surface water(c)	W1/W7
Proportion of water sourced from desalinated marine water(c)	W3.1/W7
Volume of recycled water as a proportion of total water supplied to customers.	W27
Average customer minutes-off supply (per year)	C15 × C17 / 1000 (A minimum value of 5 is imposed)
Asset quality index (Infrastructure Leakage Index)(a)	A9
Net greenhouse emissions in water supply in proportion to water supplied(b)	E9 × C4 / W8
Index of drinking water quality	Defined in section 2.4.1.
Index of the standard of wastewater treatment	Defined in section 2.4.1.
Effect of TWRs	Defined in section 2.4.1.
Average maximum temperature	Bureau of Meteorology
Total annual rainfall	Bureau of Meteorology
Share of all dwellings that are not houses (mainly flats)	ABS census data
Density of dwellings (dwellings per km^2)	ABS census data
Indicator for dam ownership (yes = 1, no = 0)	Dams Australia database

Notes: (a) A Proxy for asset age; (b) A proxy for energy use per ML of water supplied. Average value per utility (ie, cross-sectional) due to volatility of greenhouse measurements; (c) The balance of water sourced is mainly from groundwater and from bulk water purchases.

2.5 Data Limitations

Although the NPR is a comprehensive panel data set covering 15 years, there are several important limitations to the data used in this study:

(1) General limitations include:

  (i) missing values for some variables for some utilities in some years;

  (ii) changes in indicator definitions which may have affected some indicators, particularly water sources;

  (iii) not all utilities are directly comparable.

(2) Accounting treatment of costs, capitalisation rates, and cost allocations to activities, may differ between businesses, especially since some entities are arms of local governments (which provide a range of other planning and community services), whereas others are statutory corporations only concerned with supplying water and

wastewater services. Further, while some water corporations are which are horizontally integrated across a range of activities businesses, others are divisions of a single statutory corporation (eg, most of the utilities in Western Australia are divisions of Water Corporation, and two entities in the Northern Territory are divisions of Power and Water Corporation). Some entities in the sample have been combined from separate sewerage and water supply businesses to ensure that all utilities in the sample are vertically integrated water and wastewater service providers.

(3) A substantial data quality issue is differences in the methods used for reporting asset values. Some entities include only the water and sewer physical assets, while others also include corporate assets (e.g. buildings, IT, fleet) (Bureau of Meteorology 2021). This will substantially impact on the comparability of capital measures. There are also anecdotally reported differences in accounting methods used for valuing assets. As noted previously, not all entities report the written down replacement cost of assets, and the methods they use are not disclosed. Some may use historical cost and some may periodically revalue assets using different methods. Some statutory corporations were established with politically-determined asset values to avoid price disruptions. For many years some statutory corporations were exempted from complying with generally applicable Australian accounting standards, and local governments have their own Code of Accounting Practice and Financial Reporting. All of these factors may cause inconsistencies in asset valuation.

(4) Although we have sought to address such limitations in capital input measurement by developing a physical capital index, to yield an alternative set of productivity and efficiency estimates, the physical capital index is too crude a measure to be reliable. Although it uses length of water and sewerage mains which are often used as a proxy for capital inputs in water benchmarking studies, and improves on this by incorporating information on some other assets, it remains the case that for some important asset types (eg, pumping stations) there is no data,[10] and some of the asset types are likely to be of varying sizes (eg, water and wastewater treatment plants) and simply including the number of such plants is likely to lead to considerable inaccuracy.

(5) There are limitations arising from the incompleteness of information, such as:

  (i) on several aspects of the operating environment which affect the costs of supply in different supply regions (eg, topography, quality of water sources). Although we have included a wide range of OEFs to account for different operating

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[10] The 2007 NPR, and some earlier publications, included the numbers of water and sewerage pumping stations (National Water Commission and Water Services Association of Australia, 2007). We investigated whether this could be used as cross-sectional data (eg, expressed in proportion to other assets). However, even in the earlier report, this data was not available for all utilities, and hence is too incomplete to be useable.

environments, these gaps in information raise the risk of conflating differences in operating environment with differences in efficiency.

(ii) on special taxes or levies sometimes imposed by state governments on water utilities (usually for environmental reasons). Incompleteness of the data has meant that adjustment for such taxes could not be carried out.

(iii) on water supply security, which is core aspect of utility service performance. At present there is a lack of appropriate quantitative indicators of the degree of water security (Aither, Risk Edge, and HARC 2021, 60).

(6) Utilities included in the sample are not all comparable as they operate in different operating environments, with different types of organisational integration, and with differing regulatory obligations applying businesses (ie, some businesses are not price regulated).

(i) Not all operating environment factors can practically and quantitatively be accounted for in benchmarking analysis, including different regulatory obligations, government environmental policies, asset age, water sources, pumping distances and trajectory, and other input costs beyond the control of businesses. It is not possible to control for the complexity of water treatment required, and differences in wastewater (eg, between entities with ocean outfall compared to inland discharge).

(ii) Aither et al (2021) propose that in future NPRs, water utilities (excluding bulk water providers) should be grouped as follows: (a) economically regulated and price guided service providers; (b) stand-alone service providers operating without formal economic regulation; (c) local government-based service providers; (d) bulk water providers (not included in this analysis). We have not made use of a classification system of this kind in the present study, although it would be a logical next step.

(7) Finally, there are some general concerns about the quality of some of the data reported to the Bureau of Meteorology by water businesses, particularly by smaller entities, as emphasised by the Productivity Commission (2021, 170).

3 Descriptive Information and Partial Performance Indicators

This section describes the key characteristics for the 64 urban water utilities included in this study. It also partial productivity indicators to compare urban water businesses using cost indicators relative to individual outputs. For example, total cost per customer, per kilometre of main, or per litre of water supplied. These will be graphed against measures of customer density (per km of main), and asset utilisation (water and wastewater volumes per km of main). Similarly, operating cost and capital cost will be expressed relative to the same output metrics, and capital expenditure expressed as a ratio of relevant metrics.

3.1 Descriptive Information

Urban water businesses operate in varying environments often with substantial differences in network size, types of water sources, number and type of customers, levels of water demand and wastewater collection per customer. Table 3.1 presents data for some key characteristics of urban water utilities in the period 2018 to 2020.

Table 3.1: Descriptive Information on Water Utilities (average 2018 to 2020)

Utility	*Customers ('000)*	*Water supplied (ML)*	*Wastewater collected (ML)*	*Water mains (km)*	*Sewerage mains. (km)*	*Reservoir volume (GL)*
1 Icon Water	179	54,205	33,854	3,335	3,358	164,200
2 Central Coast	138	31,661	31,121	2,229	2,591	201,080
3 Hunter Water	255	74,128	63,755	5,119	5,227	189,687
4 Sydney Water	2,018	567,482	505,335	23,054	26,127	0
5 Albury	25	10,035	4,388	622	571	0
6 Clarence Valley	23	6,009	2,674	1,345	403	0
7 Coffs Harbour	28	7,663	6,143	722	650	32,630
8 Eurobodalla	20	3,900	3,048	887	556	4,900
9 MidCoast	40	10,305	6,319	1,377	1,134	0
10 Port Macquarie	31	6,967	7,293	840	913	12,500
11 Queanbeyan-Palerang	24	5,494	4,390	422	435	0
12 Riverina Water	32	16,700	5,445	1,744	691	0
13 Shoalhaven	49	17,073	7,988	1,582	1,244	14,070
14 Tamworth	23	17,191	6,306	671	584	5,700
15 Tweed	33	10,086	7,545	720	717	16,000
16 Wingecarribee	20	6,055	3,733	691	605	3,310
17 Ballina	16	4,329	5,222	381	354	0
18 Bathurst	17	6,520	4,198	446	443	32,500
19 Bega Valley	14	4,136	1,958	526	415	3,940
20 Byron	11	3,819	3,862	256	289	0
21 Essential Energy	11	5,579	1,243	382	246	0
22 Goulburn Mulwaree	12	4,246	2,002	305	298	13,550
23 Kempsey	13	4,116	2,057	581	273	2,500

Utility	*Customers ('000)*	*Water supplied (ML)*	*Wastewater collected (ML)*	*Water mains (km)*	*Sewerage mains. (km)*	*Reservoir volume (GL)*
24 Lismore	15	3,353	3,126	347	373	0
25 Orange	18	7,506	3,462	637	477	22,760
26 P&W (Darwin)	61	37,680	18,665	1,477	840	265,000
27 P&W (Alice Springs)	13	8,407	2,586	378	226	0
28 Gold Coast	265	71,448	54,141	3,486	3,435	0
29 Logan	120	26,846	20,298	2,255	2,233	0
30 Unitywater	329	67,350	58,447	6,235	5,900	0
31 Urban Utilities	626	158,573	120,834	9,475	9,677	0
32 Cairns	74	26,304	20,890	2,221	1,307	45,460
33 Toowoomba	63	15,878	7,674	1,785	1,339	135,072
34 Townsville	86	47,050	17,571	2,647	1,357	11,800
35 Fraser Coast	38	15,311	6,279	1,186	760	28,400
36 Mackay	46	17,364	8,623	1,225	968	1,486
37 Rockhampton	33	23,182	6,164	864	742	84,963
38 Gympie	13	3,848	2,691	450	423	0
39 SA Water	793	234,307	121,180	27,456	9,032	230,825
40 TasWater	210	68,196	51,046	6,396	4,781	6,742
41 Barwon Water	162	44,027	32,387	4,329	2,686	77,704
42 City West Water	474	106,952	93,970	5,358	4,482	0
43 South East Water	778	150,130	128,214	9,563	9,696	0
44 Yarra Valley	821	146,745	139,209	10,584	9,817	0
45 Central Gippsland	71	17,582	28,411	2,152	1,754	30,870
46 Central Highlands	71	16,419	11,341	2,574	1,454	83,969
47 Coliban Water	76	21,892	14,763	2,289	1,984	80,900
48 Goulburn Valley	59	25,500	14,173	1,869	1,323	1,950
49 North East Water	52	17,773	9,528	1,642	1,222	1,777
50 Western Water	68	18,763	11,222	2,270	1,410	1,240
51 East Gippsland	24	5,541	3,496	974	717	0
52 GWMWater	32	11,345	3,783	1,344	696	457,020
53 Lower Murray	34	20,490	6,414	970	658	0
54 South Gippsland	21	4,746	4,219	734	506	8,014
55 Wannon Water	43	13,667	11,065	1,977	945	760
56 Westernport Water	17	2,174	1,608	458	377	2,263
57 WC (Perth)	865	262,012	135,525	14,737	12,533	445,379
58 WC (Mandurah)	50	11,321	5,717	904	841	0
59 Aqwest-Bunbury	18	5,489	4,130	393	388	0
60 Busselton	14	5,013	1,775	334	318	0
61 WC (Albany)	17	5,829	2,058	490	328	0
62 WC (Australind)	13	4,731	698	338	248	0
63 WC (Geraldton	19	7,397	1,661	654	318	0
64 WC (Kalgoorlie)	15	7,780	2,221	366	211	0

The different operating environments of water utilities result in different customer and demand density characteristics which can have an important influence on cost of supply per customer or per megalitre (ML). This is especially important given that most costs incurred by water and wastewater utilities are largely fixed. Table 3.2, and the following charts—Figure 3.1 to 3.5—show the distribution in the sample of the following density measures, again using the average for 2018 to 2020.

- Customer density—customers per kilometre (km) of water and sewerage mains (Figure 3.1)
- Water density—water supplied per water customer in kilolitres per annum (kla) (Figure 3.2)
- Wastewater density— wastewater collected per sewerage customer in kla (Figure 3.3)
- Water network utilisation—ML per km (Figure 3.4)
- Sewerage network utilisation—ML per km (Figure 3.5).

Table 3.2: Density Measures of Water Utilities (average 2018 to 2020)

Utility	*Customer density (cust/km)*	*Water density (kla/cust)*	*Wastewater density (kla/cust)*	*Water network utilisation (ML/km)*	*Sewerage network utilisation (ML/km)*
1 Icon Water	26.7	303.5	189.5	16.3	10.1
2 Central Coast	28.6	230.2	226.1	14.2	12.0
3 Hunter Water	24.6	291.2	250.5	14.5	12.2
4 Sydney Water	41.0	281.4	250.3	24.6	19.3
5 Albury	21.2	397.4	173.7	16.1	7.7
6 Clarence Valley	13.0	267.2	118.0	4.5	6.6
7 Coffs Harbour	20.2	277.8	221.7	10.6	9.4
8 Eurobodalla	14.0	193.4	151.2	4.4	5.5
9 MidCoast	15.9	257.6	158.0	7.5	5.6
10 Port Macquarie	17.7	225.7	236.1	8.3	8.1
11 Queanbeyan-Palerang	27.4	234.6	187.9	13.0	10.1
12 Riverina Water	13.0	529.0	172.5	9.6	7.9
13 Shoalhaven	17.4	346.8	162.2	10.8	6.4
14 Tamworth	18.3	749.3	274.7	25.6	10.8
15 Tweed	23.1	303.5	227.0	14.0	10.5
16 Wingecarribee	15.7	297.5	183.2	8.8	6.2
17 Ballina	21.8	269.9	326.3	11.4	14.8
18 Bathurst	19.2	381.6	245.5	14.6	9.5
19 Bega Valley	15.3	287.2	136.0	7.9	4.7
20 Byron	19.8	355.2	359.3	15.0	13.4
21 Essential Energy	16.7	531.3	118.4	14.6	5.1
22 Goulburn Mulwaree	19.8	355.7	167.4	13.9	6.7
23 Kempsey	15.4	313.9	156.4	7.1	7.5

Utility	*Customer density (cust/km)*	*Water density (kla/cust)*	*Wastewater density (kla/cust)*	*Water network utilisation (ML/km)*	*Sewerage network utilisation (ML/km)*
24 Lismore	20.6	225.8	210.3	9.7	8.4
25 Orange	16.6	406.9	187.6	11.8	7.3
26 P&W (Darwin)	26.2	620.3	307.3	25.5	22.2
27 P&W (Alice Springs)	20.7	672.5	206.9	22.2	11.4
28 Gold Coast	38.3	269.6	204.3	20.5	15.8
29 Logan	26.7	223.5	169.9	11.9	9.1
30 Unitywater	27.1	204.8	177.8	10.8	9.9
31 Urban Utilities	32.7	253.1	193.0	16.7	12.5
32 Cairns	20.8	357.7	284.3	11.8	16.0
33 Toowoomba	20.2	251.3	121.5	8.9	5.7
34 Townsville	21.5	546.9	204.3	17.8	12.9
35 Fraser Coast	19.6	402.1	165.2	12.9	8.3
36 Mackay	21.1	374.9	186.2	14.2	8.9
37 Rockhampton	20.3	710.0	188.8	26.8	8.3
38 Gympie	15.4	285.6	200.4	8.5	6.4
39 SA Water	21.7	295.5	152.9	8.5	13.4
40 TasWater	18.7	325.4	243.6	10.7	10.7
41 Barwon Water	23.1	272.9	200.1	10.2	12.1
42 City West Water	48.1	225.9	198.5	20.0	21.0
43 South East Water	40.4	193.1	164.8	15.7	13.2
44 Yarra Valley	40.2	178.8	169.4	13.9	14.2
45 Central Gippsland	18.1	248.1	145.9	8.2	5.9
46 Central Highlands	17.6	231.6	159.8	6.4	7.8
47 Coliban Water	17.9	286.4	193.0	9.6	7.4
48 Goulburn Valley	18.6	428.7	238.2	13.6	10.7
49 North East Water	18.1	342.4	183.6	10.8	7.8
50 Western Water	18.6	274.8	163.9	8.3	8.0
51 East Gippsland	14.3	230.2	145.1	5.7	4.9
52 GWMWater	15.6	356.8	118.9	8.5	5.4
53 Lower Murray	20.9	600.6	188.0	21.1	9.7
54 South Gippsland	16.7	229.6	203.9	6.5	8.3
55 Wannon Water	14.8	315.5	255.4	6.9	11.7
56 Westernport Water	20.3	128.6	95.1	4.8	4.3
57 WC (Perth)	31.7	303.0	156.7	17.8	10.8
58 WC (Mandurah)	28.4	228.5	115.4	12.5	6.8
59 Aqwest-Bunbury	23.5	299.2	225.2	14.0	10.7
60 Busselton	21.0	367.3	130.0	15.0	5.6
61 WC (Albany)	20.6	346.3	122.3	11.9	6.3
62 WC (Australind)	22.3	362.5	53.4	14.0	2.8
63 WC (Geraldton	19.9	382.1	85.8	11.3	5.2
64 WC (Kalgoorlie)	25.3	532.2	151.9	21.2	10.5

Figure 3.1 shows that Icon Water has above-average customer density, which is to be expected since it serves a major capital city, whereas many of the utilities in the sample serve rural areas.

