Quantonomics

QUANTITATIVE ECONOMICS

Memorandum

Date: 18/11/2022

From: Michael Cunningham, Joe Hirschberg, Alice Giovani

To: Ashlyn Napier, Cameron Shields (Icon Water)

Subject: Response to Independent Competition and Regulatory Commission Draft Report for Regulated Water and Sewerage Services Prices 2023–28

This memo responds to criticisms that Marsden Jacob Associates (MJA) makes of the Quantonomics (2022) benchmarking study of Icon Water, which has informed the Independent Competition and Regulatory Commission (ICRC) draft decision on regulated water and wastewater service prices for the regulatory period 2023–28. MJA makes these criticisms in an advisory report prepared for the ICRC (Marsden Jacob 2022).

1 Complexity and Replicability

MJA has suggested that the benchmarking study is too complex to be properly evaluated in the ICRC's current review process, and says that the study may not be replicable, thereby insinuating that it could not be corroborated by other studies. We will argue that both these suggestions are false.

1.1 Is the benchmarking analysis too complex to evaluate?

> *"The Quantonomics approach is complex, in particular the stochastic frontier model. Marsden Jacob notes that we have not examined the underlying model or attempted to replicate the results using the same data applied by Quantonomics. Therefore, we are not able to verify whether the model is producing reliable and accurate results. .... Further research could be undertaken to provide independent verification but preferably outside of the current regulatory review given complexities in the modelling approach." (p.36)*

MJA says that it has not *attempted* to reproduce the results,[1] and it is only for this reason that it is not "*able* to verify" the results. This is a limitation of MJA's review, not of Quantonomics'

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[1] The terms replicable and reproducible research are often confused. 'Reproducibility' means obtaining the same results when using the same data and code as the original study (National Academies of Sciences, Engineering, and Medicine 2019, p.72). This is an important criterion of transparency and rigour.

study. We have fully documented our methodology in the report, and responded fully to information requests.

Regulatory decision-making should be evidence-based. The benchmarking study provides an empirical basis for addressing relevant questions when determining Icon Water's opex benchmarks for the forthcoming regulatory period. Evidence submitted in a review process should be properly evaluated.

MJA suggests a shortcoming of the benchmarking study is its undue 'complexity'. On the contrary, the methods used are parsimonious and similar to those used by the Australian Energy Regulator (AER) in electricity benchmarking. It is unclear why they are considered too complex to be evaluated in the ICRC's current regulatory review of Icon Water.

1.2 Is the benchmarking analysis replicable?

> *"We also understand that the National Performance Report data metrics are being reviewed and could change, which means this approach may not be replicable." (p.36-37)*

MJA's claim that the study "may not be replicable" is incorrect. 'Replicability' refers to when a new study can be conducted aimed at answering the same research question using newly collected data and obtaining similar results (National Academies of Sciences, Engineering, and Medicine 2019).[2] MJA does not mean our study has failed to be replicated, or that another researcher has attempted to replicate it but found some impediment to doing so. Rather, they suggest there is likely to be a data constraint preventing such a study because:

(a) the NPR data used in the benchmarking analysis will not be available in future; *and*

(b) other data which can be used to address similar questions or supplement NPR data could not be obtained from other sources.

Both propositions are untrue. MJA's comment is motivated by the *National Performance Reporting Framework Indicator Review* (HARC, Risk Edge & Aither 2021), which will retire around 39 indicators and introduce about 47 new indicators. The detailed recommended changes to the NPR have been available since October 2021 and all of the indicators required for water benchmarking will continue to be available, and indeed, more detailed data will be available for key data such as opex and capex and asset values and important new information on asset condition. Before discussing that review, we begin by addressing proposition (b) and then return to the future availability of NPR data.

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[2] 'Replicability' is an important test of the robustness of the findings of the first study. The degree of similarity of the results needs to be referenced to their uncertainty, as suggested by their confidence intervals. When a study fails to be replicated this means that another study is carried out with new data and obtains inconsistent results. Further, "a successful replication does not guarantee that the original scientific results of a study were correct, nor does a single failed replication conclusively refute the original claims" (National Academies of Sciences, Engineering, and Medicine 2019, p.72)

As a logical matter, the continuance of relevant NPR indicators is not essential for replicability if other sources of data are or would be available. As discussed in section 0 of this memo, several other Australian studies using different data sources have produced similar results for the trends of water industry productivity. Further, the draft report of the NPR indicator review explains that some of the indicators to be retired "overlap with other current or proposed national reporting schemes" (HARC, Risk Edge & Aither 2021, p.6). It emphasises that the NPR is focussed on performance measurement and recommends a refreshed urban water reform dialogue in which other, more specialised data gathering should be considered for other requirements as part of that process. We also note that regulators have the means for gathering information for benchmarking purposes. For example, the AER gathers the information it uses for benchmarking directly from regulated businesses by issuing regulatory information notices. In the water sector, State or Territory regulators gather detailed data from regulated businesses at present, and there is no reason to suppose that they could not continue to gather the information they need or share it for benchmarking purposes.

Turning to proposition (a), in actuality, the NPR indicator review has emphasised that support for economic benchmarking remains a key purpose of the NPR, so that it can:

> "… inform industry benchmarks and can lead to 'competition by comparison.' It informs an understanding of the financial health of service providers, customer and community outcomes and generates insight into affordability. Publicly reporting on costs can also support the assessment of policy and investment decisions and inform regulatory decisions and policy development." (HARC, Risk Edge & Aither 2021, p.23)

The table on pages 27 to 48 of HARC *et al* (2021) shows all of the current NPR indicators, indicating those that will be retired and new indicators to be added.[3] Table A.2 in Appendix A of the benchmarking report listed all the NPR indicators used in our analysis. Appendix A of this memo shows each indicator used in the benchmarking analysis alongside the draft recommendations in HARC *et al* (2001) relating to that indicator. Only one of those indicators will be discontinued (greenhouse emissions relating to water supply), but another greenhouse measure will remain as an alternative. Some data we sourced elsewhere, such as the cost of bulk water purchases and temporary water restrictions, will henceforth be available in the NPR. Many of the new indicators can improve the benchmarking analysis, such as (for each of water supply and wastewater services):

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[3] The main changes are: (i) a number of indicators relating to greenhouse emissions will be replaced by a single indicator; (ii) a few indicators related to customer service and non-payment will be replaced by different indicators, including a new customer satisfaction indicator. There will be additional hardship-related and community engagement measures; (iii) several financial performance indicators will be replaced by better-defined measures; (iv) new indicators for activities promoting water efficiency; (v) improved and additional drinking water quality measures; (vi) a new asset age and condition indicator, and measures of full-time equivalent (FTE) staffing levels; (vii) asset base values, operating expenditure ('opex'), and capital expenditure ('capex') will all be reported in more detail.

- a breakdown of opex into major types including bulk water purchases, recycled water purchases, maintenance costs and other opex, complemented by data for employee full-time equivalents;
- a breakdown of capex into asset renewal capex and other capex;
- additional asset base variables. In additional to the real replacement costs of fixed wastewater assets, new indicators include annual statutory depreciation, regulatory depreciation, and Regulated Asset Base (RAB) value. This will be complemented by an indicator for asset age and condition;[4]
- there will be a new customer satisfaction measure (which in some studies has been used as an output).

We have shown that MJA's suggestion that the benchmarking approach "may not be replicable" is misinformed and incorrect.

2 Criticisms of Econometric Modelling Choices

> *"[W]e have identified issues with the modelling which warrants some further analysis by Quantonomics to provide confidence that the analysis is producing statistically robust and unbiased results." (p.37)*
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> *"[O]ne limitation of the Quantonomics approach is that cost functions should not be log-linear in outputs. If cost functions are log-linear in outputs, then the associated output sets are unbounded, meaning there is no limit to the amount of output that can be produced using a given amount of inputs (e.g., O'Donnell, 2018, p.287)". (p.40)*
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> *Additionally, the elasticity values from the stochastic frontier model may not be correctly estimated because of issues with the stochastic frontier model (i.e. the time invariant inefficiency and time decay aspects of the model) as the estimates of inefficiency may be biased and inconsistent. …". (p.42)*

Econometric modelling requires the use of skill and judgement to make sensible choices about the model specification and estimation methods (Leamer 2012, p.26). There simply are far too many possible combinations of methods and specifications for all to be tested. In regulatory applications, modelling choices are often made on the basis of methods previously used by other researchers or regulators which have proven to be reliable. Simplicity and parsimony are also relevant considerations.

Appendix B explains why we used the approaches we did, and how these approaches derive from earlier work and take stakeholder feedback on that work into account. The methods we

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[4] This additional information in relation to assets will assist to improve measurement in an area that we have emphasised has data consistency and reliability issues, and for that reason we used two alternative measures of capital input.

used are also closely related to those used by the AER in electricity network benchmarking (AER 2021a).

This section discusses several methodological criticisms made by MJA relating to:

- the use of the Cobb-Douglas functional form;
- the specification of the SFA stochastic inefficiency term, and
- whether the Multilateral Törnqvist index is a 'proper index'.

2.1 Opex cost functional form

"[O]ne limitation of the Quantonomics approach is that cost functions should not be log-linear in outputs. If cost functions are log-linear in outputs, then the associated output sets are unbounded, meaning there is no limit to the amount of output that can be produced using a given amount of inputs". (p.40)

MJA claims that the chosen Cobb-Douglas functional form for the opex cost function is inappropriate. This criticism is based on Professor O'Donnell's view that cost functions should not be log-linear in outputs. This criticism is inconsistent with generally accepted principles in a relevant discipline of the econometrics of production and cost.[5] We first discuss commonly accepted practices in regulatory benchmarking and then consider the theoretical basis for and inferences drawn from O'Donnell's views on cost functional forms.

In regulatory applications, it is appropriate to choose widely-used, well-established, and reliable analytical methods in preference to relatively untested or novel approaches. Coelli *et al* (2005, p.211) list seven of the most commonly used functional forms for production, cost or profit functions. Among them are the Cobb-Douglas and Translog specifications, both log-log forms that are linear in parameters. O'Donnell (2018, pp.286–287) acknowledges that "it is common to assume they [cost functions] are either translog or double-log functions" and cites several studies as examples. The Translog function is a second-order flexible function, whereas Cobb-Douglas is a first-order flexible function. Choosing a functional form involves balancing different considerations. Coelli *et al* (2005) list four criteria: (a) flexibility; (b) linear in the parameters; (c) regular; and (d) parsimonious. All of the seven functions they discuss satisfy criteria (b) and (c), but criteria (a) and (d) need to be balanced.

> "All other things being equal, we usually prefer functional forms that are second-order flexible. However, increased flexibility comes at a cost – there are more parameters to estimate, and this may give rise to econometric difficulties (eg., multicollinearity). … The

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[5] This is not a criticism of Professor O'Donnell. We are not suggesting that his views, as an expert in the field of efficiency and productivity analysis, should concur with those of other experts. However, the MJA report should have disclosed that the views presented are inconsistent with widely accepted views of experts in this field, since this is relevant information for the regulatory decision to be made by the ICRC.

> principle of parsimony says we should choose the simplest functional form that 'gets the job done adequately'." (Coelli et al. 2005, pp.211–2)

In its econometric estimation of electricity distribution networks' operating cost functions, the AER uses both the Cobb-Douglas and Translog functional forms (AER 2021a). However, O'Donnell claims that both these functional forms are unsatisfactory. We also see that Ofwat uses either the Cobb-Douglas functional form or a log-log hybrid between the Cobb-Douglas and Translog functions:

> "At PR19 our starting point is the Cobb-Douglas (or "constant elasticity") model. This model assumes that scale or density effects are constant. That is, a percentage change in the explanatory variable (for example scale or density) results in the same percentage change in costs for all companies. Starting with the Cobb-Douglas specification, we would add non-linear or cross-product terms only when there is a clear economic or engineering rationale for doing so and statistical tests show such non-linear effects to be important. ... The majority of companies agreed with this approach. Some companies expressed concerns about the use of translog cost functions due to instability over different modelling specifications, multicollinearity and difficulty of interpretation."

The Translog function has the advantage of being more flexible, but the Cobb-Douglas function is more parsimonious and easier to implement.[6] In summary, we have shown that MJA's criticism is inconsistent with widely used empirical methods in the field of applied producer economics and is out of touch with established regulatory practice in regard to the estimation of cost models.

We turn now to the *theoretical* basis for, and inferences drawn from, O'Donnell's claim that a cost function cannot be of the Cobb-Douglas form because, in some circumstances, in such a function, output is 'unbounded'. O'Donnell (2018) sources this proposition from O'Donnell (2016) who, using the duality between the cost and distance function, in turn sources this proposition from Coelli and Perelman (1999). The latter authors note in passing that Lawrence Klein in 1953 observed that "the Cobb-Douglas transformation function would not be an acceptable model of a firm in a purely competitive industry because it is not concave in the output dimensions" (Coelli & Perelman 1999, p.329).[7] We have three observations to make about this issue:

(a) Although the Coelli and Perelman (1999) study preferred to use the Translog distance function rather than the Cobb-Douglas distance function in their application, we have

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[6] SFA is estimated using the maximum likelihood method, which usually uses iterative numerical algorithms to search for the parameter vector that maximises the likelihood function. Hence, when more complex models are used, depending on the characteristics of the data sample, there can sometimes be difficulty obtaining a solution.

[7] Notwithstanding this comment about applications to competitive markets, Klein used a multi-output Cobb-Douglas transformation function in his econometric analysis of railway passenger and freight services (Coelli & Perelman 1999, p.332).

already discussed the views of Coelli et al (2005) on cost functional forms, and they certainly do not reject or criticise the use of the Cobb-Douglas specification.

(b) Urban water utilities in Australia are natural or statutory monopolies within their specified supply areas. They do not operate in a "purely competitive industry" and therefore, this argument against the Cobb-Douglas specification may have been misapplied if it depends crucially on that premise.

(c) In any econometric analysis, the choice of functional form represents an approximation to the relationship of interest *within the domain of estimation and application*. The properties of the function outside that domain, such as when extrapolated to some extreme, are immaterial. Hence, even if the argument were applicable (which we have questioned), it would be incumbent on MJA to show that this point is relevant to the domain of data and forecasts relevant to the study, which they have not done. Since Icon Water is a mid-sized water utility in the data sample,[8] there is no application of the model which is not far inside the domain defined by the dataset used for estimation.