The utilities with highest density are those that serve state capital cities such as Sydney, Brisbane, Melbourne and Perth. The lowest density utilities serve rural areas in New South Wales, Victoria and Queensland.

Figure 3.1: Customers per Km Mains (average 2018 to 2020)

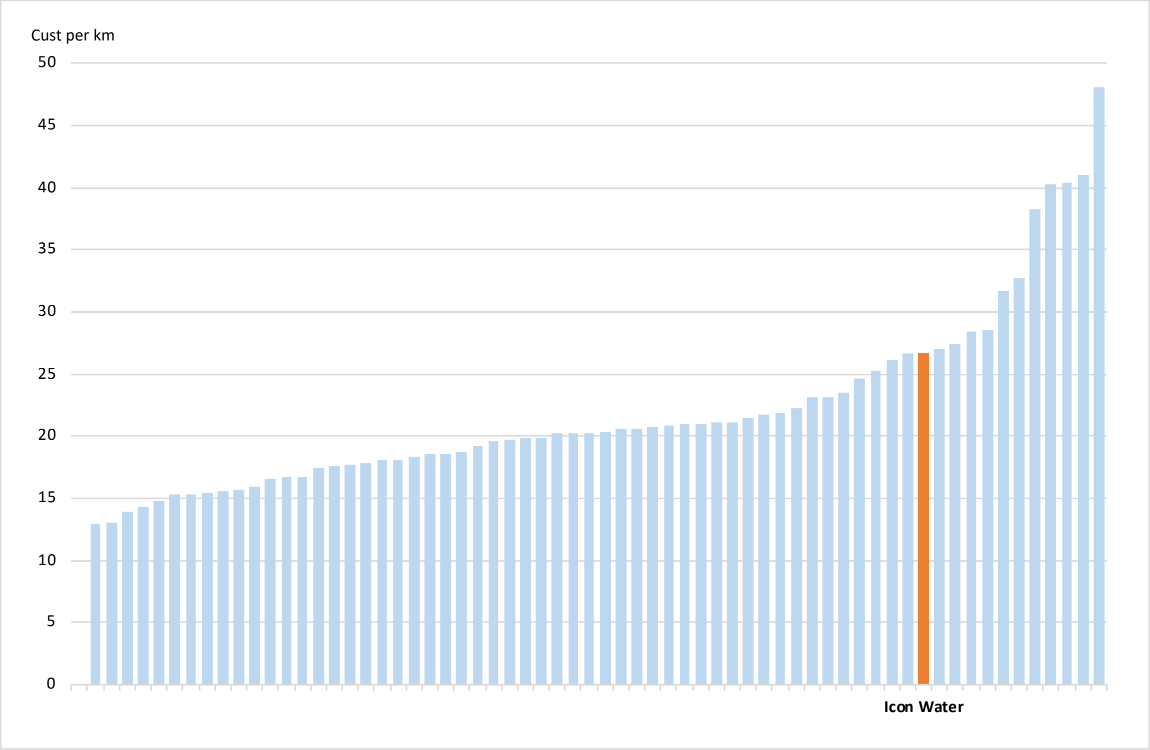


Figure 3.2 shows water supplied per customer on average 2018 to 2020, and shows that Icon Water is close to the median of the sample, with 304 kla per customer (but is below the arithmetic mean of 335 kla). Utilities with the highest water consumption levels tend to be in hot climate areas, such as the Northern Territory, northern Queensland, western NSW, inland Western Australia and north-western Victoria.

The average quantity of wastewater collected per household, for each utility in the sample, is shown on Figure 3.3. Icon Water is close to the average, with 190 kla per customer. The quantity of wastewater, in proportion to the water supplied tends to be lower in the hotter climate areas where a substantial amount of residential water is for use in gardens, and in areas where sewerage penetration is comparatively lower. Figure 3.4 shows water network utilisation measured in ML per km of water mains. Icon Water's average water network utilisation of 16.3 ML per km, 2018 to 2020, is above the average of 12.9 for all utilities in the sample. Figure 3.5 shows sewerage network utilisation measured in ML per km of sewerage mains. Icon Water's average sewerage network utilisation over 2018 to 2020 was 10.1 ML per km, is similar to the average of 9.7 for all utilities in the sample.

Figure 3.2: Water Supplied per Customer (average 2018 to 2020)

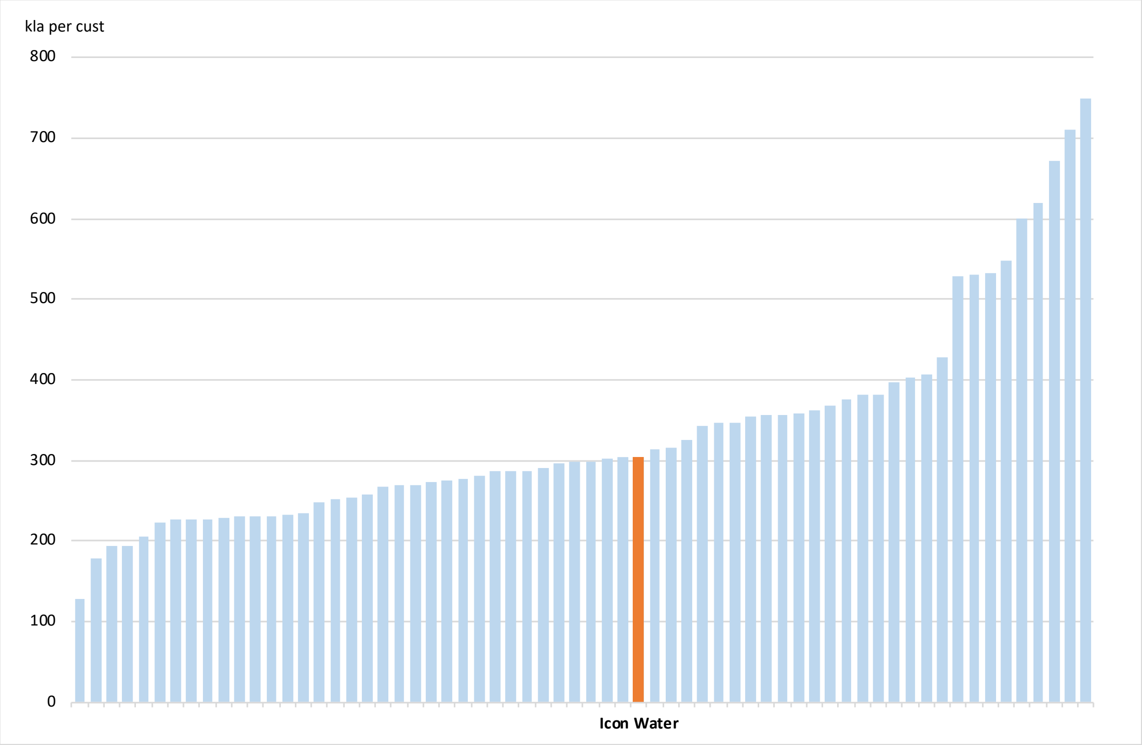


Figure 3.3: Wastewater Collected per Customer (average 2018 to 2020)

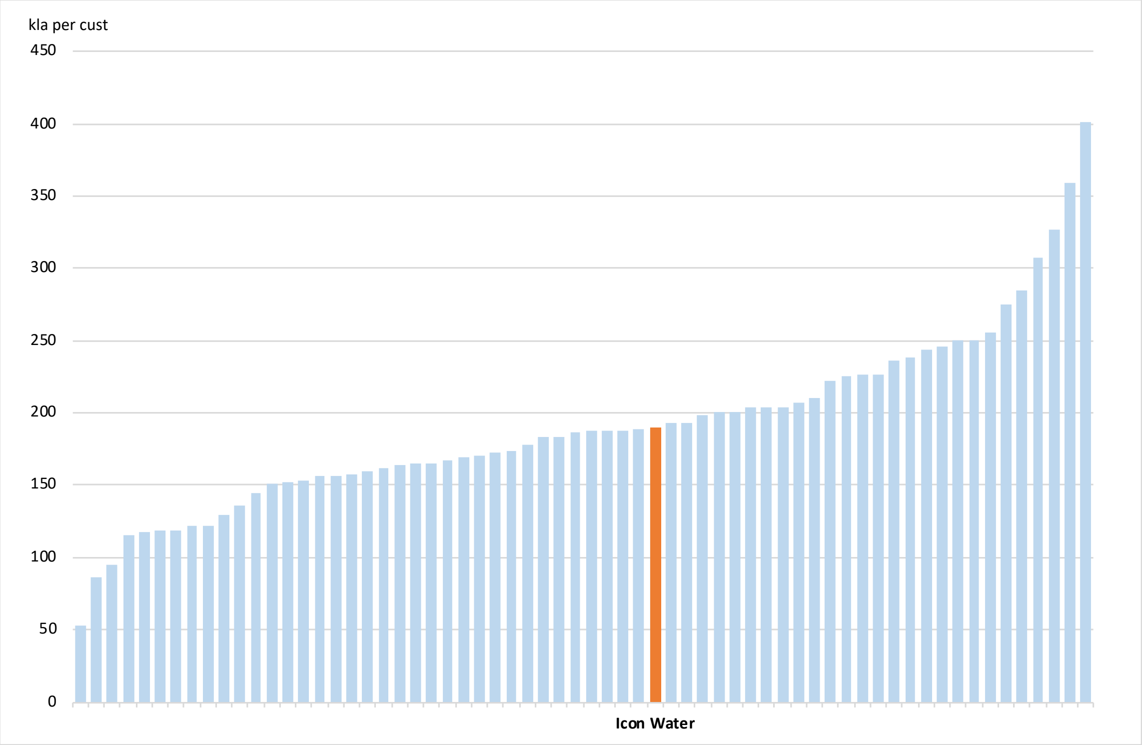


Figure 3.4: Water Network Utilisation (average 2018 to 2020)

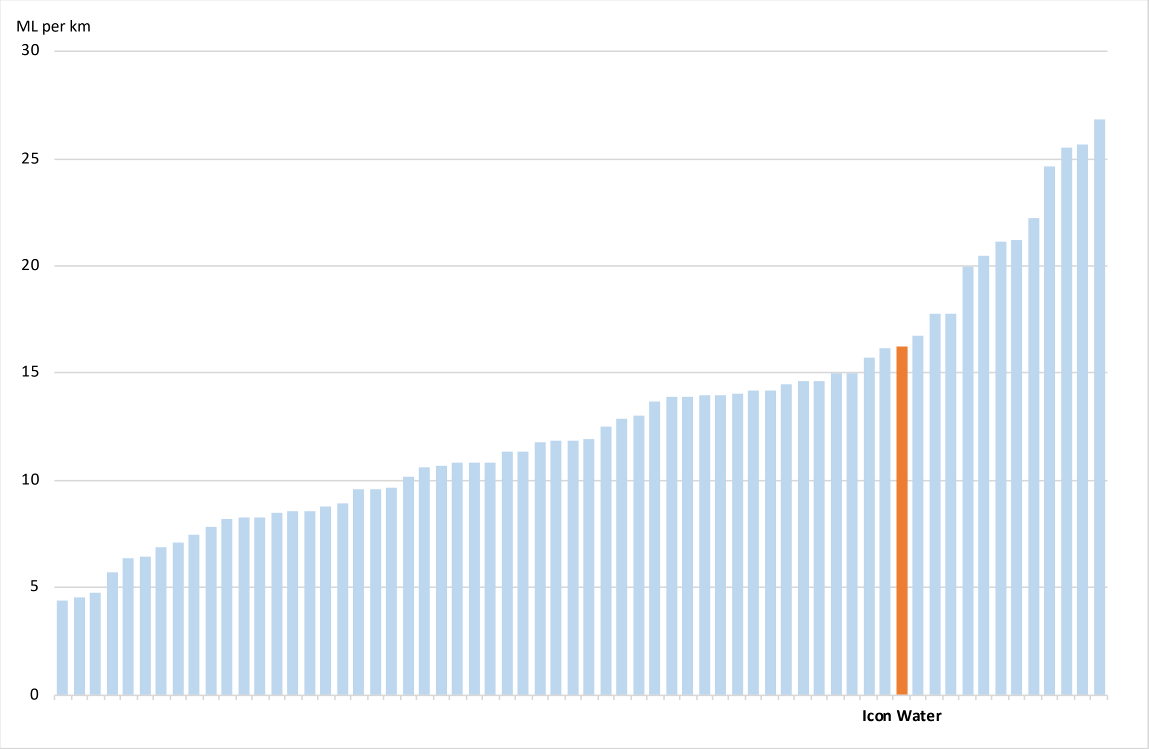
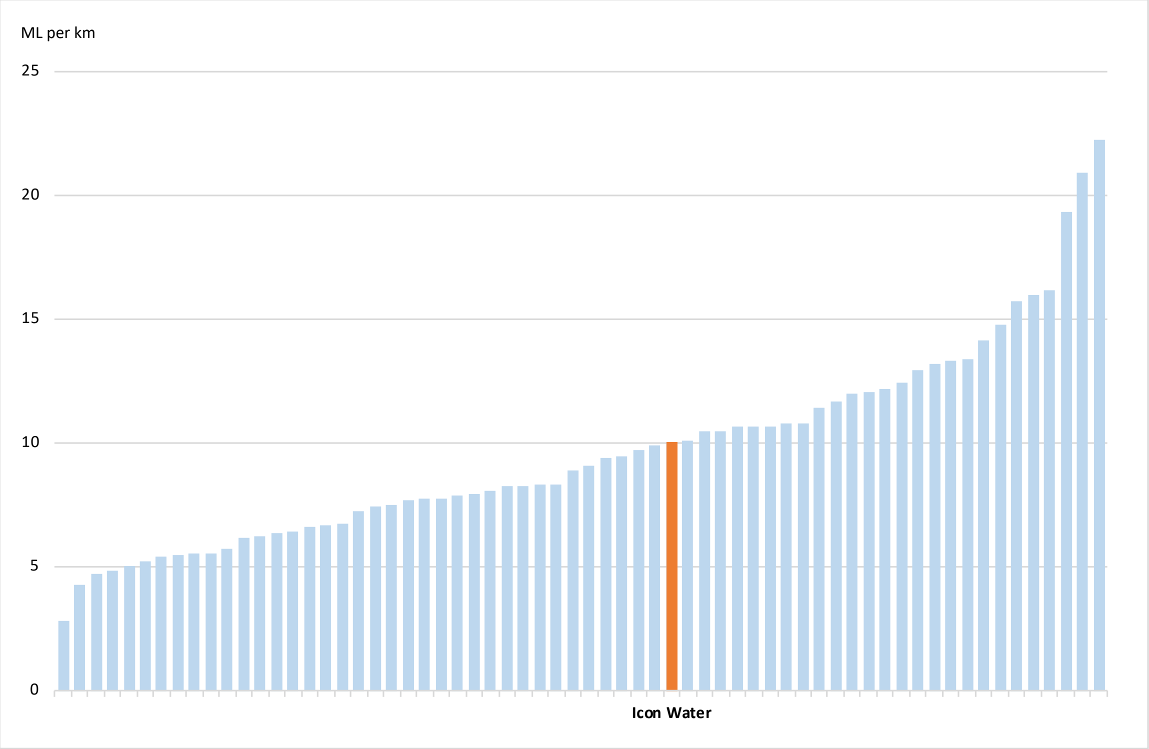