2.2 SFA inefficiency term specification

> *"Additionally, the elasticity values from the stochastic frontier model may not be correctly estimated because of issues with the stochastic frontier model (i.e. the time invariant inefficiency and time decay aspects of the model) as the estimates of inefficiency may be biased and inconsistent. … Quantonomics has developed cost efficiency scores under the assumption that the inefficiency effects (the u variable in equation 2) are either time-invariant or they decay over time. The effect of this approach is shown in Figure 13 which shows the cost efficiency scores over time across the water businesses. There does not appear to be a theoretical rationale for this restrictive assumption and it potentially has the effect of leading to biased and inconsistent estimates of efficiency if these restrictive assumptions are not correct. Moreover, this approach implies that firms do not learn from their mistakes, and the time-decay model says that if water business A is the k-th most efficient business in the sample in period 1, then it will be the k-th most efficient business in every period. … Importantly, the approach does not allow us to understand how variable cost inefficiency is changing over time for different water businesses. … Our overall assessment is that the firm specific analysis may not be useful for providing insights into Icon's variable cost inefficiency (or input-oriented technical efficiency as discussed in O'Donnell, 2018) relative to other water businesses unless the inefficiency effects are allowed to vary in the stochastic frontier model over time by firm." (pp. 42-47)*

To clarify, our benchmarking report uses the time-varying decay SFA model due to Battese and Coelli (1992), with the inefficiency terms having a half-normal distribution. The report

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[8] The number of Icon Water's customers is about 9 per cent of Sydney Water's, and the number of Byron Water's customers is approximately 6 per cent of Icon Water's.

could have been clearer on some aspects of this, but it is discussed on pages 34-35, and the results in Table 4.1 include the parameter ‘eta’, which is the decay parameter, and the parameter ‘mu’ has a value of zero associated with the half-normal assumption.

MJA is critical of the time-varying decay modelling choice but also rejects a time-invariant inefficiency specification (Pitt & Lee 1981; Battese & Coelli 1988). We will argue that these two SFA models are among the most widely used in the empirical literature and hence, this criticism is inconsistent with generally accepted principles in a relevant discipline of the econometrics of production and cost.[9] We also argue that MJA has not put forward a credible alternative which is demonstrated to be feasible in this application.

In SFA, the stochastic part of the model has two components: (a) a normally distributed random variable intended to capture the effects of statistical noise; and (b) a one-sided (ie, strictly positive or strictly negative) random variable intended to capture the effects of technical or cost inefficiency. Alternative distributions can be assumed for the one-sided component. The half-normal and exponential distributions are simplest, being single-parameter distributions, while the truncated-normal and Gamma distributions are more flexible two-parameter distributions. Kumbhakar & Lovell (2000, p.9) remark that single parameter distributions “remain the distributions of choice in the vast majority of empirical work”.

Particularly when panel data is used, the stochastic inefficiency term may be specified as the product of a cross-sectional stochastic component and a deterministic part: $u_{it} = u_i . g(\mathbf{z}, t)$; where u_i is a cross-sectional inefficiency term, and $g(.)$ is a function of time (t) and possibly other variables ($\mathbf{z}$). Important special cases are the time-invariant inefficiency model, in which g is a constant and equal to 1, and the time-varying decay inefficiency model, in which $g(t) = \exp[-\eta(t - T_i)]$; where η is the decay parameter and T_i is the last period in the sample for utility i. These specifications are simple and relatively robust given the challenges of estimating SFA models previously mentioned, and they are among the most widely used SFA models when applied to panel data. This is evidenced by the fact that these are the only two options offered in standard Stata (the *xtfrontier* command).[10]

In short panels, time-invariant efficiency may be assumed, but the “longer the panel, the less tenable this assumption becomes” (Kumbhakar & Lovell 2000, p.10). Hence, the time-varying inefficiency may be preferable in longer panels. Our study uses the time-varying decay model.

This discussion supports the view that the assumptions we employed, using a half-normal distribution for inefficiency parameters, and the time-varying decay model are consistent with widely-used practices with a panel dataset, as used in the study.

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[9] This is not a criticism of Professor O’Donnell. We are not suggesting that his views, as an expert in the field of efficiency and productivity analysis, should concur with those of other experts. However, the MJA report should have disclosed that the views presented are inconsistent with widely accepted views of experts in this field, since this is relevant information for the regulatory decision to be made by the ICRC.

[10] A wider set of SFA models is available in the user-contributed command, *sfpanel* (Belotti et al. 2012).

MJA argues that the time-varying decay model is not flexible enough, and there should be utility-specific time trends in the inefficiency parameters. Greater flexibility comes at a cost, namely the need to estimate a great many more parameters. For example, with a sample of 64 urban water businesses, adding a separate linear inefficiency trend term for each utility would increase the number of parameters to be estimated from 25 to 88 (or more). Such a proliferation of time-trend parameters can produce a number of estimation problems, including an inability to adequately estimate the effects of the main variables in the model (the outputs and capital stock) and the possibility (or likelihood) of spurious estimates for the trended efficiency effects due to multi-collinearity.[11]

MJA has not specified the actual approach they are proposing, nor referred to any studies where their proposed approach has been carried out. Hence, it is not possible to respond specifically to this argument. However, the points we have raised above, and the lack of examples where such an approach has been employed, strongly suggest that it is doubtful that MJA's proposed approach would be feasible in practice in this application.

2.3 Is the Multilateral Tönrqvist index improper?

> *"The multilateral Opex PFP is essentially a Törnqvist index … one concern is whether the Törnqvist indices are proper indices which means that they meet the axioms listed in O'Donnell (2018, Ch. 3) . The implication is that the multilateral indices will provide a misleading picture of productivity unless the output or input weighting shares are constant over time (which is what would be required for a proper index)." (p. 44)*

MJA appear to have made an error by failing to distinguish between the ordinary bilateral or chained bilateral Törnqvist index and the Multilateral Törnqvist index used in our study.[12] This distinction is important because these two types of indexes perform differently against the usual tests, including importantly the 'circularity' test. Thus, criticisms of the chained bilateral Törnqvist index not satisfying the circularity (or 'transitivity') test do not carry over to the Multilateral Törnqvist index.

In addition to highlighting this possible error, we also point out that MJA's statements about the chained bilateral Törnqvist index, while not applicable to our study, are also inconsistent with generally accepted principles in a relevant discipline of the index numbers and

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[11] This point is exemplified by the additional modelling presented in Appendix C and discussed in section 4.2 These models add an additional 14 parameters to the benchmarking model (for time-varying technical change), increasing the number of parameters to be estimated to 39. Here we see the wastewater collected output is not statistically significant (at a 0.05 level) in either the real financial capital or the physical capital models. This highlights our point that multiplying the parameters to be estimated using time-trend effects make it more difficult to adequately estimate the main effects of the model. Increasing the number of parameters to 88, in this sample, would greatly amplify this problem and be likely render all the main effects insignificant, and the resulting model unreliable.

[12] A chained bilateral index compares a sequence of observations over time. A multilateral index compares cross-sectionally (eg, countries or firms) and over time.

inconsistent with the practices of Australian and international statistical agencies.[13] We do not believe that a broad-based rejection of widely-accepted principles and practices within the applied economics and statistics field of index numbers is, or should be, part of the ICRC's agenda in regulating Icon Water.

2.3.1 Transitivity, characteristicity and the Multilateral Törnqvist index

Numerous index number formulae have been developed and the well-established approach to choosing among them involves specifying a number of desirable characteristics (either in the form of tests or axioms) and finding those that meet or best meet the chosen criteria. Among the various criteria (Coelli et al. 2005, pp.95–96), one is circularity/transitivity, whereby the index formula when applied to two periods, say 0 and 2, is equal to the product of the indexes between these periods via another period; eg, $I_{0,2} = I_{0,1} \times I_{1,2}$. Another criterion often considered important is 'characteristicity', which means that when comparing two observations, an index should use information sufficiently closely related to those two observations. One problem that arises is in balancing the circularity and characteristicity criteria. Caves *et al* (1982, p.74) state "... 'characteristicity and circularity are always... in conflict with each other.' The implication is that some degree of characteristicity must be sacrificed to obtain circularity".

It is well known that the chained bilateral Törnqvist index does not satisfy the circularity (ie, transitivity) test, and the same applies to the Fisher Ideal index (Coelli et al. 2005, p.96). However, the Multilateral Törnqvist index *does* meet this test. Caves *et al* (1982, p.84) state: "These indexes provide transitive multilateral comparisons that maintain a high degree of characteristicity". And Fox (2003, p.407) states:

> "Multilateral index numbers are used for price, output, input and productivity comparisons across economic entities, such as countries. They satisfy a circularity (transitivity) requirement so that the same result is achieved if countries are compared with each other directly, or with each other through their relationships with other countries. Standard (bilateral) index-number formulae do not satisfy this circularity requirement."

Caves *et al* (1982) observe that even though 'superlative multilateral indexes' such as the Multilateral Törnqvist index satisfy the circularity test:

> "… they are not necessarily preferable to chain-linked bilateral indexes for time series comparisons. This follows because chronology provides a natural ordering of time series data that is lacking for cross-section or panel data" (p.84).

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[13] This is not a criticism of Professor O'Donnell. We are not suggesting that his views, as an expert in the field of efficiency and productivity analysis, should concur with those of other experts. However, we think that MJA ought to have disclosed that the views presented are not widely held among experts in this field, which is relevant to the regulatory decision to be made by the ICRC.

When additional data is added, the Multilateral Törnqvist index will result in changes in index numbers over all observations, which is an undesirable property in many time series indexes. This is why statistical agencies such as the Australian Bureau of Statistics (ABS) most often use chain-linked bilateral indexes which do not satisfy the circularity test.

This discussion shows that MJA appears to have incorrectly conflated the Multilateral Törnqvist index with the chained Törnqvist index, since these two index formulae perform differently against the criteria of the test approach. Importantly, the Multilateral Törnqvist index satisfies the property of circularity/transitivity while maintaining a high degree of characteristicity.

2.3.2 Transitivity, characteristicity and the chained Törnqvist index

It is also relevant to examine MJA's general criticism that the Törnqvist index is not a 'proper index', which we take to be mainly directed to the chained bilateral Törnqvist index's not satisfying the circularity test, although we acknowledge that MJA also makes the stronger claim that a 'proper index' should have fixed weights. This discussion will highlight the nature of some of the criticisms made of our study, which are motivated by a broad-based rejection of widely-accepted principles and practices within the applied economics and statistics field of index numbers.

The claim that the chained Törnqvist index is not a 'proper index', and that output or input weights should be constant, is not widely accepted in the relevant discipline. Professor O'Donnell's view has been specifically criticised by other experts in the productivity and efficiency field:

> "O'Donnell (2012, 2014, 2016) takes … Circularity (or "Transitivity") as an essential property for his output and input quantity indexes. ... The U.S. Bureau of Economic Analysis used … [fixed price weights] to compute its historical series of real GDP for the US economy for many years but they eventually switched to chained Fisher quantity indexes because they found that whenever they updated their old historical series using a new set of price weights, they dramatically changed US economic history. Fisher (1922; p. 274) noted that … "the only formulae which conform perfectly to the circular test are index numbers which have constant weights..." Fisher (1922; p. 275) went on to assert: "But, clearly, constant weighting is not theoretically correct. If we compare 1913 with 1914, we need one set of weights; if we compare 1913 with 1915, we need, theoretically at least, another set of weights. ... Similarly, turning from time to space, an index number for comparing the United States and England requires one set of weights, and an index number for comparing the United States and France requires, theoretically at least, another." Frisch (1936; p. 6) was even blunter in his criticism of fixed weight price indexes: "The fundamental difficulty is that, in most cases, particularly for geographical comparisons or comparisons between remote points of time, it is absurd to assume constant q's". Thus along with Fisher and Frisch, we do not favor the fixed weight quantity indexes used by O'Donnell." (Diewert & Fox 2017, p.279)

It is common practice for statistical agencies to use chained indexes (with changing weights) for official statistics, and the Törnqvist and Fisher Ideal index formulae, which do not satisfy the circularity test, are widely used by Australian and international statistical agencies for measuring productivity. The OECD manual on *Measuring Productivity* (Schreyer 2001, p.83) recommends using chain index number formulae, where indexes are rebased and linked in successive years, and not a fixed weights index formula. The *System of National Accounts 2008* (SNA08) recommends the use of chain indexes for inter-temporal comparisons over longer periods because:

> "… over time the pattern of relative prices in the base period tends to become progressively less relevant to the economic situations of later periods to the point where it becomes unacceptable to continue using them to measure volume changes from one period to the next. … The more frequently weights are updated the more representative will the resulting price or volume series be. Annual chain indices result from compiling annual indices over two consecutive years each with updated weights" (United Nations et al. 2009, p.299).

The SNA08 also states: "It has been shown on theoretical grounds that long time series of volume and price indices are best derived by being chained" (United Nations et al. 2009, p.306).

On the choice of the specific index number formula, the OECD observes that when the different formulae are tested against a number of criteria, the Fisher and the Törnqvist index come out first on most criteria, and they both produce very similar empirical results (Schreyer 2001, p.83). Coelli *et al* (2005, p.97) similarly conclude that "the choice of formula is essentially between the Fisher and Törnqvist indices." For calculating its productivity measures, the ABS uses the Törnqvist index formula for each constituent input index (Australian Bureau of Statistics 2021a, pp.513–16).

We have shown that the claims that the Törnqvist index is not a 'proper index' and that fixed weight indexes should be used are inconsistent with widespread practices and express recommendations of Australian and international statistical agencies. Also, they are inconsistent with the view of many experts in the relevant fields of the economic and statistical theory of index numbers and of productivity measurement. We do not believe that a broad-based rejection of widely-accepted principles and practices within the applied economics and statistics field of index numbers is, or should be, part of the ICRC's agenda in regulating Icon Water.

3 Output and Productivity Forecasts in the Base-Step-Trend Framework

"Our analysis indicates that scaling the output weightings to sum to unity is appropriate provided that the productivity growth factor (currently 0.5 per cent proposed in Icon's price submission) incorporates

factors that are not just scale related but includes other drivers of productivity. This provides some evidence that the value of the productivity growth factor is above 0.5 per cent per annum." (p.38)

"[The modelling] indicates increasing returns to scale as a 1 per cent increase in output quantities increases variable costs by 0.76 per cent. This straight application approach is not used by Icon Water in setting output growth. Rather, the elasticities have been used to create weightings that sum to unity, thereby ensuring a constant return to scale assumption (i.e., a 1 per cent increase in output quantities increases variable costs by 1 per cent)." (p.41)

We will argue that the foregoing statements are mistaken, and the conclusions reached are incorrect. MJA appears to be unclear about our methodology and calculations used to derive output weights and productivity trends from the estimated opex cost function, even though these methodologies and calculations are clearly set out in our report, and we have responded in detail to questions raised by MJA on these matters. Furthermore, some of MJA's recommendations are inconsistent with the base-step trend method of forecasting opex.

In this section we repeat the main steps in the calculations, as set out in the benchmarking report, to clarify the nature of the foregoing errors. Section 3.1 addresses a confusion, implicit in the quotes above, about the base-step-trend method of forecasting opex. Section 3.2 shows that certain statements of MJA, also implicit in the quotes above, incorrectly claim that constant returns-to-scale has been assumed in forecasting opex. Section 3.3 shows that the "other drivers of productivity" mentioned in the quotes above are taken into account in our productivity forecast and are separately shown in our report. Finally, in section 3.4, some concluding comments are made.

3.1 The base-step-trend method

In section 4.4 of the benchmarking report we clearly stated our methodology for using the results of the econometric opex cost function to: (i) calculate output weights, which are used to forecast the output index from individual output forecasts; and (ii) project trends in productivity based on the distinct effects of technical change, economies of scale and the effects of changes in the (quasi-fixed) capital stock. In Table 6.1 of our report, we show each component of the drivers of opex growth, including the separate elements determining the forecast productivity growth rate. This method of using the opex cost function to separately forecast output growth and productivity is consistent with the base-step trend method.

MJA criticizes our method, saying:

> "A more significant concern is the application of the output weights in Table 13 to generate an overall output growth figure which is used to calculate the rate of change in Equation 1. A straight application of the results of the stochastic frontier analysis would be to place forecasts for each of the variables (x, q, z and λ) into Equation 2 to forecast future variable costs" (Marsden Jacob 2022, p.41).

This statement is to be inconsistent with the base-step-trend approach for forecasting opex, which requires, among other things, separate forecasts of output growth and opex productivity growth. The method which we clearly present in the report *does* use the opex cost function, but uses it in a format that is consistent with the base-step-trend approach. We separately forecast the rate of output growth and opex partial factor productivity (PFP_o) consistent with the model.

3.2 Is constant returns-to-scale implied?

MJA incorrectly claims that constant returns-to-scale has been assumed in forecasting opex, stating: "This approach implies constant returns to scale as it results in a 1 per cent increase in overall output quantities increasing variable costs by 1 per cent" (Marsden Jacob 2022, p.40).

The derivation of our forecast productivity growth in Table 6.1 clearly shows a positive effect of output growth on productivity growth of 0.34 in 2024 increasing to 0.44 in 2028. This is the benefit to productivity arising from economies of scale. We proceed to explain this in more detail.

By definition of the rate of change in opex partial factor productivity ($P\dot{F}P_o$), the rate of change in real variable cost ($\dot{VC}$) is:[14] $\dot{VC} = \dot{Q} - P\dot{F}P_o$ (where dots above variables indicate rates of change, and $\dot{Q}$ denotes the rate of change in the output index). This is in the format of the base-step-trend method and is the format of presentation in Table 6.1 of the report.

In equation (4.4) of the report, we show that the effect of changes in scale on $P\dot{F}P_o$ is: $(1 - \varepsilon_Q)\dot{Q}$, where $\varepsilon_Q \equiv \sum_{m=1}^{M} \varepsilon_{q_m}$, the sum of the individual cost-output elasticities is called the *elasticity of scale*. It follows that the proportionate effect of output growth on variable cost growth is: $\dot{VC}/\dot{Q} = 1 - (1 - \varepsilon_Q) = \varepsilon_Q$. Table 4.3 of the report shows the estimated value of the elasticity of scale for the Australian urban water industry is 0.76, which is consistent with economies of scale because it is less than 1. This shows that MJA's statement that "a 1 per cent increase in overall output quantities increasing variable costs by 1 per cent" is false. A 1 per cent increase in the output index increases the variable cost (ie, opex) by the value of the elasticity of scale (0.76).

This is clearly presented in Table 6.1. The effect of output growth on variable cost growth is equal to:

- the direct effect, which as Table 6.1 shows is 1.43 per cent in 2024, increasing to 1.83 per cent in 2028, *minus*

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[14] The opex cost function model uses real variable cost as the dependent variable, defined as nominal variable cost deflated by a price index of opex inputs. Real variable cost is a measure of the quantity of non-capital inputs. The opex partial factor productivity is defined as: $PFP_o = Q/VC$.

- the effect of output growth on PFP, which is 0.34 per cent in 2024 increasing to 0.44 per cent in 2028.

The net result of these two effects, divided by the output growth rate is equal to the elasticity of scale: (1.43 – 0.34)/1.43 = 0.76 in 2024, and (1.83 – 0.44)/1.83 = 0.76 in 2028. Hence, we have shown that MJA is incorrect in its claims concerning the assumed returns to scale as increasing returns to scale is implied.

3.3 Calculation of the opex PFP growth measure

Equation (4.4) of our report explains how the rate of productivity change, $P\dot{F}P_o$, is calculated using the estimated parameters of the opex cost function. Equation 4.4 is derived to calculate partial factor productivity (PFP), and is given as:

$$P\dot{F}P_o = (1 - \varepsilon_Q)\dot{Q} - \varepsilon_{x_k}.\dot{x}_k - \sum_n \gamma_n \frac{z_n}{\partial t} - \left(\lambda + \frac{\partial u}{\partial t}\right) \tag{4.4}$$

We now discuss each of the terms on the right-hand side of equation (4.4):

- $(1 - \varepsilon_Q)\dot{Q}$ is the effect of economies of scale (output) discussed in section 3.2 above, which contributes 0.34 percentage points to Opex PFP change in 2024 increasing to 0.44 percentage points in 2028;
- $-\varepsilon_{x_k}.\dot{x}_k$ is the effect of changes in the capital stock, which as Table 6.1 of the report shows, contributes –0.08 percentage points in 2024 decreasing to –0.17 percentage points in 2028;
- $-\sum_n \gamma_n \frac{z_n}{\partial t}$, is the combined effect of changes in the OEFs. As the report states (p.45), there is assumed to be no change in any of the OEFs for the purpose of forecasting Opex PFP. This a common assumption, reflecting the nature of OEFs as background conditions which are assumed to be relatively stable over short spans of time, and these effects are generally small (Economic Insights 2019, pp.76–77, 2020, pp.74–75);
- $-\left(\lambda + \frac{\partial u}{\partial t}\right)$ represents the two remaining components of productivity change, namely the rate of frontier shift (λ), and the average rate of catch-up productivity change for the industry ($\partial u/\partial t$). Equation (4.5) of the benchmarking report shows that in the time-varying decay SFA model: $\partial u/\partial t = -\eta\bar{u}$, where $\bar{u}$ is the mean value of u_i (the inefficiency measures for each business in the sample), and η (eta) is the estimated rate of decay of inefficiency over time. Averaging over the two models (ie, the financial capital and physical capital models), the average value of λ is 0.208; the average value of η is 0.303, and the average of the reported values of $\bar{u}$ is 0.278. Hence the rate of underlying industry-wide productivity change is –1.23 per cent per year, which is shown in Table 6.1 of the report.

- The rate of Icon Water's catch-up productivity change is in excess of the average industry rate of catch-up gain and forecast separately based on Icon Water's estimated degree of efficiency (see section 7.4 of the report), and hence is not part of the calculation in Table 6.1 of the report.

This shows that:

- the estimated opex cost function *has* been used in making the forecasts shown in table 6.1 of the report in a way that is consistent with the base-step-trend method, and as used in previous regulatory benchmarking studies (eg, Economic Insights 2019, 2020).
- the other drivers of productivity, such as the effects of changes in the capital stock and the effects of economies of scale have not been excluded. We have accounted for *all* the drivers of variable costs.

3.4 Concluding comments

We have shown that MJA is incorrect to claim that the effects of economies of scale and of "other drivers of productivity" were not accounted for in our forecast. However, these claims by MJA formed the basis of their argument that "the value of the productivity growth factor is above 0.5 per cent per annum" (Marsden Jacob 2022, p.42). Therefore, we have established that MJA's views on the outlook for productivity growth do not have a sound basis.

4 Estimating Industry Productivity Trends

> *"A further concern is that the growth rate of -0.9 per cent per annum used by Quantonomics for the industry wide component appears to be too low when considering the movement in the index in recent years. Much of the negative growth rate appears to have been driven by large falls in productivity in the first half of the total modelled period and the cumulative average annual growth rate for the second half of this period (i.e. 2012 to 2020) is 0.3 per cent per annum. This suggests that a more relevant productivity figure may well be 0.3 per cent per annum than -0.9 per cent per annum." (p.45)*
>
> *"… it is possible that the impact of the frontier shift on Opex PFP over the period 2006 to 2020 has occurred because of shifts in the frontier in the first half of this period. This conclusion could be validated by placing two time variables for two different time periods into the stochastic frontier model (e.g. 2006 to 2012 and 2013 to 2020). However, it is noted that this addition may not to be necessary if the time invariant inefficiency and time decay restrictions are removed from the model." (p.46)*

In section 3 we discussed how we forecast Icon Water's underlying opex productivity change (or 'frontier shift'), which does not include its forecast 'catch-up' productivity (ie, its improvement relative to the more efficient cohorts of urban water businesses). Icon Water's catch-up productivity is discussed in section 5 below.

This separation of Icon Water's productivity forecast into frontier shift and catch-up is not accurately characterised by MJA as 'industry-wide' and 'firm-specific' factors.[15] Nevertheless, we showed that using the Opex PFP index from the Multilateral Törnqvist index analysis, the average industry Opex PFP rate of change of –0.9 per cent per annum is similar to the estimated rate of frontier shift for Icon Water, which was also estimated to be –0.9 per cent per annum. This section contests MJA's assertion that this estimate "appears to be too low".

We have previously identified MJA's error in relation to whether the effects of scale and other factors affecting productivity were taken into account when forecasting Icon Water's underlying productivity trend using the econometric model. This section discusses:

- MJA's use of the pattern of the Opex PFP index over time to infer a change in the historical opex productivity trend and its claim that using a historical average trend to forecast the rate of technical change is "backward-looking" (section 4.1);
- the empirical question of whether there has been a change in the time-trend of technical change over the sample period and whether MJA's claim that this can be characterised as a faster decline in the first half of the sample period and a slower decline in the second half (section 4.2); and
- whether MJA's subjective judgement that the productivity trend "appears to be too low" has any empirical support from other studies relevant to Australian water industry productivity trends (section 4.3).

4.1 Opex PFP Index & Structural Change in the Productivity Trend

> *"Another concern is that the use of a partial productivity index, which only uses one of the inputs (i.e. operating expenditure), is not a holistic examination of productivity since it provides insights into historical movements in Opex PFP which may have been influenced by changes in historical capital expenditure. This is relevant as the interrelationship between these two variables is not considered in setting a productivity adjustment for operating expenditure and highlights the limitation of using Opex PFP to provide guidance on setting a future productivity adjustment for operating expenditure. … Additionally, a further limitation of the analysis is that estimating the productivity growth factor using the methods applied by Quantonomics is a backward-looking approach since it assumes that historical productivity growth provides insights into future productivity growth." (p. 45)*

In the quoted statements, MJA argues that the Opex PFP index, as a partial productivity index, provides an unreliable basis for setting a future productivity adjustment for operating expenditure. And they also criticise the use of historical productivity trends as a basis for opex forecasting productivity trends as being 'backward-looking'. However, MJA contradicts both

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[15] As previously noted, Icon Water's frontier shift (or underlying Opex PFP change) includes some effects such as economies of scale and the effects of changes in the capital stock which will differ in degree between utilities. Firm-specific 'catch-up' productivity gain is only one kind of firm-specific effect on productivity.

of these opinions because it relies on historical movements in the Opex PFP index (Marsden Jacob 2022, pp.45–46, Table 17 & Figure 12) to reach its main conclusion about the industry-wide opex productivity trend in the period 2013 to 2020, on which it bases its forecast of the industry-wide opex productivity component over the next regulatory period.

As previously discussed, MJA also rejects the Multilateral Törnqvist index number method we used (because Professor O'Donnell regards a 'proper index' as one with fixed weights). However, they state that the Opex PFP measure is not subject to this particular criticism because the output index has constant weights over all periods and utilities; but they do not discuss the opex input index. Section 2.4 of the report discusses the variables used in the report and shows in detail how each variable is calculated. The measure of non-capital (or, 'opex') input is an index combining two components, (a) an index of the real operating expenses excluding expenditure on bulk water (or 'real net operating expenses'); and (b) an index of the quantity of bulk water purchases. "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" (Quantonomics 2022, p.13). Thus, the non-capital input index is not a fixed-weight index; it is unlikely to meet the axioms which O'Donnell (2018) uses to define a 'proper index'. If not, then MJA has also contradicted this criticism by relying on the Opex PFP index.

In this section we argue that:

- the use that MJA makes of the Opex PFP index is potentially misleading; and
- using historical trends of estimates of the rate of technical change is a widely used method for aggregate productivity projections by official agencies, also for determining productivity factors in economic regulation plans.

4.1.1 Use of Opex PFP trends

MJA arbitrarily divides the sample period into two halves, without regard to the long-lived nature of water and wastewater assets, and estimates that there has been a slow average rate of increase in the Opex PFP index in second of these two periods. It is then inferred that there has been an opex productivity increase in more recent years:

> "Much of the negative growth rate appears to have been driven by large falls in [Opex PFP] productivity in the first half of the total modelled period and the cumulative average annual growth rate for the second half of this period (i.e. 2012 to 2020) is 0.3 per cent per annum. This suggests that a more relevant productivity figure may well be 0.3 per cent per annum than -0.9 per cent per annum". (Marsden Jacob 2022, p.45)

This observation forms the basis of its main recommendation to the ICRC, even though it has expressly stated that the Opex PFP index provides an unreliable basis for forecasting productivity and that historical averages in general do not provide a good guide for forecasting productivity. That is, MJA has used a methodology which it has explicitly rejected.

We have relied on the results of the econometric opex cost function to forecast Icon Water's underlying opex productivity trend and used the Multilateral Opex PFP index analysis to provide additional information. We found that the trend of industry-wide opex productivity using the index approach was similar to Icon Water's projected rate of frontier shift using the econometric model. And as discussed in section 4.1.2, we do not agree with MJA's suggestion that historical average rates of productivity change should not be used for forecasting productivity trends.

It should be noted that when calculating averages over sub-periods of a data sample, the results can be strongly affected by the choice of the start and end years of the sub-period, and many sub-periods that could be defined for a sufficiently long sample period. Hence, MJA's method of arbitrarily choosing to divide the sample into two halves can be misleading, if relied on to reach strong conclusions about changes in trends. In section 4.2 we consider whether MJA's claim that there has been an underlying change in the rate of industry opex productivity in recent years is empirically supported by undertaking further econometric analysis of the opex cost function for the Australian urban water industry. This analysis will further clarify our point that the choice of sub-periods can produce misleading inferences.

4.1.2 Is the use of historical average productivity trends "backward-looking"?

The rate of technical change is typically estimated as the residual, after controlling for the observable factors which determine productivity change (such as scale economies and 'catch-up' effects). By implication, it is problematic to develop a deterministic forecast of technical change based on the expected future values of its determinants because the causal determinants of technical change are difficult to quantify. A common approach is to view technical change as having an underlying trend, although with considerable year-to-year volatility. Technical change is often forecast by extrapolating its trend into the future, assuming no shocks that cause volatility. The trend component may be determined using the average growth rate over a long period, or by using a more sophisticated time series analysis method. In either case, this involves extracting historical trends from historical data.

For instance, Petropoulos et al. (2022, p.74) observe with respect to aggregate productivity forecasting:

> "The most common approach for forecasting productivity is to estimate the trend growth in productivity using aggregate data. … The Office for Budget Responsibility (OBR) in the UK and the Congressional Budget Office (CBO) in the US follow similar approaches for generating its forecasts of productivity based on average historical growth rates as well as judgments about factors that may cause productivity to deviate from its historical trend in the short-term. Alternative approaches include forecasting aggregate productivity using disaggregated firm-level data … and using time-series models."

This leaves the important issue of the historical timeframe over which the trend rate of growth should be calculated, and judgements to be made about other factors that could cause deviation from past trends, but confirms that the use of historical trend is common practice for forecasting productivity.