Figure 3.5: Sewerage Network Utilisation (average 2018 to 2020)

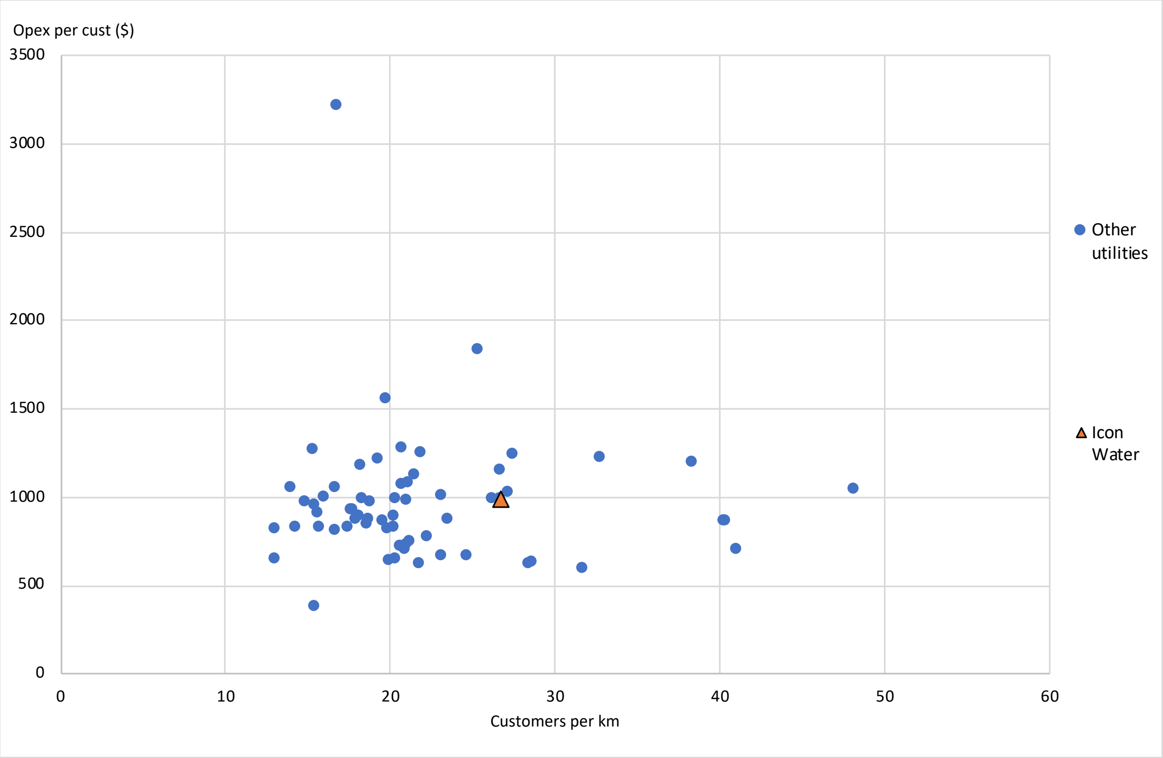


3.2 Partial Performance Indicators

Figure 3.6 shows utility operating cost (in 2020 dollars) in proportion to customer numbers plotted against customer density. All data are averages over the period 2018 to 2020. The scatter of points show that, aside from a few outliers, there is no systematic relationship between customer density and opex per customer. Icon Water's average opex per customer of $989 per year, is similar to the average for the sample as a whole ($969). It is also around the average for utilities of similar customer density. For the nine utilities with customer density in the range 25 and 29,[11] the average opex per customer is $1,019, and their median is $997.

Figure 3.7 makes a similar comparison of operating cost per km of mains against customer density. Again, the data are averages over the period 2018 to 2020, and the dollar values are in 2020 prices. Since opex per customer tends to be unrelated to customer density (as shown in Figure 3.6) opex per km tends to increase with customer density, which can be seen in Figure 3.7. Icon Water has opex per km of $26.4, which is close to the average for utilities of similar customer density such as Power & Water Darwin, Logan, and Unity Water. For example, taking the nine utilities with customer density in the range 25 and 29, the average opex per km is $27.1, and the median is $26.4.

Figure 3.6: Water and Wastewater Operating Cost per Customer (average 2018 to 2020)



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[11] Icon Water's average customer density from 2018 to 2020 of 27 per km, plus or minus 2 customers per km.

Figure 3.7: Water and Wastewater Operating Cost per km Mains (average 2018 to 2020)

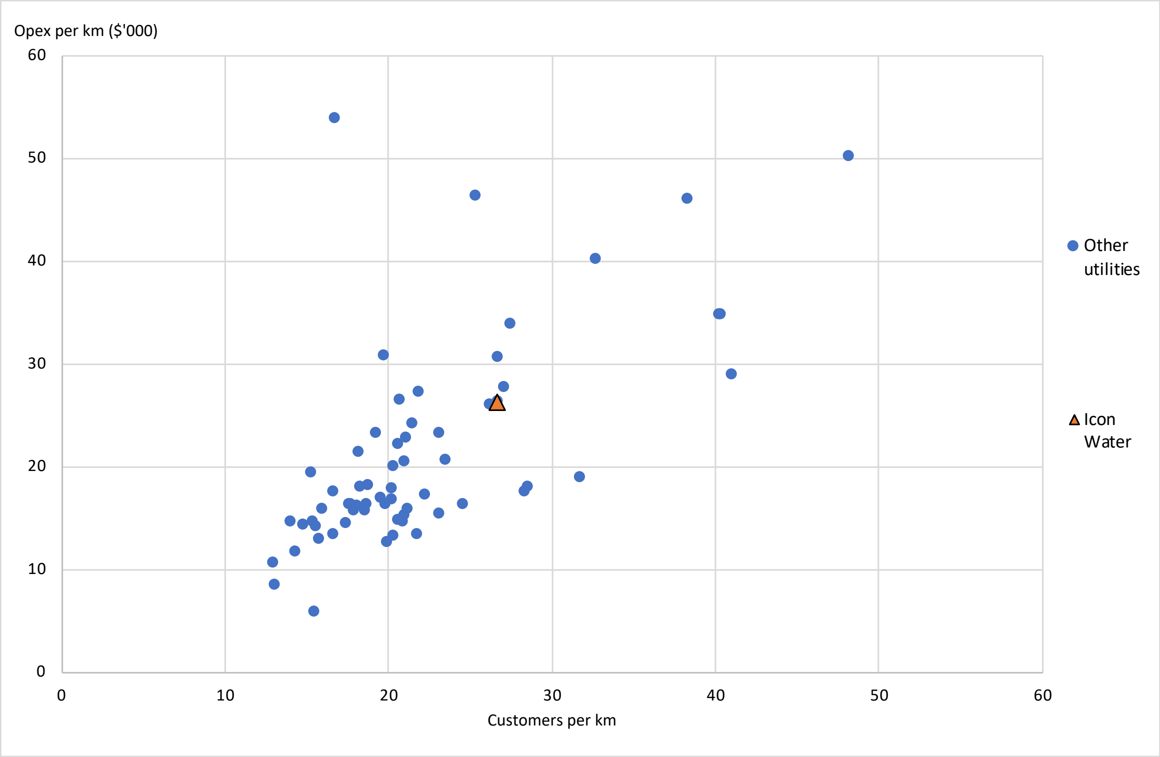


Figure 3.8 and 3.9 show respectively, asset cost per customer plotted against customer density and asset cost per km plotted against customer density. Figure 3.8 shows that asset cost per customer tends to decrease as customer density increases. Icon Water's average asset cost per customer from 2018 to 2020 was $1,542, which was higher than the average asset cost per customer for all utilities of $1,353. There are a number of outliers which complicate the interpretation, but Icon Water appears to have slightly above average asset cost per customer for utilities of similar customer density. For example, taking the nine utilities with customer density in the range 25 and 29, the average asset cost per customer is $1,493, and the median is $1,361. Icon Water's higher average asset cost per customer may be related to the comparatively recent investment in the Enlarged Cotter Dam expansion.

In figure 3.9, asset cost per km is compared to customer density. Icon Water's asset cost per km ($41.1), is above the sample average asset cost ($28.5). This is partly explained by the fact that asset cost per km appears to generally increase with customer density (although this interpretation is complicated by outliers). When compared to comparator utilities with similar customer density, Icon Water's asset cost per km appears to be only slightly above average. For example, the nine utilities with customer density in the range 25 and 29 have average asset cost per km of $39.4; and a median of $38.1.

Figure 3.8: Water and Wastewater Asset Cost per Customer (average 2018 to 2020)

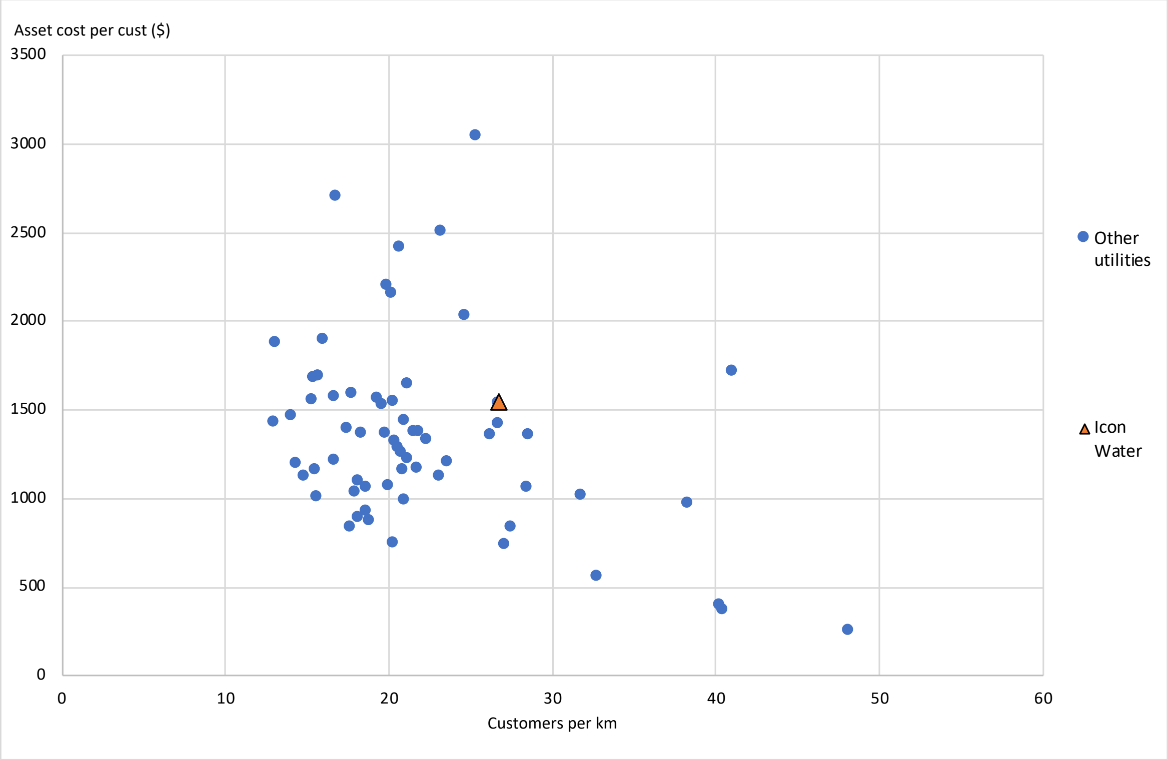
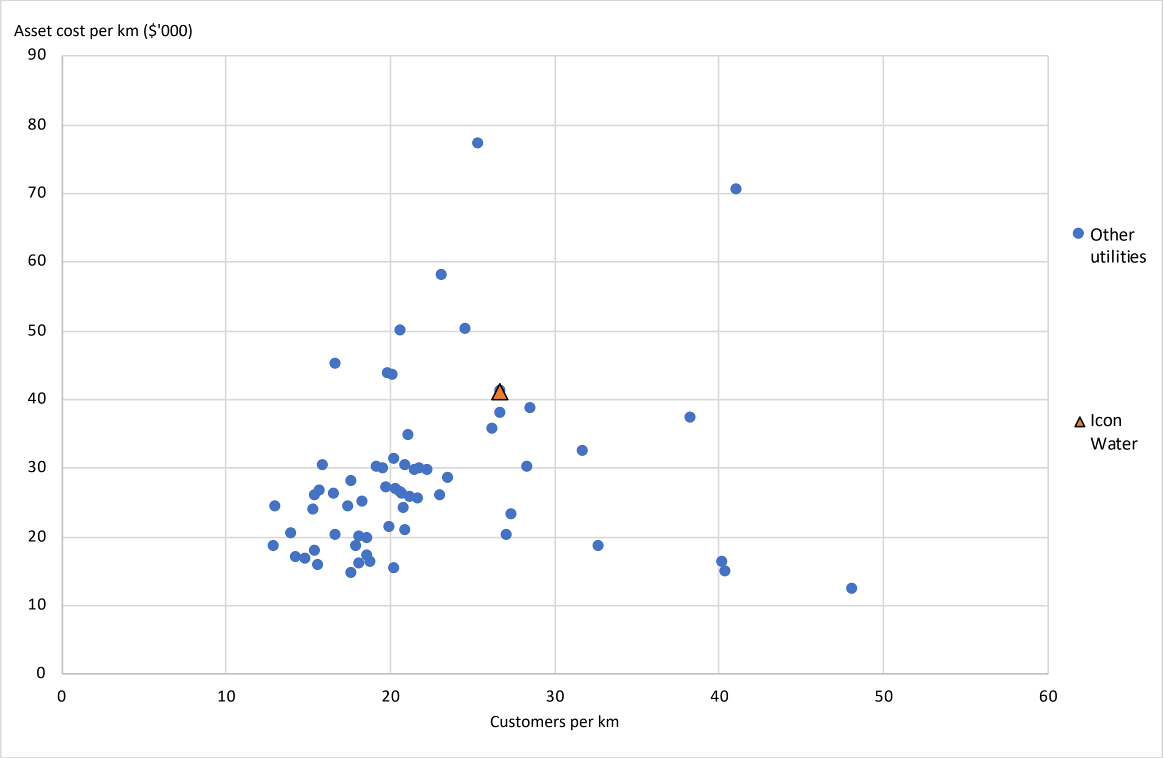


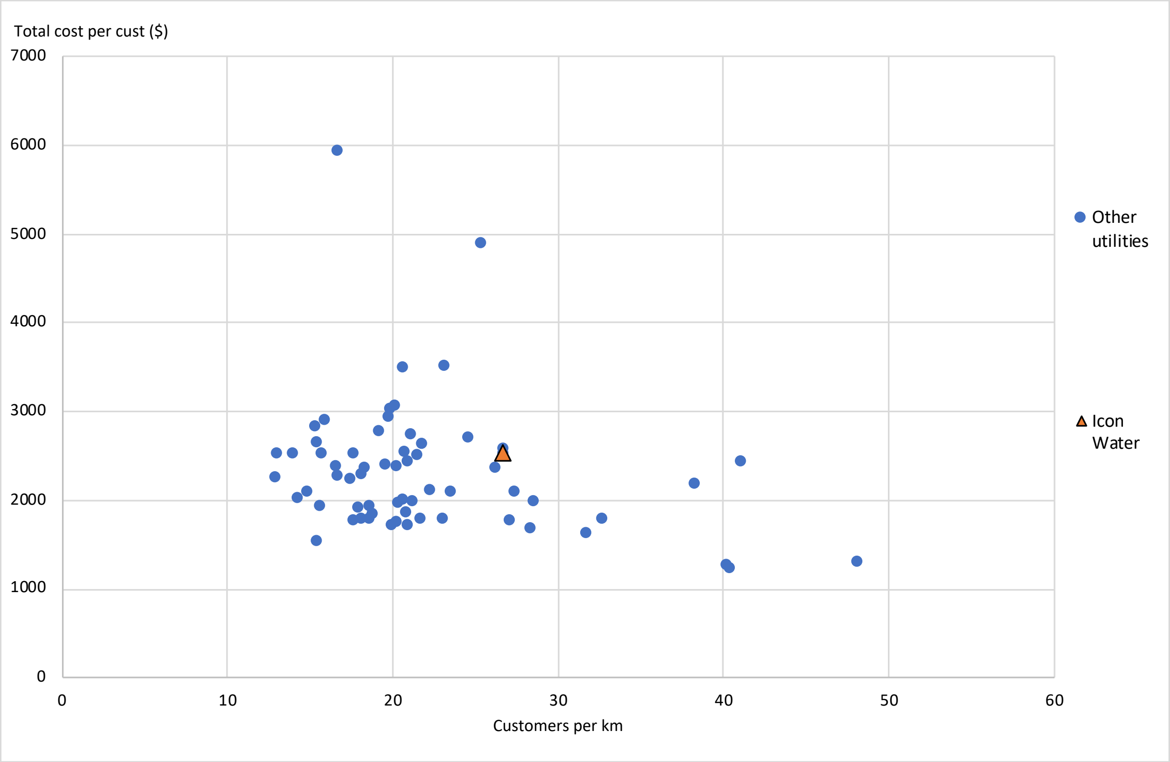
Figure 3.9: Water and Wastewater Asset Cost per km Mains (average 2018 to 2020)



Figures 3.10 and 3.11 show comparison of total cost per customer and per km plotted against customer density. As previously noted, opex per customer tends *not* to decrease with customer density, whereas asset cost per customer does tend to decrease with greater customer density. Hence, for total cost per customer there is a small tendency to decline with customer density.