In applications of productivity forecasting in economic regulation, the historical average growth rate is widely used. Lowry and Kaufmann (2002) describe the North American approach to performance-based regulation, in which utility price movements are constrained by a price cap index (PCI). The PCI can be formulated in a variety of ways, with one approach being for the PCI for each forthcoming year to be calculated using a formula using recent actual movements in an index of input prices and on the historical trend in productivity. The productivity trend component may be based on a rolling average of recent firm-specific outcomes, or the long-term industry TFP trend, with the latter being typical. For example, Pacific Economic Group (PEG) forecast productivity growth based on the long-run average rate over its sample period of 11 years (PEG 2007, p.22).

In Australian regulation of electricity distribution, the AER has adopted a forecast opex productivity factor of 0.5 per cent per year, based in part on historical time trend for opex productivity in the gas distribution industry and historical opex PFP trends in the electricity distribution industry (AER 2019).

Kaufmann (2010, p.14) finds that "observed data from Victoria and other jurisdictions shows that this longer-trend trend [in the TFP index] is in fact relatively stable". According to Lowry and Getachew (2009a, p.328): "The recent long run trend in an industry's TFP is often, if not always, a good proxy for the prospective trend over the next several years". These authors specifically recommend the approach of separating the effects of technical change, returns-to-scale and the catch-up effect on which our approach is based. In this approach, only the technical change component of productivity changes is forecast based on its historical trend.

We have shown that using historical trends of estimates of the rate of technical change is a widely used method for aggregate productivity projections by official agencies, and also for determining productivity factors in economic regulation plans. MJA has not mentioned what method of forecasting technical change it considers superior to relying on a historical trend. Therefore, we must reject MJA's claim that such methods are 'backward-looking' as being unfounded.

4.2 Is there a change in the rate of opex productivity in recent years?

> *"[T]he stochastic frontier model should be tested with two time variables to reflect the structural change that may be present for the first and last half of the total time period. However, it is noted that this addition may not to be necessary if the time invariant and time decay restrictions are removed from the model." (p.48)*

MJA recommends that further econometric analysis be carried out to establish whether there is a structural break in the time trend of opex productivity during the period 2006 to 2020. They propose that the sample period should be arbitrarily divided into two halves using a dummy variable and applying this to the time-trend variable to yield separate estimates of the rate of technical change in each of the two sub-periods. This is an inappropriate procedure because assumes that the timing of a possible structural break is known. The usual approach to testing for a structural break involves: (i) testing for a structural break of unknown timing; and (ii) estimating the timing of the structural break if one is found (Hansen 2001).

We investigate this question using a more general approach, by estimating the SFA variable cost function for the period from 2006 to 2020 with a change in specification following Baltagi and Griffin (1988), which is used to estimate a fully general index of opex productivity for the urban water industry. Rather than including a time trend variable to estimate a constant average rate of opex productivity change, in this specification there is a separate dummy variable for each year in the sample (except the first year). In all other respects the models are the same as those presented in Table 4.1 of the benchmarking report. The model estimated is specified as:

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

$$+ \sum_{s=2}^{15} \lambda_s D_{s(i,t)} + u_{(i,t)} + v_{(i,t)}$$

using the same notation as equation (4.1) of the benchmarking report, and with $D_{s(i,t)} = 1$ if $t = s$, and equals zero otherwise. The estimated models are presented in Appendix C. The estimated λ coefficients are similar for the two estimated models (ie, using the real financial capital measure and the physical capital measure).

We aim to compare the time-varying technical change estimated using this model with the constant rate of technical change estimated using the model shown in Table 4.1 of the benchmarking report.[16]

Using the Baltagi-Griffin specification, the coefficients on the dummy variables for years (ie, the λ) yield a time-varying index of opex technical change (P). This index has a value of 1.0 in year 1 (2006), and in each subsequent year is:

$$P_t^{PG} = \exp(-\lambda_t), \qquad t > 1$$

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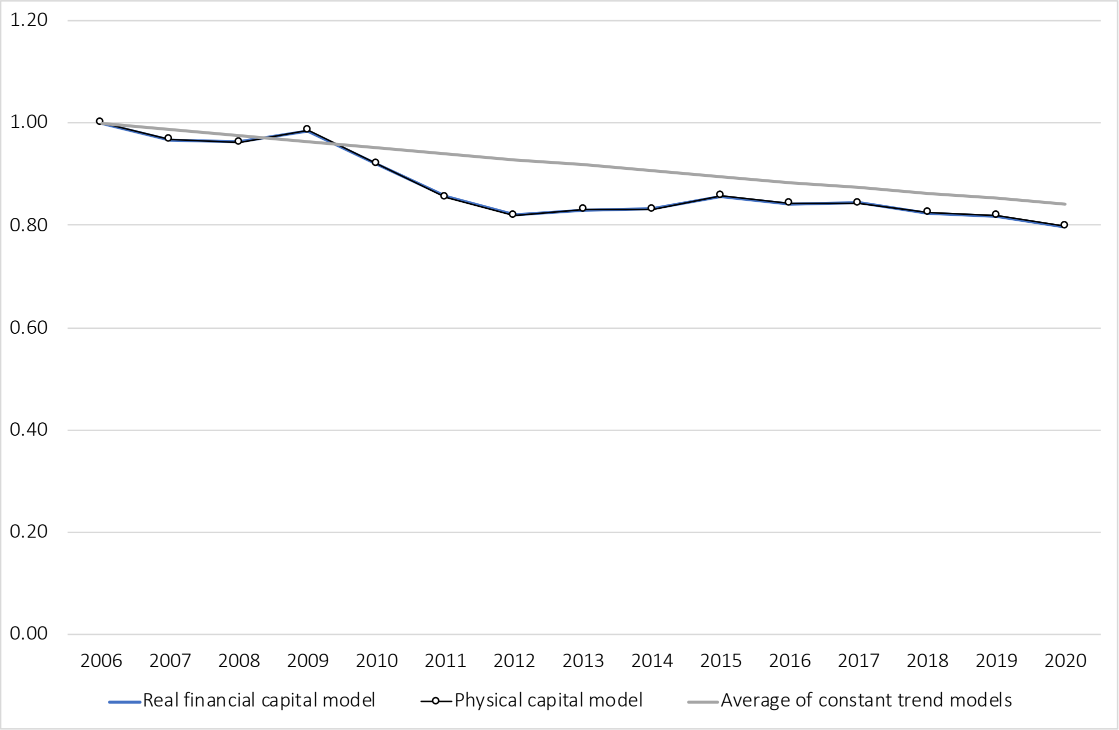
[16] This does not include the effect of the industry 'catch-up' effect via the time-varying decay terms.

This can be compared to an index calculated from the constant trend model, which again has a value of 1 in 2006 and in each subsequent year is:

$$P_t^{CT} = P_{t-1}^{CT} \exp(-\lambda)\,, \qquad t > 1$$

These indexes also need to be adjusted for the industry-wide catch-up effect.[17] Figure 1 shows the resulting time-varying opex productivity index compared to the constant trend case from the average of the two models in the benchmarking report.

Figure 1: Industry opex cost efficiency underlying trend



Source: Quantonomics analysis.

Key observations:

- The two models with a time-varying opex technical efficiency index generate almost identical generalised indexes of technical change.
- The average decline in opex technical change is slightly greater when the generalised index of technical change is used.
- Over the recent period from 2015 to 2020, the average rate of decline in the generalised index of technical change is very close to the constant trend rate of change.

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[17] That is, $P_t^j \times I_t^j$, where j represents the model, and $I_t^i = I_{t-1}^i \exp(\eta^j \bar{u}^j)$, for $t > 1$, and is equal to 1.0 for $t = 1$.

It can be seen that the generalised index of technical change dipped below trend in the period 2010 to 2014. Consequently, calculating an average with an end-point in that period will produce a misleading estimate of the recent trend. This is clearly shown by the fact that from 2015 to 2020, the generalised index of technical change declines at an average rate of 1.5 per cent per year, which is similar to:

- the average rate of decline of the same index over the period 2006 to 2020, which is 1.6 per cent per year;
- the constant rate of decline of the constant trend model, which is 1.2 per cent per year.

This analysis demonstrates that MJA's claim that the industry-wide productivity trend declined sharply in the first half of the sample period and then improved in the second half of the sample period is not supported by empirical analysis.

4.3 Other evidence of decline in water industry productivity

"A further concern is that the growth rate of -0.9 per cent per annum used by Quantonomics for the industry wide component appears to be too low when considering the movement in the index in recent years." (p.45)

"In relation to productivity growth, using the Quantonomics results as they stand, our assessment of the Quantonomics modelling indicates that productivity growth rate should be 1.4 per cent per annum allowing for a 10 year adjustment period. A higher value (2.4 per cent) could be used assuming a shorter adjustment period." (p.38)

In our benchmarking report we stated (p.50)

> 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. … 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.

MJA draws from the Quantonomics study, applies its own judgement, and forms an opinion about the future trend of industry-wide productivity. Little attention is given to other relevant sources of information on productivity trends, which might reasonably be used to inform judgements on the appropriate industry-wide component of the opex productivity factor.

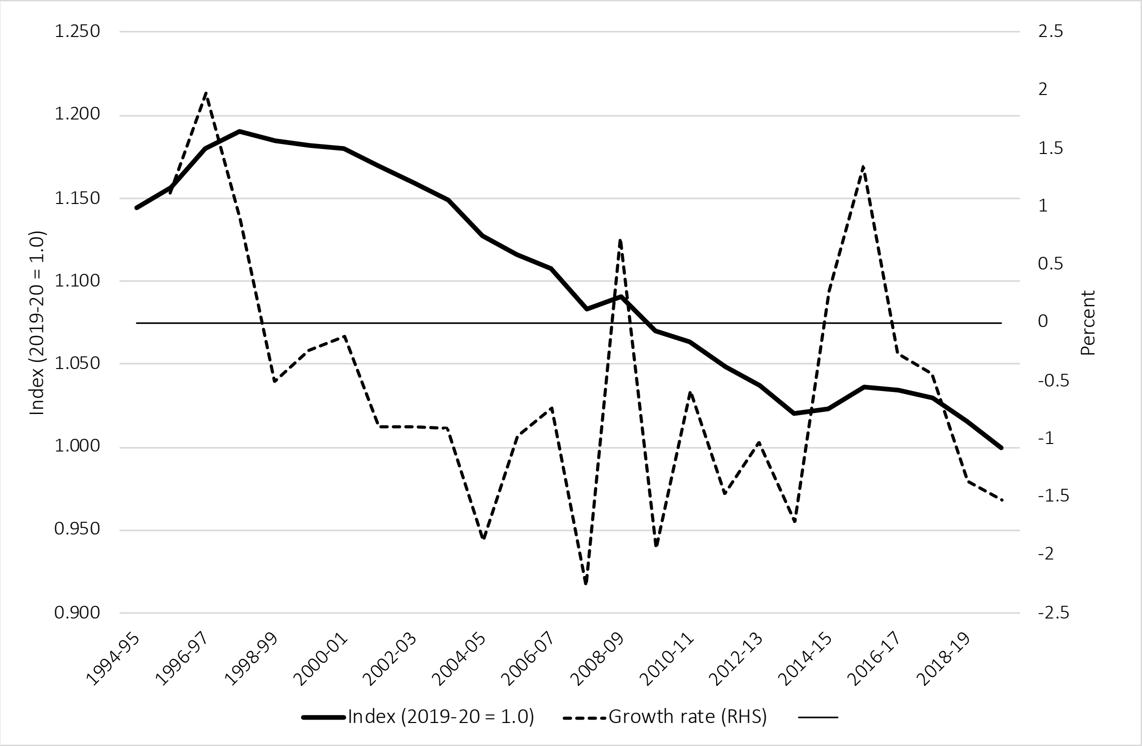
This section reviews a range of productivity estimates, including by the Australian Bureau of Statistics (ABS) for the Australian Electricity, Gas Water and Waste (EGWW) industry and the Productivity Commission's (PC) analysis of the Water industry component of that sector. Also reviewed are productivity studies of urban water businesses produced or commissioned by economic regulators, the Independent Pricing and Regulatory Tribunal (IPART) and the

Essential Services Commission of Victoria (ESC). All show a large and ongoing decline in the productivity of the urban water industry. We also consider the reasons for the ongoing water productivity decline which are discussed in some of those studies.

4.3.1 Relevant studies by the ABS and PC

The finding of an average decline in the opex productivity of the Australian urban water industry is not unusual. The ABS produces estimates of multifactor productivity (MFP) for Australian industry sectors, including the EGWW sector. The most pertinent measure for comparing the results with industry productivity studies is Gross Output based MFP.[18] Figure 2 shows the trend in the MFP index and the annual growth rates for the EGWW sector published by the ABS. The MFP index for the EGWW sector has almost continuously declined since 1997-98. Over the last 22 years, there have only been three years with positive MFP growth. And between 2005-06 and 2019-20, the average rate of change in the MFP index is –0.8 per cent per year.

Figure 2: Trend is EGWW Total Factor Productivity



Data source: ABS 5260.0.55.004 Estimates of Industry Level KLEMS Multifactor Productivity, Table 4.

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[18] MFP is synonymous with total factor productivity (TFP). For the EGWW sector, the KLEMS Multifactor Productivity index (Australian Bureau of Statistics 2021b) produces almost identical results to the Gross Output based MFP index on quality-adjusted hours worked basis (Australian Bureau of Statistics 2021c).

Unfortunately, there is limited current research on the reasons for this productivity decline. In a now-dated PC staff paper, Topp and Kulys (2012), examined the reasons for the decline in EGWW productivity over the period 1997-98 and 2009-10. Using the same data and methods as the ABS, the study examined the largest subdivisions of the EGWW industry; (a) Electricity supply and (b) Water supply, sewerage and drainage services (WSSD); and (c) Gas supply. The study found that WSSD productivity increased strongly from the mid-1980s to the late 1990s, but was generally negative over the period from the late 1990s to 2009-10. The decline in MFP from the peak of around 1997-98 through to 2019-10 was found to be greater in the WSSD industry than in the wider EGWW sector.

Topp and Kulys identified some of the factors that substantially impacted productivity in the WSSD sector in the period examined; (i) restrictions on water use in response to drought conditions; (ii) stricter sewage treatment standards; (iii) cyclical investment patterns, and (iv) a shift to higher-cost sources of new water supplies. The authors warned that if the reduced household water consumption in the drought years (through water-saving initiatives and changes in attitudes to water use) persists as a structural demand change, the recovery of productivity may take a long time. In addition to the uncertain effects of long-term changes in the structure of electricity demand, the study also highlighted the possible effects of government policies (including as owners of water utilities), regulatory settings and external shocks (especially shifts in weather patterns associated with climate change). Developments of these kinds can require additional investments, reduce utilisation or alter the maintenance costs of existing assets, or impose new sources of operating costs.

This reference to long-term movements in weather patterns raises the issue of climate change. A report by the National Water Commission in 2012 observed that water utilities are likely to incur climate change-related costs, such as adapting to lower and more variable water availability and mitigating risks associated with possible climate events (National Water Commission 2012, pp.xiii–xiv).