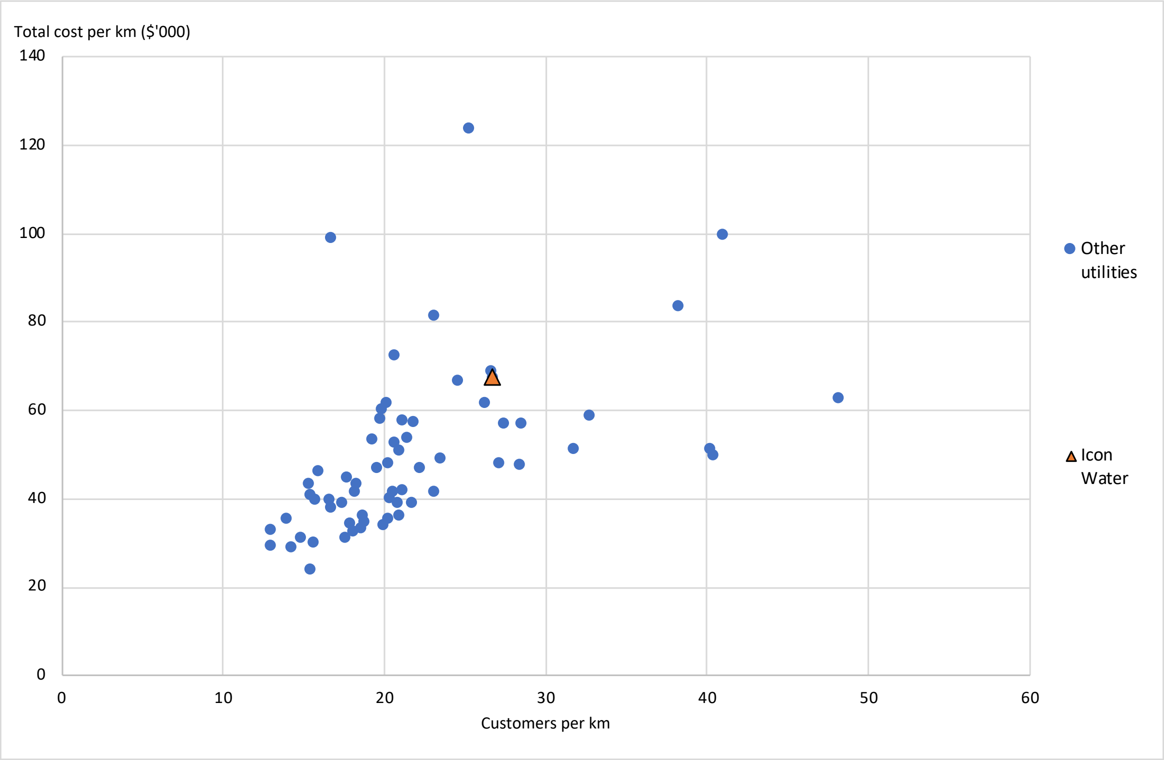
Icon Water's total cost per customer from 2018 to 2020 averaged $2,531, which was slightly higher than the average for all utilities of $2,322. Although outliers complicate inference, Icon Water appears to have around average total cost per customer for utilities of similar customer density. For example, if we take the nine utilities with customer density in the range 25 and 29, the average total cost is $2,512 per customer, and the median is $2,358.

Figure 3.10: Total Water and Wastewater Cost per Customer (average 2018 to 2020)



Lastly, in figure 3.11, total cost per km is compared to customer density. Icon Water's total cost per km was $67.5 on average from 2018 to 2020, which was above the average of $49.7 for all utilities in the sample. Figure 3.11 shows a clear tendency for total cost per km to increase with customer density. Since Icon Water has above-average customer density, this partly explains the above-average total cost per km. When compared to comparator utilities with similar customer density, Icon Water's total cost per km appears close to the average. For example, the nine utilities with customer density in the range 25 and 29 the total cost per km is $66.5 on average, which is similar to that of Icon Water. The median for this same group of nine utilities with similar customer density is $61.8, which is slightly below that of Icon Water.

Figure 3.11: Total Water and Wastewater Cost per Km Mains (average 2018 to 2020)



4 Econometric Cost Functions

This section presents the results of estimating the variable cost function for urban water utilities. Both are estimated using stochastic frontier analysis (SFA). In economic theory, total cost represents the minimum cost to produce a given set outputs with given input prices. It is suitable to estimate this function using a frontier method which can estimate the minimum cost envelope together with firm-specific cost inefficiencies which cause their costs to exceed the lower bound. The variable cost function assumes that, in the short-run, capital inputs and quasi-fixed factors of production, and are included as explanatory variables in addition to outputs and input prices. Given the length of the sample period available is much shorter than the average asset life of 50 years or more, the variable cost, or short-run cost function is the most suitable form of cost function to use for this study. Note that total cost function estimates are shown in Appendix B, which are used to derive output weights for Multilateral TFP index analysis in section 5.

4.1 Methodology

In SFA, it is convenient to choose a functional form that is linear in logs (Timothy Coelli et al. 2005, 264), and in this preliminary analysis, the Cobb-Douglas (CD) functional form for the cost function is used because it is particularly simple. These cost functions include outputs as cost drivers. Other variables are included, called operating environment factors (OEFs), which reflect exogenous differences between the operating contexts of different water utilities, including different types of water sources, differences in the customer base, the topography, and spatial characteristics of the areas served etc.

A cost function has the property that it is linearly homogeneous in input prices. In the variable cost function, there is only one input price (for non-capital inputs) and nominal opex is divided by that input price to derive the dependent variable—real opex inputs, or real variable cost.

For a panel data model with observations on firms (subscript *i*) and periods (subscript *t*), the CD real variable cost function can be written as:

$$\ln VC_{it} = \beta_0 + \beta_1 \ln x_{k(i,t)} + \sum_{m=1}^{M} \phi_m \ln q_{m(i,t)} + \sum_{n=1}^{N} \gamma_n z_{n(i,t)} + \lambda t + u_{(i,t)} + v_{(i,t)} \qquad (4.1)$$

where $x_{k(i,t)}$ is the quantity of the fixed input (capital); $q_{m(i,t)}$ is the quantity of output *m* produced by firm *i* in period *t*; $z_{n(i,t)}$ is the amount of OEF *n* in period *t* at utility *i*; and *t* is the year (where 2006 = 0, 2007 = 1 and 2008 = 2 etc). Note that OEFs may or may not be in log form. However, total cost and the outputs are all in logs. There are two stochastic terms:

- $u_{(i,t)}$ is a one-sided stochastic term which is strictly positive and assumed to have a half normal distribution. In the simplest case of time-invariant inefficiency, *u* only varies between firms but does not change over time. In the time-varying decay specification u varies between firms and also changes at the same constant annual rate for all firms. Both approaches are used here.

- $v_{(i,t)}$ is a normally distributed independent random disturbance.

4.2 Variables

In the variable cost models, the dependent variable is the index of the quantity of opex inputs, as defined in section 2.3.2. In these models fixed capital input is an explanatory variable, and models are presented using each of the two alternative measures of capital input. The variables used in the cost functions are as follows.

(1) *Outputs*:

- q_1: customer numbers;
- q_2: water supplied (ML) including bulk water exports to other utilities; and
- q_3: wastewater collected (ML).

(2) *Fixed input (variable cost function only)*: There are two alternative measures of capital input, the index of physical capital measures and the real valued financial capital measure. The capital input is denoted x_k.

(3) *OEFs*:

- z_1: share of residential customers in total water supplied to customers;
- z_2: share of trade waste in total wastewater collected;
- z_3: share of surface water in total water sourced;
- z_4: share of desalinated marine water in total water sourced;
- z_5: share of recycled water in total water supplied to customers;
- z_6: share of flats in total dwellings (cross-sectional value only).
- z_7: log customer minutes off supply;
- z_8: log infrastructure leakage index (ILI), an indicator of asset quality;
- z_9: log net water supply greenhouse emissions per ML of water supplied, a proxy for energy use per ML;
- z_{10}: log average rainfall;
- z_{11}: log, average maximum temperature;
- z_{12}: dwelling density measured by the number of dwellings per square km in the supply area (cross-sectional value only).

- z_{13}: indicator variable which takes the value of 1 if the utility owns one or more dams and 0 otherwise;
- z_{14}: adjustment factor for temporary water restrictions;
- z_{15}: log index of drinking water quality;
- z_{16}: log index of quality/standard of wastewater treatment.

4.3 Variable Cost Function Results

Table 4.1 shows the econometric results of estimating the SFA variable cost function for the period from 2006 to 2020. The first model in table 4.1 uses the real financial asset value as the measure of capital inputs, while the second model uses the index of physical measures of capital inputs. In both models the coefficient on capital stock is positive, but not significantly different from zero.

Table 4.1: Estimated SFA Variable Cost Function 2006–2020

	Real financial capital measure		*Physical capital measure*	
	coef	*t-stat*	*coef*	*t-stat*
$\ln q_1$	0.5370	(7.57)	0.5307	(7.79)
$\ln q_2$	0.0982	(2.01)	0.1046	(2.11)
$\ln q_3$	0.1175	(2.55)	0.1293	(2.86)
$\ln x_k$	0.0638	(1.04)	0.0558	(1.53)
z_1	0.4744	(3.95)	0.4856	(4.01)
z_2	0.1775	(3.09)	0.1756	(3.00)
z_3	-0.0833	(-2.26)	-0.1004	(-2.76)
z_4	0.2068	(1.12)	0.1716	(0.92)
z_5	-0.0002	(-1.00)	-0.0002	(-1.12)
z_6	1.5419	(3.22)	1.7861	(3.91)
z_7	-0.0021	(-0.17)	-0.0018	(-0.15)
z_8	-0.0098	(-0.76)	-0.0100	(-0.77)
z_9	0.0580	(2.04)	0.0650	(2.40)
z_{10}	-0.0283	(-1.32)	-0.0264	(-1.22)
z_{11}	-0.0006	(0.00)	0.0010	(0.01)
z_{12}	0.2122	(3.67)	0.2401	(3.85)
z_{13}	0.3923	(6.47)	0.4177	(6.60)
z_{14}	-0.1539	(-1.7)	-0.1730	(-1.92)
z_{15}	0.2643	(3.86)	0.2578	(3.77)
z_{16}	0.1429	(2.11)	0.1569	(2.30)
t	0.0210	(7.55)	0.0205	(7.82)
cons.	-2.0775	(-3.2)	-2.2849	(-3.31)
mu	0.0000		0.0000	
eta	0.0319	(4.93)	0.0287	(5.53)
sigma_u	0.3500		0.3668	
sigma_v	0.1500		0.1496	
N	867		867	
BIC	–436.92		–438.21	

Table 4.2 shows the short-run cost efficiency scores associated with the variable cost function models for Icon Water and all of the other water utilities averaged by state and territory. Both models indicate that Icon Water's opex cost efficiency is close to the industry average measured as the average for all states.

We regard the average of the state and territory average cost efficiency scores to be a suitable basis for comparison because some states, such as NSW, have a large number of mostly small water businesses, whilst some of the most important comparators such as TAS, SA and NT have only one or two water businesses. Individual utilities have large variations in scores due to unobserved heterogeneity which make inference less reliable.

Table 4.2: Variable Cost Efficiency Scores, 2006–2020

	Real financial capital measure			*Physical capital measure*		
	Estimate	*Lower bound*	*Upper bound*	*Estimate*	*Lower bound*	*Upper bound*
Icon Water	0.67	0.63	0.71	0.65	0.61	0.69
NSW avg.	0.77	0.73	0.83	0.76	0.72	0.81
NT avg.	0.58	0.55	0.62	0.59	0.55	0.62
QLD avg.	0.79	0.74	0.88	0.78	0.73	0.87
SA avg.	0.68	0.61	0.75	0.67	0.61	0.75
TAS avg.	0.52	0.46	0.59	0.54	0.48	0.62
VIC avg.	0.72	0.68	0.77	0.75	0.70	0.80
WA avg.	0.64	0.59	0.67	0.62	0.57	0.65
Average	0.67	0.63	0.71	0.67	0.61	0.69
Std. dev.	0.09			0.09		
67th percentile	0.71			0.72		
Icon % of avg.	99.8			96.7		

Table 4.2 shows that Icon Water's efficiency score is close to the industry average. Also shown is the 67th percentile. As there are significant limitations due to lack of data quality and availability (discussed in section 2.5), Quantonomics considers that the industry average is a reasonable comparator point for Icon Water when assessing efficiency levels. A higher level of efficiency is suitable for the medium-term efficiency target, and we have shown the 67th percentile. This is the threshold for the upper third of the efficiency scores of the states and territories.

4.4 Trends in productivity

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

$$\dot{VC} = \varepsilon_{x_k}.\dot{x}_k + \sum_{m=1}^{M} \varepsilon_{q_m}.\dot{q}_m + \sum_{n=1}^{N} \gamma_n \frac{z_n}{\partial t} + \lambda + \frac{\partial u}{\partial t} \qquad (4.2)$$

where the following changes in notation are used to emphasise that the coefficients of log variables are elasticities: $\varepsilon_{x_k} = \beta_1$ (from 4.1) is the elasticity of variable cost with respect to the capital input; and $\varepsilon_{q_m} = \phi_m$ (from 4.1) is the elasticity of variable cost with respect to the output m. Next define the rate of change in an aggregate output index using elasticities as weights. Table 4.3 shows the calculation of these weights from the elasticities of cost with respect to the outputs.

$$\dot{Q} = \sum_{m=1}^{M} \left(\frac{\varepsilon_{q_m}}{\sum_{m=1}^{M} \varepsilon_{q_m}} \right) \dot{q}_m \qquad (4.3)$$

The sum of the elasticities of cost with respect to the outputs (ie, the numerator of the term in brackets in equation (4.3)) is usually called the elasticity of scale: $\varepsilon_Q \equiv \sum_{m=1}^{M} \varepsilon_{q_m}$.[12] Recall that $\dot{VC}$ represents the rate of change in real opex inputs and hence the rate of partial factor productivity growth for non-capital inputs is: $\dot{PFP_o} = \dot{Q} - \dot{VC}$. Expanding this using (4.2) and (4.3), and the definition of the elasticity of scale, gives:

$$\dot{PFP_o} = (1 - \varepsilon_Q)\dot{Q} - \varepsilon_{x_k}.\dot{x}_k - \sum\nolimits_{n} \gamma_n \frac{z_n}{\partial t} - \left(\lambda + \frac{\partial u}{\partial t} \right) \qquad (4.4)$$

In Table 4.1, the coefficients on the outputs are elasticities of cost with respect to each output, which can be used with equation (4.4) for forecasting opex. Table 4.3 summarises the relevant elasticities, and the last column shows average elasticities.

Table 4.3: Variable Cost Function Output Elasticities

	Real financial capital measure		Physical capital measure		Average	
	Elasticity	*Weight*	*Elasticity*	*Weight*	*Elasticity*	*Weight*
q_1 (customers)	0.5370	71.3%	0.5307	69.4%	0.5339	70.4%
q_2 (water supplied)	0.0982	13.0%	0.1046	13.7%	0.1014	13.4%
q_3 (wastewater collected)	0.1175	15.6%	0.1293	16.9%	0.1234	16.3%
Total	0.7527	100.0%	0.7646	100.0%	0.7587	100.0%

Table 4.3 shows the output elasticities and weights that can be used as an input to forecasting water and wastewater operating expenditure output growth. In the time-varying inefficiency specification: $u_{it} = \exp\{-\eta(t - T_i)\}\, u_i$, where T_i is the last period of the *i*th panel, η (eta) is

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[12] Using this definition of elasticity of scale, in equation (4.2) the second term of the right-hand-side can be alternatively written as: $\sum_{m=1}^{M} \varepsilon_{q_m}.\dot{q}_m = \varepsilon_Q \dot{Q}$.

the decay parameter (shown n Table 4.1), and u_i is a stochastic (half-normal) variable which has a single variable for each utility. Hence:

$$\frac{\partial u}{\partial t} = -\eta \bar{u} \tag{4.5}$$

where $\bar{u}$ is the mean value of u_i (*after* truncation at zero).

Using coefficients from Table 4.2 and elasticities shown in Table 4.3, and noting that in the model with the real financial capital measure the mean inefficiency is: $\bar{u} = 0.2726$, and in the model using the physical capital measure $\bar{u} = 0.2840$, then applying equation (4.4):

- The *variable cost model with real financial capital measure* results in a 1.23 per cent per year underlying increase in variable cost, absent changes in the explanatory variables.
- The *variable cost model with physical capital measure* also shows a 1.23 per cent per year underlying increase in variable cost—the same estimate.

This underlying rate of change in variable cost is the net effect of changes in the efficiency frontier (ie, technical change) and changes in the average degree of inefficiency (so-called ‘catch-up’, although this could on average be a move away from the efficiency frontier). Although the time-varying inefficiency model purports to separate the effect of technical change and catch-up, in all likelihood we cannot rely on this separation, and can only rely on the estimated combined effect. The underlying increase in variable costs may be due to the combined effects of adverse movements in the OEFs, which shift the ability of efficient utilities to transform variable inputs into outputs with given capital stock; or to deterioration in efficiency, relative to the efficiency frontier, on average over all utilities in the sample over the sample period.

Equation (4.4) can be used to forecast the rate Opex PFP change over a forthcoming regulatory period, given forecasts for outputs and capital inputs, and forecasts or assumptions in relation to changes in the OEFs (Economic Insights 2015, 36–38).

5 Multilateral Total Factor Productivity Indexes

This section presents Multilateral Törnqvist TFP (MTFP) index measures for urban water utilities in Australia, showing results for Icon Water compared to average indexes for utilities in other States and Territories.

5.1 Methodology

MTFP indexes can be used to make comparisons of productivity levels and of productivity growth rates between urban water businesses. The rate of change in TFP is equal to the rate of change in the multilateral output index minus the rate of change in the multilateral input index. The rates of change in the output index, the input index, and the TFP index are given respectively by equations (5.1), (5.2) and (5.3):

$$\begin{aligned}\ln(Y_m/Y_n) &= \frac{1}{2}\sum\nolimits_i (R_{im} + \bar{R}_i)\,(\ln Y_{im} - \ln \bar{Y}_i)\\ &-\frac{1}{2}\sum\nolimits_i (R_{in} + \bar{R}_i)(\ln Y_{in} - \ln \bar{Y}_i)\end{aligned} \tag{5.1}$$

$$\begin{aligned}\ln(X_m/X_n) &= \frac{1}{2}\sum\nolimits_j (S_{jm} + \bar{S}_j)\,(\ln X_{jm} - \ln \bar{X}_j) -\\ &-\frac{1}{2}\sum\nolimits_i \left(S_{jn} + \bar{S}_j\right)\left(\ln X_{jn} - \ln \bar{X}_j\right)\end{aligned} \tag{5.2}$$

$$\ln(TFP_m/XTFP_n) = \ln(Y_m/Y_n) - \ln(X_m/X_n) \tag{5.3}$$

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

Equations (5.1), (5.2) and (5.3) represent rates of change between period n and period m. These are converted into output, input and TFP indexes by setting the value for the index at the first observation of the sample as equal to 1.0 and applying the rates of change sequentially for every subsequent observation in the sample. The index base is Icon Water in 2006 = 1.0. All other indexes are measured relative to this base. The choice of index base is arbitrary (here the first observation in the dataset) since it affects neither the comparisons (ie, relativities) between utilities nor the calculated TFP growth rates.

5.2 Variables

The MTFP is calculated using the following outputs, inputs and weights. Outputs are: (a) customer numbers; (b) quality-adjusted water supplied (ML) including bulk water exports to other utilities; and (c) quality-adjusted wastewater collected. The weights used for the outputs are derived from the total cost function model presented in Appendix B. We have used the averages of elasticities from two models, each estimated using data for the period 2006 to 2020, as shown in Table B.2, to obtain the weights:

- customers: 0.81
- quality adjusted water services: 0.0965
- quality-adjusted wastewater services: 0.0935.

Two inputs are used: (a) the index of real opex inputs including quantities of bulk water purchases; and (b) an index of capital inputs. Two alternative indexes of capital inputs are used, a real financial value of capital index, and an index of physical measures of capital inputs. The weights used for the two inputs are: (i) the share of nominal opex in nominal total cost; and (ii) the remainder share is for capital inputs.

5.3 Results

Table 5.1 shows MTFP indexes for Icon Water and for other water utilities averaged by state and territory, under each of the two alternative measures of capital inputs. It also shows the average of the two sets of indexes. *The MTFP index results are highly sensitive to the measure of capital used and means that the results must be interpreted cautiously.* This is why the average indexes are shown.

The MTFP results in Table 5.1 show that when comparing the TFP levels of utilities (here averaged by state and territory), the comparative results vary depending on the capital measure used. Icon Water’s MTFP index level of 0.900 in 2020 is lower than the average for all utilities of 1.077 in the same year when the real replacement cost index of capital inputs is used. When the physical capital index is used for capital inputs, Icon Water’s MTFP index level of 0.803 in 2020 is higher than the average for all utilities of 0.625. When the average of these two sets of indexes is used, Icon Water’s MTFP index level of 0.852 in 2020 is close to the average for all utilities of 0.859.

Table 5.1: MTFP Indexes by State, 2006–2020

	Icon Water	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Average all utilities***
Using real financial capital input									
2006	1.000	0.934	1.126	1.114	.	.	1.582	1.280	1.188
2007	0.962	0.932	1.096	1.175	.	.	1.517	1.033	1.150
2008	0.923	0.920	1.101	1.230	.	.	1.494	1.005	1.138
2009	0.899	0.909	1.086	1.093	.	.	1.498	1.116	1.135
2010	0.875	0.864	1.005	1.109	.	.	1.431	1.073	1.083
2011	0.863	0.859	1.001	1.265	.	.	1.418	1.069	1.097
2012	0.831	0.856	0.898	1.222	.	.	1.341	1.030	1.062
2013	0.845	0.843	0.804	1.192	.	.	1.397	0.979	1.060
2014	0.878	0.847	0.894	1.154	1.094	.	1.381	1.003	1.062
2015	0.886	0.876	0.910	1.188	1.134	.	1.416	0.999	1.088
2016	0.846	0.889	0.877	1.180	1.134	1.332	1.373	1.002	1.084
2017	0.839	0.880	0.995	1.199	1.172	1.304	1.387	1.021	1.093
2018	0.848	0.884	1.040	1.240	1.209	1.286	1.388	1.019	1.104
2019	0.858	0.885	1.041	1.252	1.180	1.219	1.362	1.036	1.101
2020	0.900	0.873	0.900	1.228	1.202	1.204	1.364	1.016	1.093
*Avg. growth 2006–2020**	-0.3%	-0.2%	-0.7%	0.3%	0.7%	-1.1%	-0.5%	-0.7%	-0.3%
Physical capital input index									
2006	1.000	0.606	0.614	1.380	.	.	0.607	0.833	0.667
2007	0.948	0.600	0.604	1.482	.	.	0.585	0.697	0.648
2008	0.905	0.599	0.612	1.242	.	.	0.579	0.698	0.648
2009	0.892	0.598	0.609	0.998	.	.	0.597	0.778	0.653
2010	0.896	0.565	0.577	0.997	.	.	0.585	0.773	0.631
2011	0.919	0.569	0.593	0.945	.	.	0.594	0.770	0.652
2012	0.803	0.566	0.533	0.905	.	.	0.559	0.715	0.632
2013	0.799	0.550	0.481	0.867	.	.	0.593	0.630	0.622
2014	0.840	0.538	0.541	0.782	0.656	.	0.573	0.652	0.611
2015	0.754	0.558	0.553	0.777	0.678	.	0.595	0.649	0.622
2016	0.764	0.552	0.536	0.781	0.679	0.406	0.580	0.651	0.613
2017	0.749	0.551	0.624	0.794	0.697	0.397	0.593	0.666	0.623
2018	0.762	0.553	0.668	0.814	0.723	0.392	0.600	0.671	0.631
2019	0.770	0.550	0.670	0.818	0.714	0.363	0.593	0.692	0.631
2020	0.803	0.540	0.572	0.811	0.729	0.369	0.601	0.658	0.625
*Avg. growth 2006–2020**	-0.7%	-0.4%	-0.2%	-1.6%	0.8%	-1.0%	0.0%	-0.7%	-0.2%
Average									
2006	1.000	0.770	0.870	1.247	.	.	1.095	1.057	0.928
2007	0.955	0.766	0.850	1.329	.	.	1.051	0.865	0.899
2008	0.914	0.760	0.857	1.236	.	.	1.037	0.852	0.893
2009	0.896	0.754	0.848	1.046	.	.	1.048	0.947	0.894
2010	0.886	0.715	0.791	1.053	.	.	1.008	0.923	0.857
2011	0.891	0.714	0.797	1.105	.	.	1.006	0.920	0.875

	Icon Water	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Average all utilities***
2012	0.817	0.711	0.716	1.064	.	.	0.950	0.873	0.847
2013	0.822	0.697	0.643	1.030	.	.	0.995	0.805	0.841
2014	0.859	0.693	0.718	0.968	0.875	.	0.977	0.828	0.837
2015	0.820	0.717	0.732	0.983	0.906	.	1.006	0.824	0.855
2016	0.805	0.721	0.707	0.981	0.907	0.869	0.977	0.827	0.849
2017	0.794	0.716	0.810	0.997	0.935	0.851	0.990	0.844	0.858
2018	0.805	0.719	0.854	1.027	0.966	0.839	0.994	0.845	0.868
2019	0.814	0.718	0.856	1.035	0.947	0.791	0.978	0.864	0.866
2020	0.852	0.707	0.736	1.020	0.966	0.787	0.983	0.837	0.859
*Avg. growth 2006–2020**	-0.5%	-0.3%	-0.5%	-0.6%	0.7%	-1.1%	-0.3%	-0.7%	-0.2%

Note: * Or period available. ** The average of all utilities is impacted by the imbalanced panel and hence can yield unreliable estimates of trends.

These results highlight the considerable uncertainty in regard to the comparative TFP levels due to the lack of a reliable measure of capital inputs, in part because they represent a substantial share of the total input index. The average cost share of capital inputs is 60.9 per cent (which non-capital inputs having an average share of 39.1 per cent) as a proportion of total expenditure. When using the real replacement cost measure, Icon Water's MTFP in 2020 is 16.4 per cent *below* the sample average for that year. When the physical capital index is used, Icon Water's MTFP in 2020 is 28.5 per cent above the average utility in 2020. The average of the indexes for these two cases suggests that Icon Water's MTFP in 2020 is 0.8 per cent below the sample average for the same year, that is, essentially at the average level.

When considering MTFP trends, Table 5.1 show that TFP has declined in most states and territories.

- When the real financial capital measure is used, the average rate of MTFP change for the sample as a whole over the period 2006 to 2020 is –0.3 per cent per year. Icon Water's average rate of MTFP change over the same period is also –0.3 per cent per year.
- When the physical capital index is used, the average rate of MTFP change for the sample as a whole over the period 2006 to 2020 is –0.2 per cent per year. Icon Water's average annual rate of MTFP change over the same period is –0.7 per cent.
- Using the average MTFP indexes, the average annual rate of MTFP change for the sample as a whole over the period 2006 to 2020 is –0.2 per cent. Icon Water's rate of MTFP change is –0.5 per cent. For further comparison, average MTFP growth in SA is 0.7 per cent over the same period; in Tasmania, –1.1 per cent; in NSW, –0.3 per cent; Queensland, –0.6 per cent; Victoria, –0.3 per cent; and WA, –0.7 per cent.

Tables 5.2 and 5.3 show the multilateral Opex partial factor productivity (PFP) indexes, and multilateral Capital PFP indexes. This information is useful for interpreting movements in MTFP. The Opex PFP indexes are unaffected by the measurement of capital. inputs, so only the latter table has separate panels for the different capital measures and the average.

Table 5.2: Opex PFP Indexes by State, 2006–2020

	Icon Water	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Average all utilities*
2006	1.000	0.897	0.757	1.084	.	.	0.928	1.054	0.924
2007	0.869	0.886	0.661	1.327	.	.	0.924	0.824	0.901
2008	0.799	0.881	0.659	1.254	.	.	0.924	0.765	0.895
2009	0.763	0.874	0.649	0.943	.	.	0.985	0.849	0.901
2010	0.752	0.817	0.601	0.956	.	.	0.871	0.804	0.833
2011	0.778	0.798	0.605	0.956	.	.	0.865	0.793	0.829
2012	0.715	0.782	0.513	0.937	.	.	0.801	0.785	0.799
2013	0.740	0.743	0.456	0.986	.	.	0.881	0.705	0.801
2014	0.795	0.744	0.538	0.932	0.857	.	0.895	0.739	0.811
2015	0.775	0.775	0.531	1.023	0.925	.	0.953	0.739	0.854
2016	0.657	0.802	0.498	0.954	0.896	0.747	0.866	0.744	0.826
2017	0.624	0.779	0.637	1.017	0.976	0.728	0.863	0.782	0.837
2018	0.632	0.775	0.693	1.071	1.013	0.743	0.863	0.778	0.847
2019	0.647	0.772	0.712	1.120	0.965	0.685	0.838	0.821	0.852
2020	0.678	0.745	0.533	0.989	1.053	0.682	0.856	0.783	0.818
*Avg. growth 2006–2020**	-1.2%	-0.6%	-1.1%	-0.3%	1.5%	-1.0%	-0.3%	-0.9%	-0.4%

Note: * Or period available. ** The average of all utilities is impacted by the imbalanced panel and hence can yield unreliable estimates of trends.