4.3.2 Studies by or for regulators

An investigation of productivity trends of NSW state-owned corporations in the urban water sector was carried out by IPART (2010). The study found that after 2003-04, the productivity of both Sydney Water and Hunter Water decreased substantially. IPART said (p.25):

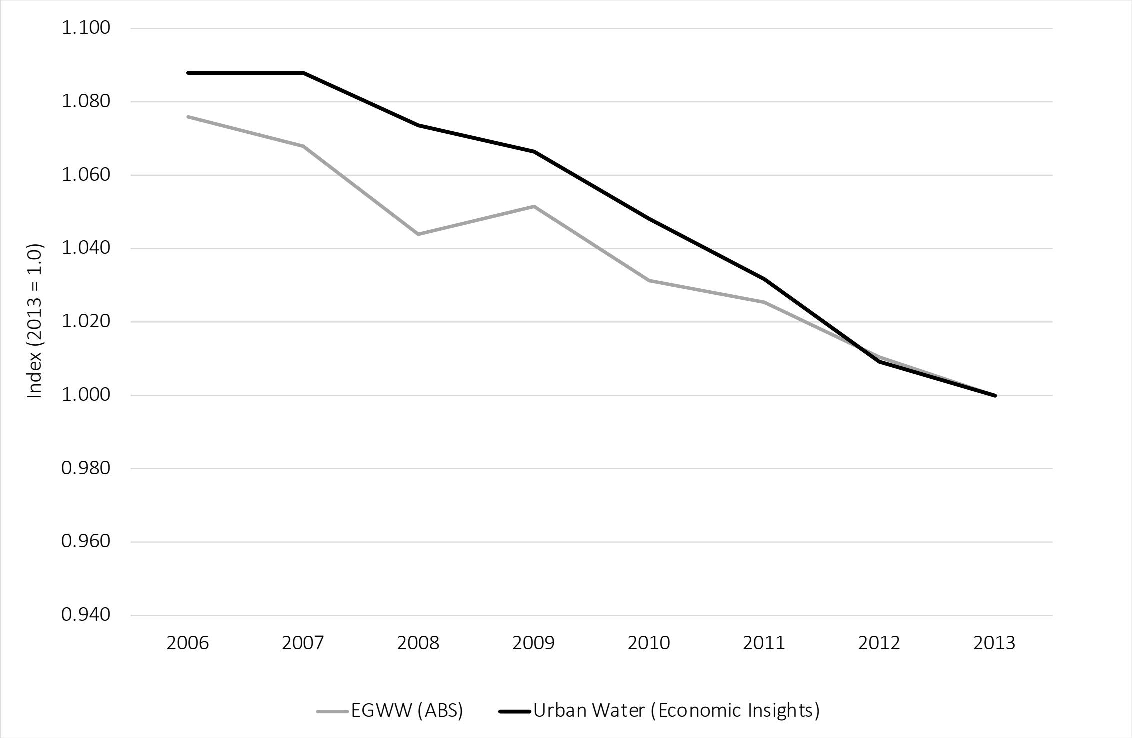
> "Indicators of Sydney Water and Hunter Water's compliance with their water quality, water security, environmental and other requirements show that they met all key requirements over the analysis period. We note that increases in these requirements, some of which are set out in their licences and others in government policies, were the main driver of the increases in their capital expenditure."

IPART predicted that there would be further deterioration of productivity due to these factors, observing that "the quality of planning and decision making on the public policy objectives that drive their expenditure will be critical for future productivity performance" (p.25). Policy requirements or standards are significant drivers of cost for urban water corporations, but the benefits are not included in the outputs used for productivity measurement. Indeed, since water businesses are almost all government-owned, policy requirements in relation to water services can be ubiquitous and often not transparent.

IPART also observed that urban water businesses often operate under policies to conserve water and reduce per-capita consumption, and hence when outputs include water volumes supplied, then in this aspect of their operations they are actually working to reduce productivity. Even though IPART did not include water volumes as an output measure, it still observed the productivity declines after 2003-04 mentioned above.

Another study of urban water productivity was done by the ESC (2012a), which involved an econometric analysis of the Translog distance function using stochastic frontier analysis (SFA). It used a large sample of urban water utilities represented in the National Water Report and earlier statistical publications of the Water Services Association of Australia (WSAA). The study estimated the industry average rate of change in TFP over the period 2006 to 2010 at –0.5 per cent per year. A subsequent study for the ESC by Economic Insights (2014a) estimated that for the period 2006 to 2013, the industry average annual rate of TFP change was –1.2 per cent per year. Figure 3 compares the trend in the TFP index derived in the Economic Insight study against the ABS's productivity index for the EGWW sector.

Figure 3: Trends in Urban Water and EGWW Total Factor Productivity



Data source: Economic Insights (2014a, p.35), ABS 5260.0.55.004.

4.3.3 Discussion

Since the foregoing studies of urban water productivity were conducted, productivity in the broader EGWW sector has mostly continued to decrease (with the exception of 2014-15 and 2015-16). Given the importance of the water industry in the EGWW sector and the reported findings that in the past the productivity trends in the water industry have been similar to the EGWW sector, there is every reason to conclude that more recent trends in EGWW MFP are likely to provide a reasonable guide to water industry productivity trends. The finding of the Quantonomics study of an average decline in the opex productivity of the Australian urban water industry is consistent with this expectation and with the results of previous studies.

Explanations of productivity movements at aggregate levels such as an industry are inherently difficult. In principle, productivity movements represent a combination of the internal performances of firms and external factors that cannot easily be observed, such as technology change or changes in standards, policies or regulations, to name just a few. The foregoing discussion has highlighted some of the external factors that may be impacting urban water industry productivity trends:

- long-term changes in household water demand patterns, particularly towards greater conservation of water use (eg, the installation of increasingly water-efficient household dishwashers and washing machines);
- climate change-related costs, such as adapting to lower and more variable water availability, and mitigating risks associated with possible climate events;
- increases in the marginal costs of water sources or supply infrastructure in the context of population growth and water security concerns associated with climate change;
- changes in regulatory settings or government policies impacting urban water industry productivity, which may include:
    - higher drinking water quality standards or compliance enforcement;
    - higher service quality standards;
    - higher safety, security of supply or technical standards;
    - greater emphasis by water businesses on environmental or social objectives; or
    - increases in regulatory compliance and policy-engagement costs.

Most of these factors are difficult to measure or explicitly incorporate into a productivity analysis. They only appear in the 'residual'—that is, the measured trend in underlying productivity of the sector.

MJA's comment that "industry wide component appears to be too low" is not reflective of the available empirical evidence. Our results are consistent with those of the previous studies we have reviewed in this section. MJA has not indicated that it had regard to other productivity analyses of the sector in assessing the reasonableness of our results. There is good reason for our opinion 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" (Quantonomics 2022, p.50).

MJA's opinion that the water industry productivity trend is likely to be positive over the forthcoming regulatory period is one of two key planks in its recommended productivity factor of 1.4 per cent per year. We have shown that MJA's forecast of future growth in water industry productivity of 0.3 per cent per year is unrealistic and at odds with the available evidence on water industry productivity trends.

4.4 Summary comments

We have shown that even though MJA rejects that use of the Opex PFP for the purposes of ascertaining productivity trends, and also rejects forecasts as 'backward-looking' if they rely on the extrapolation of historical trends, MJA actually relies on the trend in the Opex PFP index over the 2013 to 2020 period to derive its key conclusion on the likely future trend of industry-wide opex productivity growth. MJA has therefore applied a method which it has expressly rejected as unsound.

We show that using historical trends of estimates of the rate of productivity change is a widely used method for aggregate productivity projections by official agencies, and also for determining productivity factors in economic regulation plans. We have also argued that the arbitrary selection of a sample sub-period for averaging can be misleading if one of the chosen end-points is in some way unrepresentative, and therefore strongly influences the average growth rate.

For the purpose of assessing MJA's claim that there has been a change in the trend of opex productivity during the sample period (from sharp decline in the first half of the period, to slow growth in the second half) we have estimated the benchmarking model with a different parameter for technical change in each year, rather than a single time trend. Instead of a single average rate of technical change, this alternative approach yields a generalised index of technical change, with a different rate in each year. Using this approach, we show that MJA's supposition about a change in trend of opex PFP is not borne out by this empirical analysis. On the contrary, the rate of technical change over recent years has closely tracked the long-term average for the whole sample period.

This section has also surveyed a range of other analysis of productivity trends relevant to the water industry. The results of our study are consistent with those of the previous studies we have reviewed in finding a large and ongoing downward trend in productivity in the water industry over an extended period encompassing the sample period used in our study. This survey provides solid grounds for our opinion, expressed in the report, 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" (Quantonomics 2022, p.50). This evidence is also inconsistent with MJA's claim that our finding for the "industry wide component appears to be too low".

This survey shows that MJA's forecast of future growth in water industry productivity of 0.3 per cent per year is unrealistic and at odds with the available evidence on water industry productivity trends.

5 Forecasting Icon Water catch-up productivity

The second key plank of MJA's recommended productivity factor of 1.4 per cent per year is its rejection of the proposed target efficiency threshold of the 67th percentile, in favour of a threshold of the 75th percentile. This would result in an increase in the 'catch-up' component of the productivity factor from 0.8 per cent per annum to 1.1 per cent per annum. With regard to the timeframe over which this threshold is to be achieved, MJA does not reject our proposed 10-year timeframe. MJA calculates the 'catch-up' component for both 5-year and 10-year timeframes, and while they note that a five-year period would align with the regulatory period, they express uncertainty over whether the 75th percentile would be achievable within a 5-year period (which would imply a catch-up factor of 2.1 per cent per annum).

We will argue in section 5.1 that MJA has made a fundamental error in its argument for the 75th percentile target based on the AER's practice in electricity network regulation. When this error is rectified, it is seen that this precedent supports our recommended 67th percentile threshold. In section 5.2 we discuss important considerations relevant to the timeframe over which the threshold can feasibly be achieved. These considerations support our recommended catch-up period of 10 years.

5.1 The threshold 67th percentile

> *"A further issue with the approach of Quantonomics is the choice of the 67th percentile to set the target for future efficiency gains. As an arbitrary target, the choice of percentile could be set at a higher level. For example, the AER has previously used the 75th percentile to define an efficient benchmark for electricity distribution companies. Applying the 75th percentile results in a productivity catchup rate of 1.1 per cent per annum, noting the caveats with the time invariant specification of the stochastic frontier model." (pp. 47)*

Although we accept that there is a considerable degree of judgement in the proposed standard of comparison at the 67th percentile, we do not accept that it is arbitrary (as stated in the quote above) since we did provide some reasoning in support of that recommendation. We discuss that reasoning below. A more significant issue is that MJA has incorrectly characterised the AER's used of benchmarking efficiency scores. The AER uses an *efficiency score* of 0.75 as a comparator point, not the 75th percentile. We will first elaborate on MJA's error and then revisit the reasons we gave in support of using the 67th percentile.

In its 2021 Jemena decision, the AER states: "The best possible efficiency score is 1.0. We use a 0.75 *comparator point* to assess the relative efficiency of distribution businesses" (Australian Energy Regulator (AER) 2021b, pp.6–19). In its 2021 benchmarking report for electricity distribution network service providers (DNSPs), the AER says that it compares "the efficiency scores of individual DNSPs against a benchmark *comparison score* of 0.75 (adjusted further for OEFs …" (AER 2021a, p.60). The AER does say that the comparator efficiency score of 0.75 "reflects that we consider the upper quartile *of possible efficiency scores* are efficient" (Australian Energy Regulator (AER) 2020, pp.6–37, emphasis added). The range of *possible* efficiency scores is from 0 to 1. This does not refer to the distribution of the estimated *actual* efficiency scores of the 13 DNSPs the AER benchmarks (which is not uniformly distributed over the interval from 0 to 1).

The estimated efficiency scores for all DNSPs, including most importantly the averages over four econometric models, are published in the benchmarking reports. The 2021 results for average efficiency scores using the sample period 2006 to 2020 are presented in Economic Insights (2021, p.30, Table 3.4, last column).[19] The average of the efficiency scores is 0.69; the 67th percentile score is 0.77; and the 75th percentile score is 0.80. Hence, the AER's threshold efficiency score of 0.75 *corresponds to a percentile less than the 67th percentile*.

The AER's practice in electricity distribution recognises that the comparative efficiency scores obtained in benchmarking studies are subject to significant measurement error, and need to be applied with appropriate caution. Their use of a threshold less than the 67th percentile in electricity distribution strongly supports our proposed use of the 67th percentile for Icon Water.

We now turn to reasons for choosing a particular comparator standard. Lowry & Getachew (2009b) provide a useful discussion of standards of comparison in benchmarking. "While it is possible to use frontier benchmarking methods to implement the competitive standard, care must be taken in determining the reference performance against which firms are evaluated. This requires the adjustment of benchmarks from frontier methods to reflect performance some distance from the estimated frontier" (Lowry & Getachew 2009b, p.1328). The 75th percentile score is one of the possible comparator standards. Our report explains why we suggested the 67th percentile may be an appropriate benchmark standard for the urban water industry. We stated: "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 [water] 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)" (Quantonomics 2022, p.44).

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[19] The AER also uses efficiency scores estimated over the shorter 2012 to 2020 period, but for brevity we refer here only to those for 2006 to 2020.

5.2 Catch-up period

> *"…a more reasonable value would be 1.4 per cent per annum allowing for a 10-year adjustment period. A higher value (2.4 per cent) could be used assuming an adjustment period of 5 years (which would be consistent with the length of the regulatory pricing period. However, it is unclear whether this is achievable within the 5-year forecast period. The recommended adjustment using a 5 year or 10 year transition period is shown in Table 19". (p.48)*

Our benchmarking report suggested a 10-year period for Icon Water to catch up to the 67th percentile. MJA presents results for both 10-year and 5-year catch-up periods, but gives greater emphasis to the longer period. In this section we discuss some of the relevant considerations that inform a reasonable catch-up period.

The urban water industry has particularly long-lived assets, with average lives of 50 years or more. As observed by Lawrence and Diewert (2006, p.235), the capital-intensive nature of infrastructure businesses can restrict the rate at which productivity gaps can be bridged, and "a time frame of a decade, or two five-year regulatory periods, is likely to be necessary for businesses performing near the bottom of the range to lift themselves into the middle of the pack" (Lawrence & Diewert 2006, p.235).

A related, but distinct, consideration is the amount of capital expenditure relative to the overall asset base. Coelli *et al.* (2003, pp.100–101) note:

> "One factor to keep in mind when assessing a firm's ability to achieve a particular X-factor is to look at the amount of new investment in capital that is planned for that firm over the next regulatory period (usually five years). The point is that technical change can be both embodied and disembodied, and a firm that has significant investment plans, either because of demand growth or because of replacement of existing capital, will find that TFP growth is easier to achieve than a firm that has less planned investment activity."

When capital is long-lived and not subject to substantial rates of replacement, this will influence not only the ability to improve the productivity of capital inputs, but also the ability to improve the productivity of non-capital inputs, much of which is tied to the operation and maintenance of existing plant and equipment.

For these reasons, our suggested catch-up period of 10 years is reasonable, and a shorter catch-up period would be likely to impose excessive risk.

5.3 Summary comments

We have shown that MJA has made an error in claiming that the AER uses the 75th percentile target in electricity network regulation. The AER uses a 0.75 *comparator score* to assess whether a distribution business is inefficient. The AER's threshold efficiency score of 0.75 *corresponds* *to a percentile less than the 67th percentile*. This strongly supports our proposed use of the 67th percentile.