Table 5.3: Capital PFP Indexes by State, 2006–2020

	Icon Water	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Average all utilities*
Using real financial capital input									
2006	1.000	0.987	1.498	1.131	.	.	2.537	1.608	1.563
2007	1.004	0.984	1.552	1.107	.	.	2.345	1.480	1.508
2008	0.982	0.964	1.558	1.219	.	.	2.273	1.356	1.462
2009	0.966	0.949	1.513	1.204	.	.	2.222	1.294	1.425
2010	0.936	0.913	1.398	1.204	.	.	2.141	1.245	1.364
2011	0.903	0.912	1.354	1.515	.	.	2.108	1.252	1.381
2012	0.885	0.912	1.323	1.458	.	.	2.066	1.184	1.352
2013	0.889	0.909	1.246	1.371	.	.	2.022	1.173	1.321
2014	0.913	0.919	1.257	1.332	1.224	.	2.013	1.178	1.317
2015	0.932	0.941	1.327	1.334	1.239	.	2.003	1.167	1.325
2016	0.951	0.953	1.314	1.338	1.261	1.954	2.029	1.164	1.346
2017	0.969	0.946	1.302	1.341	1.266	1.928	2.041	1.160	1.346
2018	0.978	0.957	1.311	1.375	1.302	1.827	2.031	1.158	1.353

	Icon Water	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Average all utilities*
2019	0.983	0.962	1.293	1.383	1.288	1.790	2.013	1.155	1.350
2020	1.031	0.960	1.273	1.397	1.259	1.774	1.989	1.150	1.357
*Avg. growth 2006–2020**	0.1%	-0.1%	-0.5%	0.7%	0.2%	-1.0%	-0.8%	-1.0%	-0.4%
Physical capital input index									
2006	1.000	0.520	0.675	1.573	.	.	0.661	1.094	0.676
2007	1.001	0.520	0.709	1.567	.	.	0.622	0.957	0.658
2008	0.982	0.516	0.720	1.300	.	.	0.617	0.825	0.644
2009	0.987	0.517	0.711	1.103	.	.	0.629	0.834	0.646
2010	0.994	0.498	0.680	1.100	.	.	0.632	0.839	0.635
2011	1.008	0.508	0.680	1.031	.	.	0.645	0.818	0.661
2012	0.878	0.509	0.691	0.987	.	.	0.639	0.746	0.652
2013	0.858	0.503	0.688	0.931	.	.	0.643	0.653	0.637
2014	0.876	0.478	0.680	0.829	0.582	.	0.641	0.671	0.619
2015	0.764	0.490	0.731	0.826	0.588	.	0.645	0.667	0.624
2016	0.879	0.478	0.731	0.821	0.601	0.277	0.657	0.678	0.620
2017	0.892	0.484	0.725	0.841	0.596	0.270	0.669	0.676	0.628
2018	0.905	0.487	0.752	0.860	0.618	0.263	0.678	0.687	0.637
2019	0.909	0.488	0.749	0.872	0.623	0.241	0.682	0.688	0.640
2020	0.957	0.487	0.743	0.890	0.612	0.248	0.689	0.669	0.648
*Avg. growth 2006–2020**	-0.1%	-0.2%	0.3%	-1.8%	0.4%	-1.2%	0.1%	-1.5%	-0.1%
Average									
2006	1.000	0.754	1.087	1.352	.	.	1.599	1.351	1.120
2007	1.003	0.752	1.131	1.337	.	.	1.484	1.219	1.083
2008	0.982	0.740	1.139	1.260	.	.	1.445	1.091	1.053
2009	0.977	0.733	1.112	1.154	.	.	1.426	1.064	1.036
2010	0.965	0.706	1.039	1.152	.	.	1.387	1.042	1.000
2011	0.956	0.710	1.017	1.273	.	.	1.377	1.035	1.021
2012	0.882	0.711	1.007	1.223	.	.	1.353	0.965	1.002
2013	0.874	0.706	0.967	1.151	.	.	1.333	0.913	0.979
2014	0.895	0.699	0.969	1.081	0.903	.	1.327	0.925	0.968
2015	0.848	0.716	1.029	1.080	0.914	.	1.324	0.917	0.975
2016	0.915	0.716	1.023	1.080	0.931	1.116	1.343	0.921	0.983
2017	0.931	0.715	1.014	1.091	0.931	1.099	1.355	0.918	0.987
2018	0.942	0.722	1.032	1.118	0.960	1.045	1.355	0.923	0.995
2019	0.946	0.725	1.021	1.128	0.956	1.016	1.348	0.922	0.995
2020	0.994	0.724	1.008	1.144	0.936	1.011	1.339	0.910	1.003
*Avg. growth 2006–2020**	0.0%	-0.1%	-0.2%	-0.5%	0.3%	-1.1%	-0.6%	-1.2%	-0.3%

Note: * Or period available. ** The average of all utilities is impacted by the imbalanced panel and hence can yield unreliable estimates of trends.

Table 5.2 indicates that urban water utilities in most states have seen declines in Opex PFP over the period 2006 to 2020. The annual average rate of change for utilities in the sample is –0.4 per cent, while Icon Water's is –1.2 per cent. Icon Water's Opex PFP index in 2020 is 0.678, compared to 0.818 for the average of all utilities in the sample.

The measures of Capital PFP shown in Table 5.3 are again, highly sensitive to the measure of capital inputs used. Comparing Capital PFP levels in 2020: when the real financial capital measure is used, Icon Water's Capital PFP index level in 2020 is 1.03, which is 24.0 per cent below the average Capital PFP index of all utilities of 1.36 in the same year. Using the physical capital index, the Capital PFP index for Icon Water in 2020 is 0.96, which is 47.7 per cent higher than the average Capital Index for the sample in 2020 of 0.65. The average of the indexes provides an intermediate estimate within this wide range. Icon Water's Capital PFP index in 2020 is 0.99, which is similar to 1.00 for the sample as a whole.

Comparing the rates of Capital PFP growth and noting only the results from the average indexes, we see that Icon Water's Capital PFP was, on average, unchanged over the period 2006 to 2020. On the other hand, for the sample as a whole the average rate of change in Capital PFP was –0.3 per cent annually. In most states there was a decline in Capital PFP.

6 Opex Productivity Allowance

This section uses the results in previous sections to draw conclusions on the industry's rate of change in opex partial factor productivity (PFP). It also reviews Australian regulator decisions on opex PFP adjustments for urban water business price determinations. Lastly, comment is made on the appropriate allowance for opex partial factor productivity (PFP) in Icon Water's regulatory proposal for prices in the period 1 July 2023 to 30 June 2028.

6.1 Productivity Adjustment in the Base-Step-Trend Method

The Independent Competition and Regulatory Commission (ICRC) describes its approach to determining Icon Water's operating expenditure allowance, consistent with prudency and efficiency, as a 'base-step-trend' method (ICRC 2022, 22). The Australian Energy Regulatory (AER) also uses the base-step-trend method to form its view on the efficient future opex allowance for regulated energy network service providers. This method involves estimating the efficient opex for a base year, at the end of the previous regulatory period (removing non-recurrent costs); making 'step change' adjustments to reflect the costs of any new obligations in the forthcoming regulatory period; and projecting opex forward using forecasts of: (a) the rate of change in opex input prices; (b) the rate of change of an index of the relevant outputs; and (c) an opex productivity adjustment factor.

The trend in a businesses' PFP over time can be seen as comprising two parts:

- *industry-wide factors*: including the rate of technical change (ie, 'frontier shift') and the average rate of change in efficiency relative to the frontier for the industry overall. The latter is the average rate of 'catch-up' efficiency change for the industry;
- *firm-specific factors*: the expected rate of 'catch-up' efficiency improvement for the firm relative to the average for all firms in the industry.

These two parts can be used when establishing a suitable productivity adjustment factor for forecasting opex. The AER includes cost efficiencies within a base-year adjustment (AER 2019, 8). Alternatively, the forecast rate of Opex PFP can comprise the rate industry opex PFP change plus a firm-specific 'stretch factor' representing expected reduced inefficiency over time. This is essentially the approach adopted by the Commerce Commission for determining X-factors of New Zealand electricity networks described Lawrence & Diewert (2006). This approach involved:

> ... decomposing the X factor into two components: a 'B' factor reflecting the overall or average productivity trend for electricity lines businesses and a 'C' factor broadly reflecting the circumstances of each distribution business or a small number of distribution businesses. ... The distributors performing better than the industry average would possibly be set a less onerous X factor (ie, be allocated a negative C factor) and those performing worse than the industry average would possibly be set a more onerous X factor (ie, be

> allocated a positive C factor). (Lawrence 2003, iii)

As shown in section 6.2, this approach of combining frontier shift and 'catch-up' productivity change is implicitly used by some State and Territory regulators for water businesses. Like the Commerce Commission and accounting for significant data quality issues, Quantonomics has applied an average similar benchmarking standard in our analysis, and **notably, Icon Water's opex efficiency is commensurate with the industry average**.

It is necessary to determine the benchmarking standard to use as the target for determining firm-specific adjustments for 'catch-up'. Efficiency adjustments need not be referenced against the best practice utility, especially with limitations related to data quality placing limitations on benchmarking outcomes. They are more often referenced against the average utility or an intermediate standard (Lowry and Getachew 2009b, 1323). In general, the use of frontier efficiency standards in regulation is likely to lead to unrealistically high and, indeed unachievable, targets being set (Lawrence 2003, 63). A number of authors have suggested that the average firm is the most useful benchmark standard for regulation because it corresponds to the competitive market standard used as a basic aim of regulation, and to the normal industry rate of return embedded within the opportunity cost of capital (Kaufmann and Beardow 2001; Lowry and Getachew 2009a; 2009b; Tardiff 2010). These arguments are particularly relevant to industries in private ownership, which have effective profit maximisation incentives, but may not be suitable for industries largely in government ownership, where a higher efficiency threshold may be appropriate (Cunningham 2012, 11). In the UK, the electricity regulator has preferred to use the average performance in the industry (Dassler, Parker, and Saal 2006, 172). Ofwat's early decisions based opex on an assumption that 60 per cent of the gap between a company's opex and the efficient frontier opex would be closed over the five-year period.

The choice of standard should also have regard to the degree of diversity or heterogeneity of comparator firms, with higher thresholds being less reliable for more diverse groups of firms, as is the case in Australia where many utilities are not price regulated, have wide variation in their scale of operation, and differ in their structure and ownership (eg, as part of local governments or as state-owned enterprises). For application in the current study, and accounting for significant variation in the sample and the data quality issues discussed in section 2.5, Quantonomics has adopted the 67th percentile of efficiency as the medium-term target for the purpose of determining the annual productivity adjustment.

6.2 Estimating Opex PFP Frontier Shift

This section discusses how the results of the study can be used to estimate forward looking industry-wide PFP trends. A first step involves constructing an output index.

6.2.1 Output Weights

Constructing an output index involves defining the relevant outputs and deriving appropriate weights for each output. In this study the following outputs have been defined with weights presented in Table 4.3:

- Number of customers (the maximum of water and sewerage customers): 70.4 per cent;
- Volume of water supplied (to end-users or sold in bulk): 13.4 per cent;
- Volume of wastewater collected: 16.3 per cent.

6.2.2 Opex PFP Frontier Shift

Two different results from the analysis in this report can be used to provide a basis for forecasting Icon Water's Opex PFP. The first approach is that described in section 4.4, based on the parameters of the econometric variable cost function presented in section 4, which can be used to forecast the rate of change in Icon Water's Opex PFP. This requires forecast growth rates for the outputs and capital input, which are multiplied by coefficients from the model as described in equation (4.4) in section 4. A measure of frontier shift is also derived from the estimated parameters of the model.

The calculation of the forecast growth of Opex PFP in each of the period 2024 to 2028 are shown in Table 6.1, together with the average for the five-year period. The assumed growth rates of outputs and capital input, shown in Table 6.1, are based on preliminary forecasts by Icon Water. The estimated average rate of change in Opex PFP is not sensitive to small changes in these forecasts. We have assumed no change in any of the OEFs.

Table 6.1 shows that the projected Opex PFP for Icon Water is –0.9 per cent. That is, a negative rate of productivity change, corresponding to an underlying increase in Opex due to negative technical change.

Table 6.1: Opex PFP – derived from Variable Cost Model

	2024	*2025*	*2026*	*2027*	*2028*	*Average*
Assumed growth rates (%)						
Customers	1.39	1.49	1.65	2.02	2.02	
Water volume	1.54	0.91	1.35	1.41	1.33	
Wastewater volume	1.50	1.47	1.45	1.43	1.41	
Total Output	1.43	1.41	1.58	1.85	1.83	
Capital input	1.39	1.39	1.30	1.05	2.89	
Contributions to Opex PFP growth (%)						
Output	0.34	0.34	0.38	0.45	0.44	0.39
Capital input	-0.08	-0.08	-0.08	-0.06	-0.17	-0.10
Frontier shift	-1.23	-1.23	-1.23	-1.23	-1.23	-1.23
Total	-0.97	-0.97	-0.93	-0.85	-0.96	-0.94

A second approach is to simply extrapolate forward the rate of change of Opex PFP calculated in the index analysis. This is shown in Table 5.2, and for the industry as a whole, the average rate of change in the Multilateral Opex PFP index over the period from 2006 to 2020, is –0.4 per cent per annum. Neither of these two estimates includes any allowance for firm-specific ‘catch-up’ productivity gains.

6.2.3 Discussion

The reasons for declining industry-wide productivity are difficult to ascertain. The rate of productivity decline in the broader Electricity, Gas, Water and Waste services (EGWW) sector, measured by the Australian Bureau of Statistics (ABS), has been greater than that measured here for the urban water distribution sector. The Productivity Commission (PC) has suggested reasons such as: (i) possible measurement issues (eg, with capital measurement); (ii) although strong productivity gains were achieved by the sector from the 1980s to the early 2000s due to microeconomic reforms, some of these gains have since been given up, detracting from productivity growth after 2005 (Productivity Commission (PC) 2020). An additional reason may be unmeasured OEFs, such as changes in technical regulations and standards which affect costs, or changes in compliance costs or the introduction special levies or obligations relating to the environment.

With industry-wide Opex PFP having declined slowly over the period 2006 to 2020, there are clearly difficulties in forecasting industry-wide Opex PFP trends over the next five years. The factors that have influenced the industry productivity trend in the sample period may not continue to have the same effect in the forecast period. Since measured underlying productivity trends are a ‘residual’ after accounting for observed factors, the unobserved factors determining this residual effect are not well understood. It is not feasible for us to assess the likelihood of a change in underlying productivity trends.

6.3 Relevant Regulator Decisions

Table 6.2 summarizes a number of decisions of Australian regulators on productivity adjustment factors for water businesses. Some regulators include only the estimated rate of frontier shift within the opex productivity adjustment—including the Independent Pricing and Regulatory Tribunal (IPART), the Essential Services Commission of South Australia (ESCOSA), the Queensland Competition Authority (QCA) and the Economic Regulation Authority (ERA). Other regulators use a productivity adjustment that includes both frontier shift and ‘catch-up’—including the Office of the Tasmanian Economic Regulator (OTTER). Table 6.2 shows that the decisions which only include frontier shift are in the range 0.2 to 0.8 percent per year. The decision which includes catch-up productivity gains is 1.5 per cent per year.