We have also discussed important considerations relevant to the timeframe over which the threshold can feasibly be achieved. Key considerations are the longevity of assets, since businesses with long-lived assets will find it more difficult to improve productivity when part of its opex is related to the operation and maintenance of existing plant and equipment. The rate of capex relative to the capital stock can also be important, since embodied technical change may be more concentrated when a higher proportion of 'lumpy' capital is replaced. The water industry has particularly long-lived assets and therefore, these considerations support our recommended catch-up period of 10 years.

6 Precedents in other regulatory decisions

> *"An overall productivity growth of 1.4% is consistent with the minimum expectations for Victorian water business set by the Essential Services Commission for their 2023-28 operating expenditure forecasts. It is also comparable to the Office of the Tasmanian Economic Regulator's recent decision for TasWater which applied an annual productivity growth rate of 1.5% to its operating expenditure forecasts."*

In drawing examples of productivity adjustment factors adopted by other regulators, MJA has selected for comparison just one regulatory decision (Office of the Tasmanian Economic Regulator (OTTER) 2022), together with another regulator's stated expectation in preliminary guidance material prior to receiving proposals and undertaking consultations (Essential Services Commission (ESC) 2021). We will argue that:

- the narrowness of these comparisons gives a distorted picture of the pattern of recent regulatory decisions on urban water productivity factors, and
- the ESC example, which should be based on actual decisions, ignores the fact that productivity factors applied to Victorian metropolitan water utilities relate to a much narrower concept of 'controllable' opex due to their greater degree of vertical separation compared to other comparators.[20]

MJA also argues that the recommended productivity adjustment factor for Icon Water "is materially less than the productivity growth adjustment applied in the current regulatory period of 1.75 per cent" (Marsden Jacob 2022, p.42), which was put forward by Icon Water for the 2018–2023 period and accepted by ICRC (Calibre 2018, p.58). We see no reason why

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[20] It is also important to note, and relevant when we come to compare actual productivity factors of Victorian water businesses to other water businesses, that the ESC provides offsetting benefits to water businesses that propose ambitious opex productivity targets by providing a higher return on equity in its rate of return decisions. The implications of this for comparisons is briefly noted in the discussion below of the ESC's 2018 decisions for the three Melbourne metropolitan water businesses.

a productivity forecast made five years ago for the 2018–2023 period should be regarded as an appropriate forecast of Icon Water's productivity trend for the 2023–2028 period. For example, it may have included some known areas of productivity improvement which are since exhausted. Or it may be been based on different expectations about industry-wide productivity change at that time.

6.1 Summary of recent relevant regulatory decisions

This section summarizes a number of decisions of Australian regulators on productivity adjustment factors for water businesses, focussing only on large urban water businesses subject to independent regulation. The Queensland Competition Authority (QCA) does not regulate urban retail water businesses,[21] and the Economic Regulation Authority (ERA) in Western Australia does not regulate the Water Corporation.[22] The non-Victorian comparators include:[23]

- *Sydney Water*: with IPART determining annual productivity factors of 0.75 per cent in 2016, and 0.8 per cent in 2020;
- *Hunter Water*: with annual productivity factors of 0.25 per cent in 2016, and 0.8 per cent in 2020;
- *TasWater*: with OTTER determining annual productivity factors of 1.5 per cent in both 2018 and 2022;
- *SA Water*: with the Essential Services Commission of South Australia (ESCOSA) establishing annual productivity factors of 1.25 per cent in 2016, and 0.5 per cent in 2020.

These productivity factors are generally applied to 'controllable opex', and for most of these businesses the majority of opex is controllable. For all of these water businesses with the exception of Sydney Water, controllable opex appears to account for close to 100 per cent of total opex. For Sydney Water approximately 68.5 per cent of opex was controllable in 2016 (IPART 2016a, p.81) and 73.0 per cent in 2020 (IPART 2020a, p.36).

In the ICRC's application of the base-step-trend method, the productivity factor is applied to total controllable opex, including across bulk water supply, distribution and retailing services.[24]

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[21] http://www.qca.org.au/project/urban-retail-water/.

[22] https://www.erawa.com.au/water.

[23] In all cases, the productivity adjustment factor includes both frontier shift and catch-up when these two components are explicitly identified. If the productivity factor varies over the regulatory period, the average is used.

[24] For Icon Water, controllable opex was 76.7 per cent in 2018 (Calibre 2018, p.46). We treat Icon Water and Sydney Water, Hunter Water, TasWater and SA Water as being comparable in the sense that the majority of their opex is controllable.

We now turn to the Victorian metropolitan urban water businesses. As noted by MJA, the ESC (2021, p.82) suggests that it would expect a 'standard submission' for opex would incorporate a rate of efficiency improvement of approximately 1.4 per cent per year, similar to the average for such businesses in the 2018 water price review. However, one needs to look at the *actual* 2018 decisions to get a clear understanding of the comparative productivity factors that were actually applied over the five-year period 2018–2023, which are more reliable comparators than a statement of expectations.

Table 1 shows a summary of the stated productivity factors used by the three Victorian metropolitan water retailers in 2018 under the PREMO ("performance, risk, engagement, management and outcomes") framework (ESC 2016a). These factors apply to metropolitan water businesses' 'controllable cost', which is opex minus charges from Melbourne Water for bulk potable water supply and wastewater treatment, and minus licence fees and the Government Environmental Levy. The charges from Melbourne Water represent a large part of the operating costs of Melbourne water businesses, whereas Icon Water has a vertically-integrated structure.

Table 1: Metropolitan Melbourne urban water PREMO decisions 2018

Utility	*Productivity factor (%)*	*Controllable opex (% of total)*	*Comparative productivity factor (%)*
City West Water	2.0	22.6	0.45
South East Water	2.3	19.0	0.44
Yarra Valley Water	2.5	20.1	0.50

Sources: ESC (2018a, pp.10–13, 2018b, pp.11–14, 2018c, pp.11–14)

The regulatory decision applicable to Melbourne Water at the time these decisions were made, applying to the 2016–2021 period, did not have any opex productivity adjustment factor; and incorporated some significant opex increases due partly to the increased costs of the pollution response and waterways and drainage services (ESC 2016b). Hence, to provide a relevant comparison to Icon Water, the productivity factors of the three urban water distributors need to be multiplied by the percentage of their opex which was 'controllable' opex. Table 1 shows this calculation, and the comparative productivity factor for these three urban water businesses ranged from 0.45 to 0.50. MJA's reference to the ESC's expectation of 1.4 per cent is misleading because it fails to acknowledge that for metropolitan Victorian water businesses, controllable opex represents only a comparatively small proportion of total opex.[25]

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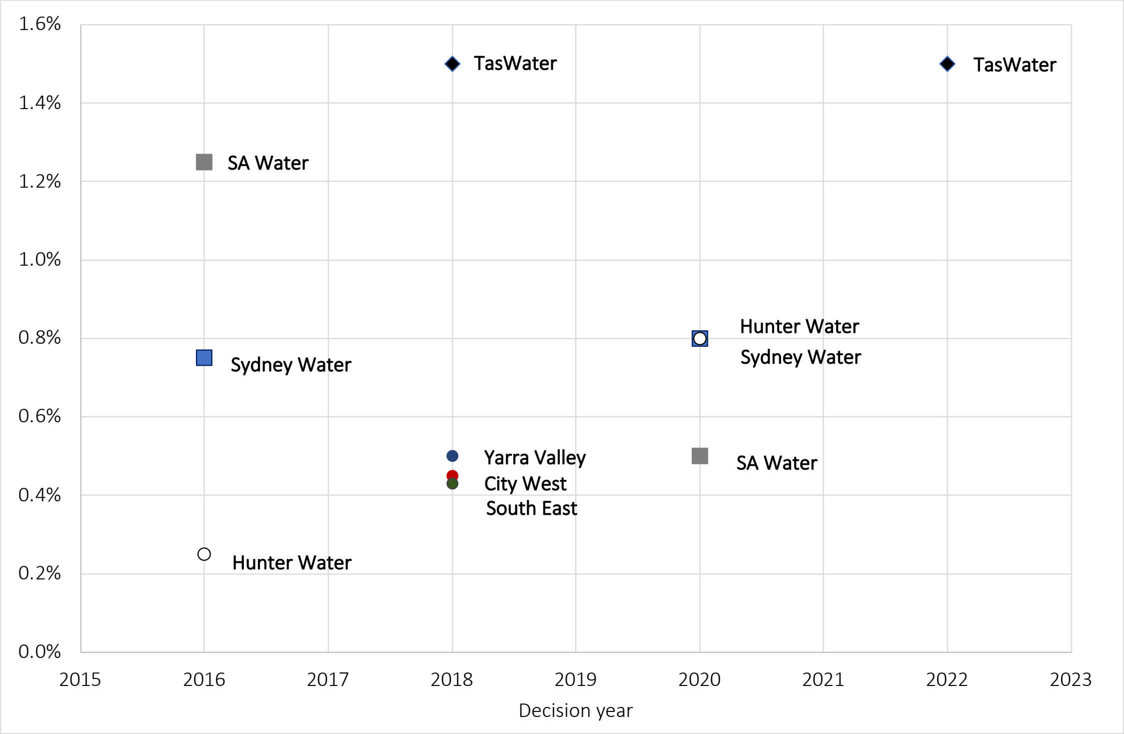
[25] This calculation does not make any adjustment for the fact that all three Melbourne metropolitan water businesses were rated by the ESC as having Advanced proposals, and it is our understanding that they consequently received a higher return on equity (ROE) than water businesses with proposals rated as Standard. This was a substantial benefit, with the indicative difference in ROE between a Standard and an Advanced proposal being an increase from 4.5 per cent to 4.9 per cent (ESC 2016a, p.13). Hence, these businesses received some financial benefit in part for their ambitious productivity proposals. If that part of the ROE uplift attributable

Figure 4 summarises the decisions of Australian regulators on productivity adjustment factors for water businesses discussed above. This includes the comparable productivity factors for Victorian metropolitan urban water businesses shown in Table 1, as well as TasWater, Sydney Water, Hunter Water and SA Water. Figure 4 shows the opex productivity factor applied in eleven recent regulatory decisions for the seven closely comparable large urban water businesses.

Figure 4: Regulator decisions on Opex Productivity Factors



Data sources: OTTER (2018, p.140, 2022, p.41), ESCOSA (2016, p.89, 2020, p.204), Atkins and Cardno (2016, p.16), IPART (2016b, p.53, 2020b, p.45, 2020a, p.36); and Table 1.

Figure 4 shows that the one actual regulatory decision that MJA referred to, namely TasWater's in 2022, is at the top of the range of productivity factors determined by Australian regulators for major urban water businesses in recent years. Similarly, the productivity adjustment factor of 1.4 per cent recommended by MJA is also at the upper end of the range of decisions for closely comparable businesses. The average of the 11 decisions for major water businesses as shown in Figure 1 is 0.8 per cent. The productivity factor we proposed 0.5 per cent per year is much closer to the average of these regulatory decisions than MJA's recommended productivity factor.

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to the more ambitious productivity proposals could be identified and removed from the opex savings, the effective productivity adjustment would be smaller.

6.2 Concluding comments

MJA used only single actual regulatory decision, and one statement of expectations, when referring to the decisions on urban water businesses on productivity factors. In this section we have examined a much wider range of decisions relating to major Australian metropolitan urban water utilities from 2016 to 2022. We have shown that:

- MJA's refers to the ESC's expected annual productivity factor of 1.4 per cent in recent guidance material. This reference is misleading because it fails to acknowledge that with their vertically-separated structure, the controllable opex of the metropolitan Victorian water businesses represents only on average approximately 20 per cent of total opex. In the latest actual regulatory decisions for these businesses in 2020, the average productivity factor was approximately 2.3 per cent per annum, but there was no corresponding productivity factor for Melbourne Water. Hence, the effective productivity factor was, on average, approximately 0.5 per cent per annum—considerably lower than that suggested by MJA.
- Eleven regulatory decisions are presented for seven major metropolitan urban water businesses from 2016 to 2022. This survey shows that the only actual regulatory decision that MJA referred to, namely TasWater's in 2022, is at the top of the range of productivity factors determined by Australian regulators for major urban water businesses in recent years. Similarly, the productivity adjustment factor of 1.4 per cent recommended by MJA is also at the upper end of the range of decisions for closely comparable businesses. The average of the 11 decisions for major water businesses as shown in Figure 1 is 0.8 per cent. The productivity factor we proposed 0.5 per cent per year is much closer to the average of these regulatory decisions than MJA's recommended productivity factor.

7 Conclusions

This section begins by addressing one further criticism of our study by MJA (in section 7.1), and then provides a summary of the main conclusions of the foregoing sections (section 7.2).

7.1 Usefulness of benchmarking in water industry regulation

> *"The approach used in the Quantonomics report is similar to the approach used in the electricity sector, but it has rarely been applied in the water sector."* (p.37)

The statement might be interpreted as insinuating that the application of benchmarking methods in water industry regulation is novel, and ought to be accorded less weight because of that. Benchmarking studies are not entirely novel in water industry regulation, since we have noted that the ESC has previously carried out benchmarking analysis of Victorian water utilities against other Australian utilities, and Ofwat in the UK has used benchmarking for many years. The Queensland Competition Authority (QCA) has benchmarked Sunwater's local area and corporate support costs against the rural water utilities Southern Rural Water and Lower Murray Water (rural) (QCA 2020). And the Department of the Environment has benchmarked the Murray Darling Basin's River Murray Operations against a group of rural water authorities (Economic Insights 2014b). We have also noted that the National Performance Reporting Framework Indicator Review has emphasised the importance of benchmarking for competition by comparison in the water industry.

It is important that regulatory decision-making be evidence-based. The benchmarking study provides a useful source of information relating to some parameters of the decision the ICRC needs to make. Indeed, in reaching its recommendations, MJA has drawn on (and as we have shown, misapplied) the benchmarking analysis, and offered very little, if any, other empirical investigation. It is difficult to see how the parameters that are needed to apply the base-step-trend method could be obtained without an empirical study. Hence, MJA's observation on the novelty of the application of benchmarking in the regulation of water businesses should not be taken as having any particular significance or implications.

7.2 Main conclusions

In section 1 we have shown that:

- The benchmarking study is *not* unduly complex. It is parsimonious and broadly similar to opex benchmarking econometric analysis carried out by the AER for electricity distribution network service providers;
- MJA is *incorrect* to claim that changes to the NPR may mean that the benchmarking study is not replicable in future. A study is replicable if other data sources may be available, and it is unreasonable to suggest that regulators could not gather such data. Furthermore, detailed information on the future changes to the NPR has been available since October 2021, and it clearly shows that support for benchmarking remains one of its priority purposes, and we have shown that the future NPR will have more, not less, data suitable for benchmarking purposes, including the data we have used in our study.

In section 2 we have discussed MJA's methodological criticisms:

- With regard to the criticism of the use of the log-log functional forms, including the Cobb-Douglas specification used in our study, we have shown that such functional forms are among the most widely used the field of applied producer economics and benchmarking, among those recommended in leading texts in this field, and are also widely used in benchmarking studies carried out by, or for, economic regulators. MJA's criticism is inconsistent with accepted academic and research practice in the relevant fields of applied producer economics and benchmarking.