Table 6.2: Annual Productivity Adjustment Factors Applied to Opex

Jurisdiction	*Business*	*Date*	*Annual productivity adjustment*	*Type*
NSW	Sydney Water	IPART (2020b, 213)	0.8%[(a)]	Frontier shift
	Hunter Water	IPART (2020a, 46)	0.8%[(a)]	Frontier shift
SA	SA Water	ESCOSA (2020, 2)	0.5%	Frontier shift
TAS	TasWater	OTTER (2022, 33)	1.5%	Incl. catch-up
QLD	Sun Water	QCA (2020, 54)	0.2%	Frontier shift
NEM	Energy Networks	AER (2019, 9)	0.5%	Frontier shift

Notes: (a) Not applied to the first year of the regulatory period due to disruption from COVID.

6.4 Recommendations

Regulatory decisions on productivity adjustments have usually assumed rates of frontier shift based on long-run economy-wide productivity trends, rather than estimates of Opex PFP trends for the urban water industry. The estimates of Opex PFP trends presented here show declining industry Opex PFP rates of between –0.4 and –0.9 per cent per year, for reasons that are not well understood. The likelihood that such underlying trends may continue should not be lightly dismissed. The results suggest that a forecast industry productivity trend of zero per cent would be optimistic, whilst a continued decline at –0.9 per cent per year is quite possible.

As shown in Table 4.2, the econometric variable cost function results suggest that Icon Water has a degree of cost efficiency which is equal, or almost equal, to the average for all states and territories. This finding is supported by the partial indicator analysis in section 3, which suggests that Icon Water's cost metrics are close to average for firms of similar customer density. Given these findings, we would assume that a base-year efficiency adjustment is not needed. Instead some allowance for 'catch-up' efficiency gains can be included within the Opex PFP annual adjustment factor.

The state and territory efficiency scores shown in Table 4.2 have a 67th percentile of 0.72.[13] For Icon Water to reach the 67th percentile of opex cost efficiency over ten years would require an annual 'catch-up' productivity adjustment of 0.7 per cent. Combining this with a projected underlying industry productivity trend of 0.0 to –0.9 per cent per year yields an annual combined productivity adjustment of –0.2 to 0.7 per cent. We consider this to be a feasible and suitable range for an annual productivity adjustment.

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[13] The 67th percentile is 0.709 in the model using the real financial capital measure and 0.724 in the model using the physical capital index. The average 67th percentile is 0.717.

7 Findings & Recommendations

This section firstly summarizes some of the information and findings from earlier sections of this report, and the key recommendations on output weights and forecast rate of change in Opex PFP.

7.1 Descriptive Information and PPIs

The data sample used in this study includes water utilities of widely varying sizes. The largest in the Sample is Sydney Water with over 2 million customers, while more than half the sample (33 utilities) have less than 35,000 customers. Icon Water, with 179,000 customers, is just above the sample average of 151,000 customers. Icon Water has above average customer density per km of mains, and water consumption per customer is close to the sample average. Wastewater collected per sewerage customer is also close to the sample average.

Partial productivity indicators indicate the following comparisons against other urban water businesses:

- Icon Water's average opex per customer of $989 per year, is similar to the average for the sample as a whole ($969). It is also around the average for utilities of similar customer density. For the nine utilities with customer density in the range 25 and 29,[14] the average opex per customer is $1,019, and their median is $997.
- Icon Water has opex per km of $26.4, which is close to the average for utilities of similar customer density such as Power & Water Darwin, Logan, Unity Water and Queanbeyan-Palerang. For example, taking the nine utilities with customer density in the range 25 and 29, the average opex per km is $27.1, and the median is $26.4.
- Icon Water's average asset cost per customer from 2018 to 2020 was $1,542, which is slightly above that for comparator utilities of similar customer density. For the nine utilities with similar customer density, the average asset cost per customer is $1,493, and the median is $1,361. Icon Water's higher average asset cost per customer may be related to the comparatively recent investment in the Enlarged Cotter Dam expansion. There is no other new dam in the sample period for the included utilities.
- Icon Water's asset cost per km ($41.1), is slightly higher than comparator utilities with similar customer density. The nine utilities with similar customer density have average asset cost per km of $39.4; and a median of $38.1.
- Icon Water's total cost per customer from 2018 to 2020 averaged $2,531, which was slightly higher than the average for all utilities of $2,322, but around average for utilities

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[14] Icon Water's average customer density from 2018 to 2020 of 27 per km, plus or minus 2 customers per km.

of similar customer density. For the nine utilities with similar customer density, the average total cost is $2,512 per customer, and the median is $2,358.

- Icon Water's total cost per km was $67.5 on average from 2018 to 2020, which is close to the average for comparator utilities with similar customer density, for which the mean is $66.5 and the median is slightly lower at $61.8.

7.2 Variable Cost Function Analysis

The variable cost function assumes that, in the short-run, capital inputs and quasi-fixed factors of production, and are included as explanatory variables in addition to outputs and input prices. Given the length of the sample period available is much shorter than the average asset life of 50 years or more, the variable cost, or short-run cost function is the most suitable form of cost function to use for this study. We estimate a Cobb-Douglas variable cost function for the period 2006 to 2020 using stochastic frontier analysis (SFA). Two alternative measures of capital input are used, a real financial capital measure and a physical capital measure. The resulting efficiency estimates shown in Table 4.2 indicate that Icon Water's opex cost efficiency is close to the industry average measured as the average for all states.[15]

The econometric results also yield appropriate output weights to use for constructing an output index for forecasting opex. The output definitions used and the associated weights are:

- Number of customers (the maximum of water and sewerage customers): 70.4 per cent;
- Volume of water supplied (to end-users or sold in bulk): 13.4 per cent;
- Volume of wastewater collected: 16.3 per cent.

7.3 Multilateral TFP and PFP Indexes

The Multilateral Total Factor Productivity (MTFP) indexes calculated in section 5 show that when comparing the TFP levels of utilities (averaged by state and territory), the comparative results vary depending on the capital measure used. Icon Water's MTFP index level of 0.900 in 2020 is lower than the average for all utilities of 1.077 in the same year when the real replacement cost index of capital inputs is used. When the physical capital index is used for capital inputs, Icon Water's MTFP index level of 0.803 in 2020 is higher than the average for all utilities of 0.625. The large difference in results depending on the capital measure used highlights the limitations of the measures of capital available. The average of the indexes using each capital measure are considered to be the most informative, and indicate the following.

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[15] We regard the average of the state and territory average technical efficiency scores as most suitable basis for comparison because some states, such as NSW, have a large number of mostly small water businesses, whilst some of the most important comparators such as TAS, SA and NT have only one or two water businesses.

- When the average of the two sets of MTFP indexes is used, Icon Water's MTFP index level of 0.852 in 2020 is close to the average for all utilities of 0.859.
- Using the average of MTFP indexes, the average annual rate of MTFP change for the sample as a whole over the period 2006 to 2020 is –0.2 per cent. Icon Water's rate of MTFP change is –0.5 per cent.
- The Opex PFP indexes show that Icon Water's Opex PFP of 0.68 is lower than the average for all utilities of 0.82. Icon Water's average annual rate of Opex PFP change over the period 2006 to 2020 is –1.2 per cent, compared to the average rate for all utilities of –0.4 per cent.
- The average of the Capital PFP indexes indicates that Icon Water's Capital PFP index in 2020 is 0.99, which is similar to 1.00 for the sample as a whole.
- Using the average of Capital PFP indexes, the average rate of change in Capital PFP for all utilities was –0.3 per cent annually, whilst Icon Water's Capital PFP was, on average, unchanged over the same period.

7.4 Forecasting Opex PFP

Two different results from the analysis in this report can be used to provide a basis for forecasting Icon Water's Opex PFP. The first uses the estimated variable cost function presented in section 4. Using this model, with forecast growth rates for the outputs and capital input, the projected Opex PFP for Icon Water is –0.9 per cent (ie, an underlying increase in Opex due to negative technical change). The second approach is to extrapolate using the industry-wide average rate of change in the Opex Multilateral PFP index over the period from 2006 to 2020, which is –0.4 per cent per annum. Neither of these two estimates includes any allowance for firm-specific 'catch-up' productivity gains.

With industry-wide Opex PFP having declined slowly over the period 2006 to 2020, there are clearly difficulties in forecasting industry-wide Opex PFP trends over the next five years. Regulatory decisions on productivity adjustments have usually assumed rates of frontier shift based on long-run economy-wide productivity trends, rather than estimates of Opex PFP trends for the urban water industry. However, in our view, since the reasons for declining productivity are not well understood, the likelihood that such underlying trends may continue should not be lightly dismissed. The results suggest that a forecast industry productivity trend of zero per cent would be optimistic, whilst a continued decline at –0.9 per cent per year is quite possible.

Since the econometric variable cost function results, and the partial indicator analysis, suggest that Icon Water's opex efficiency is similar to the industry average for all states and territories, and given substantial data limitations, Quantonomics recommends that a base-year efficiency adjustment should not be applied. Instead some allowance for 'catch-up' efficiency gains can be included within the Opex PFP annual adjustment factor. For Icon Water to reach the 67th percentile of opex cost efficiency over ten years would require an annual 'catch-up' productivity adjustment of 0.7 per cent. Combining this with a projected underlying industry productivity trend of 0.0 to –0.9 per cent per year yields an annual combined productivity adjustment of –0.2 to 0.7 per cent. We consider this to be a feasible and suitable range for an annual productivity adjustment.

Appendix A: Data Sources

A.1 National Performance Report

The primary source of data for Australian urban water businesses is the National Performance Report (NPR) for urban water utilities produced by the Bureau of Meteorology (BOM). The NPR was first developed by the former National Water Commission (NWC) in association with the Water Services Association of Australia (WSAA), and produced from 2006. The NPR has been produced by BOM annually since 2015 in the same format. The data used in this study is based on the NPR published in January 2021 for the period up to 2019/20.[16]

The present analysis is based on data from 2006 to 2020, for 64 urbane water utilities. The utilities included in the analysis, and the data range available for each utility, are listed in Table 2.1. Bulk water suppliers and some utilities with insufficient data have been excluded. Some utilities which only supply water have been combined with utilities in the same locality that only supply sewerage (see notes to Table 2.1). In Table 2.1, the included utilities are grouped by State/Territory and ordered alphabetically within each size category. The size categories are:

1. Major–100,000+ connected properties
2. Large–50,000–100,000 connected properties
3. Medium–20,000–50,000 connected properties
4. Small–10,000–20,000 connected properties.

Table 2.2 lists the NPR indicators used in the analysis. Indicator codes grouped as follows:

- *W*: sources and uses of water and wastewater, mostly in megalitres (ML);
- *A*: assets indicators, relating to quantity and condition of assets;
- *C*: customer-related indicators; eg, the number of water and sewerage customers, customer complaints and interruptions to supply;
- *E*: environmental indicators; eg, the degree of wastewater treatment and greenhouse gas emissions;
- *H*: health-related indicators, particularly measures of drinking water quality;
- *F*: financial indicators, including revenue, capital expenditure, operating expenditure, financial asset measures, and profitability indicators. All indicators with units in dollars are expressed in 2020 prices using the All Groups CPI for Australia.

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[16] BOM's NPR reports are available at: <http://www.bom.gov.au/water/npr/>. Appendix B of the NPR is an Excel spreadsheet database: 'The_complete_dataset_2019_20-2.xlsx'. This is the main source of the NPR data used in this study. The next NPR is due to be published on 28 February 2022. Although the associated dataset from 2020/21 is already available on the BOM website, it has not been used in this study.

Table A.1 Summary of Dataset by Utility

Utility	*Sample Period*	*# Obs.*	*Utility*	*Sample Period*	*# Obs.*
Australian Capital Territory			20 Byron	2006 - 2019	14
1 Icon Water	2006 - 2020	15	21 Essential Energy	2006 - 2020	15
New South Wales			22 Goulburn Mulwaree	2010 - 2020	11
2 Central Coast(1)	2006 - 2019	14	23 Kempsey	2006 - 2020	15
3 Hunter Water	2006 - 2020	15	24 Lismore	2006 - 2020	15
4 Sydney Water	2006 - 2020	15	25 Orange	2006 - 2020	15
5 Albury	2006 - 2020	15	**Northern Territory**		
6 Clarence Valley	2006 - 2020	15	26 P&W (Darwin)	2006 - 2020	15
7 Coffs Harbour	2006 - 2020	15	27 P&W (Alice Springs)	2006 - 2020	15
8 Eurobodalla	2006 - 2020	15	**Queensland**		
9 MidCoast	2006 - 2020	15	28 Gold Coast	2006 - 2020	15
10 Port Macquarie-Hastings	2006 - 2020	15	29 Logan	2006 - 2020	15
11 Queanbeyan-Palerang	2006 - 2020	15	30 Unitywater	2011 - 2020	10
12 Riverina Water(2)	2006 - 2020	15	31 Urban Utilities	2011 - 2020	10
13 Shoalhaven	2006 - 2020	15	32 Cairns	2008 - 2020	13
14 Tamworth	2006 - 2020	15	33 Toowoomba	2013 - 2020	8
15 Tweed	2006 - 2020	15	34 Townsville	2012 - 2020	9
16 Wingecarribee	2006 - 2020	15	35 Fraser Coast	2011 - 2020	10
17 Ballina	2006 - 2020	15	36 Mackay	2009 - 2020	12
18 Bathurst	2006 - 2020	15	37 Rockhampton	2014 - 2020	7
19 Bega Valley	2006 - 2020	15	38 Gympie	2014 - 2020	7

Table A.1 (cont.)

Utility	*Sample Period*	*# Obs.*	*Utility*	*Sample Period*	*# Obs.*
South Australia			51 East Gippsland Water	2006 - 2020	15
39 SA Water	2014 - 2020	7	52 GWMWater	2006 - 2020	15
Tasmania			53 Lower Murray Water	2007 - 2020	14
40 TasWater	2016 - 2020	5	54 South Gippsland Water	2006 - 2020	15
Victoria			55 Wannon Water	2006 - 2020	15
41 Barwon Water	2006 - 2020	15	56 Westernport Water	2006 - 2020	15
42 City West Water	2006 - 2020	15	**Western Australia**		
43 South East Water	2006 - 2020	15	57 WC (Perth)	2006 - 2020	15
44 Yarra Valley Water	2006 - 2020	15	58 WC (Mandurah)	2006 - 2020	15
45 Central Gippsland Water	2006 - 2020	15	59 Aqwest-Bunbury(3)	2007 - 2020	14
46 Central Highlands Water	2006 - 2020	15	60 Busselton(4)	2013 - 2020	8
47 Coliban Water	2006- 2020	15	61 WC (Albany)	2006 - 2020	15
48 Goulburn Valley Water	2006 - 2020	15	62 WC (Australind/Eaton)	2012 - 2020	9
49 North East Water	2006 - 2020	15	63 WC (Geraldton)	2011 - 2020	10
50 Western Water	2006 - 2020	15	64 WC (Kalgoorlie-Boulder)(5)	2006 - 2020	15

(1) Before 2016, data for Gosford City Council and Wyong City Council (which were combined to form Central Coast Council) have been aggregated.

(2) Riverina water (water supply) and Wagga Wagga Council (sewerage) have been combined.

(3) Aqwest - Bunbury Water Board (water supply) and Water Corporation - Bunbury (sewerage) have been combined.

(4) Busselton Water (water supply) and Water Corporation - Busselton (sewerage) have been combined.

(5) Water Corporation - Kalgoorlie-Boulder (water supply) and City of Kalgoorlie-Boulder (sewerage) have been combined.

Table A.2: NPR indicators used in the analysis

Indicator	*Description*
W1	Surface water (e.g. dams, rivers or irrigation channels) (ML)
W2	Sourced from groundwater (ML)
W3.1	Water sourced from desalination of marine water (ML)
W5	Received from other service providers or operational areas (ML)
W7	Total water sourced (ML)
W8	Water supplied to residential customers (ML)
W9	Water supplied to non-residential customers (ML)
W14	Water exported to other service providers or operational areas (ML)
W16	Volume of wastewater, excluding trade waste, collected (ML)
W17	Volume of trade waste collected (ML)
W27	Recycled water as a % of total wastewater collected
A1	Number of water treatment plants providing full treatment
A2	Length of water mains (km)
A4	Number of wastewater treatment plants
A5	Length of sewer mains & channels (km)
A9	Infrastructure leakage index (ILI)[17]
C4	Total connected properties - water supply (000s)
C8	Total connected properties - sewerage (000s)
C9	Number of water quality complaints per 1000 water customers
C15	Average duration of an unplanned interruption: water supply (minutes)
C17	Number of unplanned interruptions per 1,000 water customers
E1	Percentage of sewage treated to a primary level (%)
E2	Percentage of sewage treated to a secondary level (%)
E3	Percentage of sewage treated to a tertiary or advanced level (%)
E9	Greenhouse emissions: water (tonnes CO2-equiv. / 1000 water properties)
H3	Percentage of population where microbiological compliance was achieved (%)
H4	Number of zones where chemical compliance was achieved (eg 23/24)
F9	Written-down value of fixed water supply assets ($000s)
F10	Written-down value of fixed sewerage assets ($000s)
IF11	Operating cost - water ($’000s)
IF12	Operating cost - sewerage ($’000s)
F16	Total water supply and sewerage capital expenditure ($000s)
F26	Capital works grants - water ($000s)
F27	Capital works grants - sewerage ($000s)

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[17] ILI = CARL / UARL; where CARL is current annual real losses (L/service connection/day), and UARL is unavoidable annual real losses (L/service connection/day).

A.2 Other Data Sources

A.2.1 Bulk water

Whilst some urban water utilities have their own water sources, such as rivers, dams or groundwater, others purchase a substantial amount of their water from other utilities or specialised bulk water authorities. Some utilities rely entirely on such purchases, including the three metropolitan water utilities in Victoria (from Melbourne Water), Sydney Water (from WaterNSW), and water utilities in south-east Queensland, such as Queensland Urban Utilities (from Seqwater). Many other water utilities in NSW obtain all or part of their water supplies from WaterNSW or Rous County Council. Several water utilities in Victoria outside the metropolitan area obtain water from Melbourne Water or from Goulburn-Murray Water.

The NPR provides information on the quantity of bulk water purchases (in ML), but not for the cost of bulk water. The latter is needed in order to decompose opex into the cost of bulk water and other opex. Sources for data on bulk water cost or prices are:

(a) regulator decisions, which report fixed and variable charges appliable to specific regions (eg, Independent Pricing and Regulatory Tribunal (IPART) 2020b; 2020c; Queensland Competition Authority (QCA) 2018; Essential Services Commission (ESC) 2021; 2020);

(b) bulk water provider published price schedules and Annual Reports;[18]

(c) Annual Reports of urban water utilities which buy bulk water .

A.2.2 Temporary Water Restrictions

Data on temporary water restrictions (TWRs) for each utility were obtained from two main sources:

- Historical TWR data by utility gathered with the assistance of the Department of Treasury library for an earlier published study (Cunningham 2013).
- Data on water restriction in more recent years, for all Australian urban water utilities, was provided by the Bureau of Meteorology (BOM) by email on 27-10-2021.

A.2.3 Weather

Weather data was collected for representative locations in the supply areas of Australian urban water utilities. For most water utilities a single weather station has been used, but in some cases two weather stations are used to cover the period needed, due to limitations in the periods for which data is available for each of the two weather stations. The data source is: http://www.bom.gov.au/climate/data/. The data is for: mean minimum temperature by

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[18] Eg, <https://rous.nsw.gov.au/annual-reports>.

month; mean maximum temperature by month; and total rainfall per month. These data are averaged (for temperature) or summed (for rainfall) over each financial year.

A.2.4 Census data

Demographic data has been compiled from ABS Census data for 2011; providing only for cross-sectional comparisons between utilities of urban density (in terms of dwellings per hectare) and the mix of dwelling types. ABS Census data has been sourced by Urban Centres and Rural Locality (UCL). For census year 2011, all of the UCLs in each utility supply area have been identified. Selected community profile data for each UCL in 2011 (such as the number of dwellings, the population, and the area of the UCL in square kms) has been obtained and aggregated within each utility to obtain the equivalent data at the utility-level.[19]

Some UCLs are split between more than one urban water utility. Examples include Brisbane (which is split between Qld Urban Utilities and Logan City) and Melbourne (which is split between City West Water, South East Water, and Yarra Valley Water). There are some other examples; eg Bunbury UCL is split between Aqwest/Bunbury Water and WC (Australind-Eaton). Hence, the share of a UCL attributed to the part in a particular water utility supply area needs to be estimated. In most cases this has been worked out by local government area, but for Melbourne it has been worked out by postcode. These shares are multiplied by the number of dwellings, population, and area of the UCL in the process of aggregation.

The census data has only been assembled for 2011 because, firstly, it is not a small exercise to assemble such data even for a single census year. Second, UCL boundaries can change between censuses. For example, two nearby townships which experience residential growth may effectively merge, and become one single UCL. The resulting lack of direct alignment between UCL classifications from census-to-census means that the whole of the exercise undertaken for one census (including identifying UCLs that belong to a utility supply area and estimating the shares of UCLs that belong in a particular utility supply area), would need to carried out separately for each census.

A.2.5 Input Prices

Information on consumer prices is obtained from the Australian Bureau of Statistics (*6401.0 - Consumer Price Index, Australia*). Information on interest rates is obtained from the Reserve Bank of Australia.[20]

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[19] Some UCLs are split between more than one urban water utility. Examples include Brisbane (which is split between Qld Urban Utilities and Logan City) and Melbourne (which is split between City West Water, South East Water, and Yarra Valley Water). There are some other examples; eg Bunbury UCL is split between Aqwest/Bunbury Water and WC (Australind-Eaton). Hence, the share of a UCL attributed to the part in a particular water utility supply area needs to be estimated. In most cases this has been worked out by local government area, but for Melbourne it has been worked out by postcode. These shares are multiplied by the number of dwellings, population, and area of the UCL in the process of aggregation.

[20] <https://www.rba.gov.au/statistics/>.

A.2.6 Dams

A database for large dams in Australia is available from the Australian National Committee on Large Dams (ANCOLD).[21] For each dam it includes data on attributes such as: (i) height; (ii) dam volume; (iii) surface area; (iv) catchment area; (v) spill capacity; (vi) owner; (vii) purpose (eg, urban water supply, recreation, irrigation); and (viii) date when the dam was commissioned.

A.2.7 Desalination Plants

Data on desalination plants capacity, cost, ownership and operations has been sourced from urban water utility websites and various other public domain information. Only two of the 64 utilities included in our dataset own desalination plants: Water Corporation Perth (which owns two desal plants) and SA Water (which has one desal plant). Several utilities pay for the entitlement to obtain desalinated water from separate entities which own desal plants (eg, Gold Coast, Sydney Water, City West Water, South East Water and Yarra Valley Water).

A.2.8 Physical Capital Weights

To construct an index of physical measures of capital, it is necessary to use unit value weights. These are based on Icon Water's financial data for the value of fixed assets by asset type, shown in Table A.2. The unit values shown in the last column are applied to the five types of physical capital quantities for each utility, to obtain an index of physical capital assets. IN addition to these, the unit value used for desal plants is $24 million per GL/a, based on published costs of desal plants in Australia and their capacities as shown in Table A.3.

Table A.3: Physical capital index weights

	Asset value ($'000)	*Assets quantity*		*Unit value ($'000)*
Water treatment plants providing full treatment	143,416	2		71,708.2
Water mains	551,470	3,348	km	165.7
Water pumping stations	193,599	n.a.(a)		
Wastewater treatment plants	252,157	6		42,026.2
Sewer mains & channels	616,518	3,378	km	183.5
Wastewater pumping stations	12,119	n.a.(a)		
Dams	522,577	164,200	ML	3.2

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[21] <https://www.ancold.org.au/?page_id=24>. The dataset is: Dams-Australia-2010-v1.xls.

Table A.4 Australian Marine Water Desalination Plants

Facility	*Details*	*Owner*	*Use*
Perth Seawater Desalination Plant	Completed 2006; Cost $387m; Capacity 45 GL/a.	Water Corporation	In continuous operation
Southern Seawater Desalination Plant	Completed 2013; Cost $1,085m; Capacity 100 GL/a.	Water Corporation	In continuous operation
Adelaide Desalination Plant	Completed 2011; Cost $1,824m; Capacity 100 GL/a.	SA Water	Standby mode
Gold Coast Desalination Plant	Completed 2009; Cost $1,120m; Capacity 45 GL/a.	Seqwater (owned by WaterSecure pre-July 2011)	Standby mode (until dam levels are below 60%)
Kurnell Desalination Plant	Completed 2010; Cost $1,803m; Capacity 90 GL/a.	Sydney Desalination Plant Pty Ltd (under 50-year lease from NSW Government)	Standby mode (until dam levels are below 70%)
Victorian Desalination Plant	Completed 2012; Cost $3,500m; Capacity 150 GL/a.	Aquasure consortium (under long-term BOOT arrangement).	Standby mode (until dam levels are below 65% in March).

Appendix B: Total Cost Function & Output Weights

This appendix reports the results of estimating the total cost function for urban water businesses in Australia. These are used for developing output weights used in the Multilateral Total Factor Productivity (MTFP) index analysis.

A cost function has the property that it is linearly homogeneous in input prices. This means that if all input prices increased by the same proportion, then the optimal mix of inputs remains unchanged because their price relativities remain unchanged, and cost must therefore also increase by the same proportion as the input prices. The total cost function here would have two input prices, for capital and non-capital inputs, and linear homogeneity implies that there is only one unknown parameter relating to them. Rather than including input prices as explanatory variables in the econometric model, we have taken an alternative approach of constructing a composite input price index (CIPI), and dividing nominal total cost by that price index to obtain real total cost; which is used as the dependent variable. There are two inputs (non-capital and capital inputs) and the cost shares of each input are used as its weight in the CIPI. This approach assumes that inputs are supplied in competitive markets so that their price relativities reflect the values of their marginal products.

For a panel data model with observations on firms (subscript *i*) and periods (subscript *t*), the CD total cost function can be written as:

$$\ln C_{it} = \beta_0 + \sum_{m=1}^{M} \phi_m \ln q_{m(i,t)} + \sum_{k=1}^{K} \gamma_k z_{k(i,t)} + \lambda t + u_{(i,t)} + v_{(i,t)} \qquad (5.1)$$

where C is total cost; $q_{m(i,t)}$ is the quantity of output *m* produced by firm *i* in period *t*; $z_{k(i,t)}$ is the amount of OEF *k* in period *t* at utility *k*; and *t* is the year (where 2006 = 0, 2007 = 1 and 2008 = 2 etc). Note that OEFs may or may not be in log form. However, total cost and the outputs are all in logs. There are two stochastic terms:

- $u_{(i,t)}$ is a one-sided stochastic term which is strictly positive in the SFA cost function and is assumed to have a truncated normal distribution. In the simplest case of time-invariant inefficiency, *u* only varies between firms but does not change over time. In the time-varying decay specification *u* varies between firms and also changes at the same constant annual rate for all firms. Both approaches are used here.
- $v_{(i,t)}$ is a normally distributed independent random disturbance.

Table B.1 shows the econometric results of estimating the SFA total cost function model, using and the period from 2006 to 2020. The dependent variable in these models is real total cost, which is nominal total cost divided by CIPI. The two models shown in Table B.1 use two different measures of real total cost based on two different CIPI measures, based on alternative capital input measures (and hence different measures of the price of capital inputs). One of these uses the real financial capital measure (ie, based on the real written-down replacement cost of fixed assets) and the other uses the index of physical capital inputs. Both models use an SFA Cobb-Douglas specification, and assume time-varying inefficiency (at the rate indicated by parameter *eta*) and a half-normal distribution for the stochastic inefficiency term. The dependent variable and the outputs were all centred by subtracting their mean values.

Table B.1: Estimated SFA Total Cost Function 2006–2020

	Real financial capital measure		*Physical capital measure*	
	coef	*t-stat*	*coef*	*t-stat*
$\ln q_1$	0.6204	(13.42)	0.7829	(16.52)
$\ln q_2$	0.0942	(3.26)	0.0731	(2.01)
$\ln q_3$	0.1280	(4.82)	0.0340	(1.08)
z_1	0.3206	(4.71)	0.1491	(1.68)
z_2	0.1248	(3.40)	0.0170	(0.40)
z_3	-0.1317	(-6.20)	-0.0721	(-2.66)
z_4	0.2092	(1.88)	0.1968	(1.47)
z_5	0.0000	(0.24)	-0.0001	(-0.85)
z_6	1.6704	(5.19)	1.9669	(4.72)
z_7	-0.0092	(-1.33)	0.0000	(0.00)
z_8	0.0020	(0.28)	0.0119	(1.36)
z_9	0.0693	(2.66)	0.0965	(4.25)
z_{10}	-0.0007	(-0.05)	0.0110	(0.73)
z_{11}	-0.0856	(-0.74)	0.0655	(0.53)
z_{12}	0.0744	(1.55)	-0.0109	(-0.25)
z_{13}	0.1201	(3.53)	0.1552	(3.79)
z_{14}	-0.0929	(-1.89)	-0.0708	(-1.16)
z_{15}	0.1175	(3.24)	0.1942	(4.28)
z_{16}	0.1287	(3.20)	0.0212	(0.43)
t	0.0083	(5.29)	0.0090	(4.95)
cons.	-0.8360	(-1.44)	-0.9403	(-1.57)
mu	0.0000	.	0.0000	.
eta	0.0066	(1.98)	0.0196	(4.52)
sigma_u	0.3635	.	0.3457	.
sigma_v	0.0809	.	0.1004	.
N	867		867	

The coefficients on the outputs in Table B.1 are elasticities of total cost with respect to each output. These cost elasticities are used to formulate weights which reflect the value shares associated with each output, based on marginal costs rather than market prices. These weights are suitable for the TFP analysis in section 5, which is based on the assumption that all inputs are variable and at optimal levels .Table B.2 summarises the relevant coefficients from Table B.1. It shows how they are scaled up so the weights sum to one. The last column shows weights derived from the average of the elasticities from the two models. These weights are used in the MTFP index analysis.

Table B.2: Total Cost Function Output Elasticities

	Real financial capital measure		Physical capital measure		Average	
	Elasticity	*Weight*	*Elasticity*	*Weight*	*Elasticity*	*Weight*
q_1 (customers)	0.62	73.6%	0.78	88.0%	0.70	81.0%
q_2 (water supplied)	0.09	11.2%	0.07	8.2%	0.08	9.7%
q_3 (wastewater collected)	0.13	15.2%	0.03	3.8%	0.08	9.4%
Total	0.84	100.0%	0.89	100.0%	0.87	100.0%

We have not used the total cost function to estimate technical efficiency scores, because:

- capital in the water industry is particularly long-lived, with average asset lives of 50 years or more. This is far longer than the data sample period available. Hence, fixed assets are best viewed as quasi-fixed inputs for the purpose of water utility benchmarking. Hence the use of the variable cost function in section 4.
- capital data is considered to be of comparatively lower quality than most other data used here as discussed in section 2.5. Since total cost needs to be estimated from opex and measures of capital, this implies that total cost measures are affected by the reliability issues pertaining to capital measures.

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