- We have also noted two conceptual weaknesses in Professor O'Donnell's claims relating to the use of log-log functional forms in the present application. First, the theoretical premises on which Professor O'Donnell relies include a 'purely competitive industry' and to the extent this is a crucial premise, his argument against the Cobb-Douglas specification in the urban water business may have been misapplied. Second, in econometrics, a functional form serves as an approximation to the 'true' relationship within the domain of estimation and application, and O'Donnell has not shown that his argument relates to this relevant domain.
- With regard to the criticism made of modelling choices relating to the SFA model, and particularly the time-varying decay of inefficiency specification, we have shown that the modelling choices we adopted are among the most widely used in econometric frontier analysis applied to panel data. This is evidenced by the fact that the specifications which O'Donnell criticises are the only two options offered in standard Stata. Although there are model complicated SFA specifications, they can be difficult to implement, and for this reason they are used less often in the literature.
- Although MJA argues that the time-varying decay model is not flexible enough, and there should be utility-specific time trends in the inefficiency parameters, it has not referenced any studies where this has been done, or shown its feasibility in the present application. We believe that with the large number of utilities in the sample and the great proliferation of time-trend parameters to be estimated, it would be infeasible to adequately estimate the effects of the main variables in the model (the outputs and capital stock) and most likely yield spurious estimates for the trended efficiency effects due to multi-collinearity. The lack of examples where such an approach has been employed, strongly suggest that it is doubtful that MJA's proposed approach would be feasible in practice in this application.
- With regard to the criticism made of the Multilateral Törnqvist index and the claim that only a fixed-weighted index is a 'proper index', we have shown that MJA has incorrectly conflated the Multilateral Törnqvist index with the bilateral or chained Törnqvist index. The Multilateral Törnqvist index satisfies the test of circularity, which O'Donnell has emphasised as a test that chained indexes do not satisfy.
- MJA's methodological criticisms are inconsistent with widely accepted principles and practices among experts in the relevant disciplines of index numbers, and the econometrics of cost and production functions. The criticisms are inconsistent with established empirical literature, the benchmarking practices of regulatory agencies such as the AER and Ofwat, and the established practices in the use of index numbers and in the calculation of productivity trends by Australian and international statistical agencies including the ABS, the OECD and the international standards for Systems of

National Accounts.[26] MJA ought to have disclosed this, because we do not believe that a broad-based rejection of widely-accepted principles and practices within the relevant fields of applied economics is, or should be, part of the ICRC's agenda in regulating Icon Water.

In section 3 we have shown that:

- MJA's claim that the effects of economies of scale and of "other drivers of productivity" were not accounted for in our productivity forecast is incorrect. Our methods and formulas were fully explained in the report, and in this memo we have further highlighted where the effects of scale and other factors are accounted for.
- These mistaken claims by MJA form a key plank of their argument that the productivity growth factor should be above 0.5 per cent per annum. Therefore, we have established that MJA's view on the outlook for productivity growth does not have a sound basis.

In section 4:

- It is shown that the method used by MJA to develop its forecast of the industry-wide productivity trend component of 0.3 per cent per annum is to use the trend in the Opex PFP index over the 2013 to 2020 period. This directly contradicts MJA's explicit rejection of both the use of the Opex PFP index for inference in general, and the use of historical averages for forecasting productivity. That is, MJA uses a method which it has explicitly rejected as unreliable, and hence therefore, as a matter of logic, their forecast must be rejected.
- We reject MJA's statements about the use of historical trends for forecasting productivity by showing that this is a widely used method for aggregate productivity projections by official agencies, and also for determining productivity factors in economic regulation plans.
- For the purpose of assessing MJA's claim that there has been a change in the trend of opex productivity during the sample period, we estimate the benchmarking model with a less restrictive specification of technical change, which yields a generalised index of technical change, with a different rate in each year. Using this approach, we show that MJA's supposition about a change in trend of opex PFP is not borne out by this empirical analysis. On the contrary, the rate of technical change over recent years has closely tracked the long-term average for the whole sample period.

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[26] This is not a criticism of Professor O'Donnell. We are not suggesting that his views, as an expert in the field of efficiency and productivity analysis, should concur with those of other experts. However, we think that MJA ought to have disclosed that the views presented are not widely held among experts in this field, which is relevant to the regulatory decision to be made by the ICRC.

- We surveyed a range of other analysis of productivity trends relevant to the water industry, including by the ABS, the PC, the ESC and IPART. The results of our study are consistent with the of the previous studies in finding a large and ongoing downward trend in productivity in the water industry over an extended period encompassing the sample period used in our study. Various factors that are influencing this trend are discussed. Nevertheless, many of the factors affecting water industry, such as higher operating and service standards, new regulations, wider environmental responsibilities and changing markets are not accounted for in the modelling and hence affect productivity. These effects are not well understood. This survey supports our opinion 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" (Quantonomics 2022, p.50).
- This survey of studies does not support MJA's claim that our finding for the "industry wide component appears to be too low". It suggests that MJA's forecast of future growth in water industry productivity of 0.3 per cent per year is unrealistically at odds with the available evidence on water industry productivity trends.

In section 5:

- We have shown that MJA has made an error in claiming that the AER uses the 75th percentile target in electricity network regulation. The AER uses a 0.75 comparator score to assess whether a distribution business is inefficient. The AER's threshold efficiency score of 0.75 corresponds to a percentile less than the 67th percentile. This strongly supports our proposed use of the 67th percentile.
- We also discussed important considerations relevant to the timeframe over which the threshold can feasibly be achieved. Key considerations relating to the longevity of assets in the water industry support our recommended catch-up period of 10 years.

Section 6 shows that MJA presents a very narrow basis of comparison of their recommended productivity factor against other relevant decisions on productivity factors by other regulators. We have shown:

- MJA's reference to the ESC's expected annual productivity factor of 1.4 per cent in recent guidance material is potentially misleading by failing to acknowledge that with their vertically-separated structure, the controllable opex of the metropolitan Victorian water businesses, to which the productivity factor applies, represents only on average approximately 20 per cent of total opex. When adjusted to a comparable basis, the 2018 decisions for the Victorian water businesses' productivity factors averaged close to 0.5. This supports our recommended productivity factor and is inconsistent with MJA's recommendation.

- By reviewing regulatory decisions from 2016 to 2022 for the seven major metropolitan urban water businesses which are subject to economic regulation (eleven regulatory decisions in total)—including correcting the Victorian metropolitan water utilities to put them on a comparable basis—we find that:
    - the only actual regulatory decision that MJA referred to, namely TasWater's in 2022, is at the top of the range of productivity factors in these determinations;
    - the productivity adjustment factor of 1.4 per cent recommended by MJA is close to the upper end of the range of decisions;
    - the average productivity factor for the 11 decisions is 0.8 per cent per annum;

  The productivity factor we proposed 0.5 per cent per year is much closer to the average of these regulatory decisions than MJA's recommended productivity factor.

Appendix A: NPR Review Draft Recommendations on Relevant Indicators

Table A.2 of our benchmarking report listed all of the National Performance Report (NPR) indicators used in the analysis. Table A.1 below lists the same indicators and reports the draft recommendations pertaining to each indicator in the *NPR Framework Indicator Review* (HARC, Risk Edge & Aither 2021). Further information is included in footnotes.

Table A.1: NPR indicators used in the analysis & relevant HARC recommendations

Indicator	*Description*	*Recommendation*
W1	Surface water (e.g. dams, rivers or irrigation channels) (ML)	Kept
W2	Sourced from groundwater (ML)	Kept
W3.1	Water sourced from desalination of marine water (ML)	Kept
W5.3	Received from other service providers or operational areas (ML)	Kept
W7	Total water sourced (ML)	Kept
W8.3	Water supplied to residential customers (ML)	Kept
W9.3	Water supplied to non-residential customers (ML)	Kept
W14	Water exported to other service providers or operational areas (ML)	Kept
W16	Volume of wastewater, excluding trade waste, collected (ML)	Kept
W17	Volume of trade waste collected (ML)	Kept
W27	Recycled water as a % of total wastewater collected	Kept
A1	Number of water treatment plants providing full treatment	Kept
A2	Length of water mains (km)	Kept
A4	Number of wastewater treatment plants	Kept
A5	Length of sewer mains & channels (km)	Kept
A9	Infrastructure leakage index (ILI)	Kept[27]
C4	Total connected properties - water supply (000s)	Kept
C8	Total connected properties - sewerage (000s)	Kept

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[27] Other alternative measures are also available and retained: A8—Number of water main breaks, bursts and leaks, per 100 km of water mains; A15—Number of property connection sewer breaks and chokes per 1,000 properties.

Indicator	*Description*	*Recommendation*
C9	Number of water quality complaints per 1000 water customers	Retain with updated definition/supporting notes providing greater clarity on reporting of complaints indicators.[28]
C15	Average duration of an unplanned interruption: water supply (minutes)	Modified to 80th percentile duration of an unplanned interruption
C17	Number of unplanned interruptions per 1,000 water customers	Modified to Percentage of properties that experience more than 1 unplanned interruption in the last 12 months.
E1	Percentage of sewage treated to a primary level (%)	Kept
E2	Percentage of sewage treated to a secondary level (%)	Kept
E3	Percentage of sewage treated to a tertiary or advanced level (%)	Kept
E9	Greenhouse emissions: water (tonnes CO2-equiv. / 1000 water properties)	Retired[29]
H3	Percentage of population where microbiological compliance was achieved (%)	Kept
H4	Number of zones where chemical compliance was achieved (eg 23/24)	Modified to Percentage of population provided with chemically compliant drinking water. This is an improvement on our measure which involved dividing H4 by H4a to obtain the percentage of zones that were chemically compliant.
F9	Written-down value of fixed water supply assets ($000s)	Kept and complemented with several new indicators.[30]
F10	Written-down value of fixed sewerage assets ($000s)	Kept and complemented with several new indicators.[31]
IF11	Operating cost - water ($'000s)	Replaced by more detailed new indicators which can be summed to obtain this indicator.[32]

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[28] There will also be a new customer satisfaction indicator.

[29] IE12—Total net greenhouse gas emissions will be retained, and could be used as an alternative.

[30] The additional new indicators are: Real replacement costs of fixed water supply assets; Annual statutory depreciation: water supply assets; Regulatory depreciation: Water supply; and Regulated Asset Base (RAB) Value: Water.

[31] The additional new indicators are: Real replacement costs of fixed wastewater assets; Annual statutory depreciation: wastewater assets; Regulatory depreciation: wastewater; and Regulated Asset Base (RAB) Value: Wastewater.

[32] The new indicators are: Operating cost: purchase bulk potable and raw water; Operating cost: purchase bulk recycled water; Operating cost: maintenance water supply; Operating cost: water supply – any other costs.

Indicator	*Description*	*Recommendation*
IF12	Operating cost - sewerage ($'000s)	Replaced by more detailed new indicators which can be summed to obtain this indicator.[33]
F14	Capital expenditure: water supply	Kept with additional indicator which can be used to breakdown into renewal and the remainder (expansion).[34]
F15	Capital expenditure: wastewater	Kept with additional indicator which can be used to breakdown into renewal and the remainder (expansion).[35]
F16	Total water supply and sewerage capital expenditure ($000s)	Kept
F26	Capital works grants - water ($000s)	Kept
F27	Capital works grants - sewerage ($000s)	Kept

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[33] The new indicators are: Operating cost: maintenance wastewater; Operating cost: bulk wastewater transfers; Operating cost: wastewater – any other costs.

[34] The new indicator is: Capital expenditure – asset renewal: water supply.

[35] The new indicator is: Capital expenditure – asset renewal: wastewater.

Appendix B: Discussion of Modelling Choices

All modelling exercises involve methodological choices which must be made to focus the analysis within a practical scope and to yield reliable results. Our approach has been to build on and seek to improve approaches taken in the past. The benchmarking report explains that there are limitations to the study, including those associated with data availability. This appendix discusses the modelling choices made in the benchmarking study.

B1 Overall modelling strategy

In our benchmarking of Icon Water we have sought to maintain a degree of continuity with previous urban water benchmarking carried out by the Essential Services Commission of Victoria (ESC 2012a, 2012b) and Economic Insights (2014a) on behalf of the ESC. The main aspects of the study which differ from those earlier studies are:

- A variable (ie, opex) cost function is modelled rather than an input-oriented distance function. This choice is based on the present regulatory application in which the model is intended to shed light on opex efficiency, which is directly relevant to the ICRC's base-step-trend method. This is analogous to the AER's use of an opex cost function in its benchmarking of electricity distribution network service providers (AER 2021). The distance function approach used by the ESC and Economic Insights assesses technical efficiency rather than cost efficiency, and is more suited to a general appraisal of efficiency not directly for use within the building block price regulation framework.
- The inclusion of a wider range of operating environment factors (OEFs), including cross-sectional census data on urban density and the mix of dwelling types. Table B.1 compares the OEFs used in the different studies. Some of the variables used as OEFs were previously used to make *ex ante* adjustments to the water supply and wastewater collection outputs. By making them separate variables our model specification is less restrictive in this regard than the previous models. The use of a wider set of OEFs is consistent with stakeholder feedback from previous modelling which has emphasised the heterogeneity of operating conditions of urban water businesses. We have sought to take account of this by including a wide range of OEFs, as is evident in Table B.1.
- The use of a Cobb-Douglas specification for technology, rather than the more flexible translog specification, is motivated by the greater use of OEFs, and the desire to reasonably limit the dimensionality of the explanatory variables in the model, and better enable the effects of the OEFs to be identified.

Table B.1 Operating environment factors used compared to previous studies

	ESC 2012	*Economic Insights 2014*	*Quantonomics 2022*
Share of residential customers in total water supplied to customers	✗	✗	✓
Share of trade waste in total wastewater collected	✓	✓	✓
Share of surface water (or of groundwater) in total water sourced	✓	✓	✓
Share of desalinated marine water in total water sourced	✗	✗	✓
Share of recycled water in total water supplied to customers	✗	✓	✓
Share of flats in total dwellings (cross-sectional value only)	✗	✗	✓
Log customer minutes off supply	✗	✗	✓
Log infrastructure leakage index (ILI), an indicator of asset quality	✗	✗	✓
Log net water supply greenhouse emissions per ML of water supplied, a proxy for energy use per ML	✗	✓	✓
Log average rainfall	✗	✗	✓
Log average maximum temperature	✗	✗	✓
Dwelling density measured by the number of dwellings per square km in the supply area (cross-sectional value only).	✗	✗	✓
Indicator variable which takes the value of 1 if the utility owns one or more dams and 0 otherwise	✗	✗	✓
Adjustment factor for temporary water restrictions	Included as an adjustment to water supplied	Included as an adjustment to water supplied	✓
Log index of drinking water quality	Included as an adjustment to water supplied	Included as an adjustment to water supplied	✓
Log index of quality/standard of wastewater treatment	Included as an adjustment to wastewater collected	Included as an adjustment to wastewater collected	✓
Share of sewerage penetration	✓	✓	✗

The aspects of the study which are consistent with those earlier studies by the ESC and Economic Insights include:

- The use of stochastic frontier analysis (SFA). While the earlier studies also used a random effects specification in addition to SFA, we have sought to keep reasonable limits to the scope of the modelling exercise and have not used the random effects model.
- The use of a wide sample of urban water utilities from the National Performance Report (NPR) for urban water utilities, being all those utilities for which there was data. By doing so, we are benchmarking Icon Water against the industry as a whole, rather than against selected utilities.
- The treatment of urban water utilities as integrated providers of water supply and sewerage services. This is discussed in more detail later in this memo. This approach assumes there are economies of scope between water supply and wastewater collection activities, especially in relation to the provision of customer-related services. It also avoids data errors associated with differences between businesses in the allocation of common costs between water and wastewater services. This specification is used in the studies of Saal and Parker (2006), Saal, Parker & Weyman-Jones (2007), which influenced the approach taken by the ESC, and by Economic Insights on behalf of the ESC. Among the 64 water supply regions included in the analysis, 60 are serviced by integrated water and sewerage providers. Four have been combined together.
- The specification of outputs and inputs is similar to the ESC and Economic Insights studies, with three outputs, customer numbers, water supplied and wastewater collected, and two inputs capital inputs and non-capital inputs. Non-capital inputs are measured by an index which aggregates two component non-capital inputs, bulk water purchases and all other non-capital inputs.

The output specification uses measures of water supply volume, wastewater volume and customer numbers as outputs. Mains length was not used as an output because it is a major component of the physical capital inputs measure, so it would be inappropriate to also include it as an output. In saying this, we are not suggesting that mains length should never be used as an output. Mains length is often used as an output to measure the spatial dimension of the supply activity. Our study used a measure of the urban density of the areas supplied by each utility as an OEF. Since all the variables are in log form, and customer numbers is included as an explanatory variable, this adequately captures the spatial dimension of supply.

These specification choices are based on previous consultation with industry stakeholders in the benchmarking exercises of the ESC and Economic Insights on behalf of the ESC, has highlighted that industry participants do not regard the financial capital measures in the NPR to be reliable. For this reason, we have used two alternative capital measurement methods, one of which relies on mains length and physical measures of other capital inputs.

B2 Sampling choices

We used a broad sample of Australian urban water utilities, representing all distribution businesses in the NPR for which there was sufficient data. We aimed to benchmark Icon Water against the industry overall, rather than against selected peers. We have not undertaken an analysis of a subset of utilities. The econometric methods we used are most effective when there are a large number of utilities in the sample.

We accept that with further research it would be desirable to identify utilities that are most comparable to Icon Water and to make direct comparisons with those peers. To some small extent we have done this in our discussion of partial productivity indicators, where we have made most comparisons against utilities with similar customer density.

HARC (2021) suggests that in future, the NPR will classify urban water businesses (excluding bulk water providers) as either: (a) economically regulated and price-guided service providers; (b) stand-alone service providers operating without formal economic regulation; or (c) local government-based service providers. These categories will be useful in identifying more closely comparable peers in future benchmarking exercises.

B3 Combined analysis of water supply and sewerage services

The study treats water supply and wastewater collection as the two key outputs of integrated water and sewerage suppliers which use a multi-output technology and captures economies of scope from services provided. This corresponds to the approach used by the Essential Services Commission of Victoria (ESC 2012a, 2012b) and Economic Insights (2014a). The ESC's approach benefited from considerable input of industry expertise and stakeholder consultation.

The approach of analysing the integrated water and sewerage industry is consistent with a number of studies of the productivity of the UK water industry, including Lynk (1993), Hunt and Lynk (1995), Saal and Parker (2001, 2006), Saal, Parker & Weyman-Jones (2007) and Frontier Economics (2017). The vertically integrated structure of the water businesses studied resulted from the 1973 UK water industry reforms which were predicated on assumed substantial economies of scope between water and wastewater services and assumed substantial economies of scale. Abbot and Cohen note that this vertically integrated structure is common worldwide, reflecting a general view that there may be economies of scope between water distribution and sewerage collection.

Several Australian studies have modelled water supply activities excluding wastewater services, such as Woodbury and Dollery (2004), Coelli and Walding (2006), Byrnes *et al* (2010) and Worthington (2011). None of these studies modelled wastewater services activities. Hence these studies *do not* support the contention in the question that water and wastewater services are commonly modelled separately.

Among a large number of studies of water industry productivity and efficiency surveyed by Abbott and Cohen (2009, pp.241–243), many model water supply services alone (especially among the earlier studies) and many include water supply and sewerage treated as separate outputs of integrated utilities. Very few studies examine sewerage services separate from water supply. An example of separate efficiency analyses of water supply and sewerage services is Thanassoulis (2000, 2002).

Ofwat (2019) does separately model wholesale water supply and wholesale wastewater activities, and indeed uses further disaggregation. In water supply it uses separate models for: (a) the upstream activities of water resources, raw water distribution and water treatment; and (b) treated water distribution. It also has models for wholesale water activities in total. For wastewater activities, it has separate models for: (a) sewage collection; (b) sewage treatment; and (c) bioresources. It also has models for combined sewage treatment and bioresources activities. Ofwat uses the random effects estimation method and has moved away from translog models to the Cobb-Douglas specification, or a hybrid where specific nonlinear terms can be justified with an engineering rationale.[36]

The NPR for Australian urban water businesses provides a separation of costs and assets associated with water supply services and wastewater collection services. Hence, it would be possible to model these two activities separately, if they are essentially separate operations. This approach would rely on all water utilities adopting similar methods of allocating costs (eg, customer costs and corporate costs) between water and wastewater activities. However, a common observation of industry stakeholders about NPR data is that urban water businesses in different states, or with different structures, have adopted differing accounting standards and methods of reporting, which may mean different approaches are used for allocating common costs between water supply and wastewater. The Quantonomics study models water and wastewater costs together, which reduces assumptions required for cost allocation between services.

As previously stated, the decision to treat water supply and wastewater services as joint products assumes there are economies of scope between these activities. Abbott and Cohen's (2009) literature review of water industry productivity and efficiency studies finds that "with regard to economies of scope between water supply and wastewater activities, there is considerable support for the view that there are economies of scope that accrue to a company that operates both jointly" (Abbott & Cohen 2009, p.237). Lynk (1993) finds economies of scope between water supply and wastewater collection. Conversely, Saal *et al* (2013) find that the empirical evidence for economies of scope between water and sewerage activities is mixed.

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[36] Ofwat states: "While the translog has appealing properties in that estimated elasticities2 vary with company size, in practice we find that individual company elasticities can have a counter-intuitive sign, that some translog terms are highly insignificant and (individually) unstable, and that the specification takes up degrees of freedom that could be dispensed with more relevant cost drivers" (Ofwat 2019, p.7).

The surveys emphasize that more research is needed on this question. We noted this debate on page 8 of our report.

As the foregoing discussion and the literature surveys cited show, the analysis of water supply and wastewater services as joint products of combined entities is the most common approach in the literature. Although there are also many studies, among them several of the Australian studies, that have analysed only water supply services and excluded wastewater services, there are very few studies that analyse wastewater services and exclude water supply services. Ofwat's disaggregated modelling approaches are an exception, reflecting the mature development of a very well-established benchmarking framework over many years, which benefits from information gathering powers. Urban water benchmarking in Australia within regulation frameworks does not have the same maturity, accuracy, and consistency between utilities.

We are not suggesting that the separation of water supply and wastewater services benchmarking lacks merit. In fact, it represents a useful direction of further research and analysis. However, given that the widespread practice in the benchmarking literature, including among some leading studies carried out in the UK, is to treat water supply and wastewater services as joint products, we feel it is not necessary to justify this modelling choice on the basis of separate analyses of water and wastewater activities.

B4 Own-supply versus buying of bulk water

Non-capital inputs are defined in section 2.4.2 of the report. Opex is deflated by an opex input price index which is effectively a weighted average of bulk water prices and a price index for other non-capital inputs. The weights of this index are specific to each utility. For a utility which has no bulk water purchases, the deflator is equal to the Consumer Price Index (CPI), whereas for a utility with bulk water purchases, the deflator is a weighted average of the price index for that utility's bulk water purchases and the CPI. The weight is based on the average proportion of bulk water costs in its total opex.

B5 Period of sample

The period of 15 years was the maximum period of reliable data for most of the utilities in the sample, given that the National Water Commission began publishing NPR data from 2006. There is earlier data from 1998 published by the Water Services Association of Australia (WSAA), but this is only available for a smaller number of major utilities. That data was used in the ESC and Economics Insights (2014) studies, but since it is less recent and causes the panel to be much more unbalanced, we decided to omit that data for this study.[37] Although the resulting dataset over 15 years is not balanced, it is much closer to being balanced.

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[37] A balanced panel is one which has data for the same periods for each unit in the panel (here utility). This is not the case for an unbalanced panel—eg, there is data for a longer period for some utilities than for others.

We tested three sub-periods each of 5 years. However, we found that the models were not sufficiently stable in the 5-year sub-periods. In our view, with such a heterogenous sample of utilities, it is only with the full 15-year sample period that the number of observations is large enough to produce stable and reliable results.

B6 Scaling of Output Weights to Unity

To calculate any output index, the weights applied to the constituent outputs must sum to unity. This is elementary. For example, if weights are defined by revenue shares of products, those revenue shares are defined as: $w_i = R_i/\sum R$ (where R is revenue and i refers to product i), and the must sum to unity. Similarly, when elasticities are used, the weights are defined as: $w_i = \epsilon_i/\sum \epsilon$ (where ϵ is the cost-elasticity with respect to output i), and again, they must sum to unity. Otherwise the result would not be an index number.[38]

The rationale for using elasticities rather than revenue shares in a regulated setting is because regulated businesses are not constrained by market forces to set prices for their different outputs in proportion to the marginal costs of those outputs, which is a standard result of microeconomics for competitive markets. Each elasticity is defined as:

$$\epsilon_i = \frac{\partial \ln C}{\partial \ln q_i} = \frac{\partial C}{\partial q_i} \cdot \frac{q_i}{C}$$

where C is cost, q_i is the quantity of output i and $\partial C/\partial q_i$ is the marginal cost of producing output i, which serves as the shadow price of output i. Hence: $(\partial C/\partial q_i)q_i = V_i$ is the shadow value of the quantity of output i produced. Further:

$$\frac{\epsilon_i}{\sum_k \epsilon_k} = \left(\frac{V_i}{C}\right) \Big/ \left(\frac{\sum_k V_k}{C}\right) = \frac{V_i}{\sum_k V_k}$$

The weight applying to product i is its shadow value as a share of the total shadow value of all products produced. This is directly analogous to using revenue shares for the output index where revenue is calculated using shadow prices (marginal costs) rather than market prices. This is a standard approach in applying productivity analysis to regulated businesses: see Denny, Fuss and Waverman (1981), and Coelli *et al* (2003 ch. 3).

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[38] Quantity index numbers can be expressed as weighted averages of 'quantity relatives' (eg, ratios of quantities between periods of the products included in the index) and price index numbers can be expressed as weighted average of 'price relatives' (eg, ratios of prices between periods of the products included in the index). The weights must sum to unity. See Yeomans (1968 ch.4, esp. s. 4.2 'Weighted index numbers') or Allen (Allen 1975 s 1.4 'Choice of Formula: Aggregative/Weighted Average Approach').

Appendix C: Additional Econometric Results

This appendix presents results of estimating the SFA variable cost function for the period from 2006 to 2020 using an alternative method of estimating opex productivity trend, due to Baltagi and Griffin (1988). Rather than including a time trend variable to estimate a constant average rate of opex productivity change, in this specification there is a separate dummy variable for each year in the sample (except the first year), which yields a time-varying index of opex productivity. The models presented in table C.1 are the same as those presented in Table 4.1 of the report in all respects except that the time trend variable is replaced by a series of dummy variables for years. The notation of the variables remains the same, and for convenience, it is listed below the table. The dummy variables for years 2007 to 2020 are denoted λ_2 to λ_{15}.

Table C.1: Estimated SFA Variable Cost Function 2006–2020, Baltagi-Griffin Method

	Real financial capital measure		*Physical capital measure*	
	coef	*t-stat*	*coef*	*t-stat*
$\ln q_1$	0.5427	(7.35)	0.5034	(7.08)
$\ln q_2$	0.1750	(3.25)	0.1797	(3.27)
$\ln q_3$	0.0835	(1.79)	0.0843	(1.83)
$\ln x_k$	0.0149	(0.23)	0.0563	(1.61)
z_1	0.5563	(4.34)	0.5639	(4.32)
z_2	0.1555	(2.72)	0.1518	(2.65)
z_3	-0.0865	(-2.36)	-0.0974	(-2.65)
z_4	0.1512	(0.83)	0.1131	(0.62)
z_5	-0.0002	(-1.39)	-0.0003	(-1.46)
z_6	1.7084	(3.72)	1.8255	(4.10)
z_7	-0.0017	(-0.14)	-0.0009	(-0.08)
z_8	-0.0147	(-1.16)	-0.0156	(-1.23)
z_9	0.0541	(1.86)	0.0501	(1.89)
z_{10}	-0.0424	(-1.92)	-0.0426	(-1.94)
z_{11}	-0.0522	(-0.35)	-0.0447	(-0.29)
z_{12}	0.1909	(3.18)	0.2239	(3.41)
z_{13}	0.4034	(6.64)	0.4174	(6.68)
z_{14}	-0.3276	(-3.16)	-0.3415	(-3.29)
z_{15}	0.1915	(2.78)	0.1851	(2.69)
z_{16}	0.1053	(1.53)	0.1189	(1.72)
λ_2	0.0431	(1.38)	0.0423	(1.36)
λ_3	0.0560	(1.72)	0.0554	(1.71)
λ_4	0.0414	(1.30)	0.0414	(1.30)
λ_5	0.1193	(3.62)	0.1185	(3.62)
λ_6	0.1980	(5.61)	0.2002	(5.68)
λ_7	0.2520	(6.97)	0.2531	(7.05)
λ_8	0.2477	(6.89)	0.2471	(6.94)
λ_9	0.2549	(6.82)	0.2538	(6.88)
λ_{10}	0.2327	(6.03)	0.2323	(6.12)
λ_{11}	0.2612	(6.55)	0.2601	(6.69)
λ_{12}	0.2668	(6.46)	0.2667	(6.65)
λ_{13}	0.2978	(6.89)	0.2969	(7.07)

	Real financial capital measure		*Physical capital measure*	
	coef	*t-stat*	*coef*	*t-stat*
λ_{14}	0.3148	(7.17)	0.3145	(7.40)
λ_{15}	0.3496	(7.84)	0.3496	(8.17)
cons.	-1.8619	(-2.69)	-2.0886	(-2.88)
mu	0.0000		0.0000	
eta	0.0320	(4.47)	0.0315	(5.63)
sigma_u	0.3468		0.3543	
sigma_v	0.1468		0.1464	
N	867		867	
BIC	–384.38		–387.08	

Notation:

- q_1: customer numbers output;
- q_2: water supplied output (ML) including bulk water exports to other utilities;
- q_3: wastewater collected output (ML);
- x_k: fixed capital input;
- 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.

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