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Efficiency, technology, and productivity change in Australian urban water utilities

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Efficiency, technology, and productivity change in Australian urban water utilities

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ABSTRACT

In this paper, we investigate productivity growth in 55 major Australian urban water utilities using nonparametric frontier techniques over the period 2005/06 to 2008/09. The five outputs included in the analysis are chemical and microbiological compliance, and the inverses of real losses per connection, the number of water main breaks per 100 km of water main, and water quality and service complaints per 1,000 properties. The input is operating expenditure. Using Malmquist indices, we decompose productivity growth into technical efficiency and technological change. The results indicate that annual productivity growth averaged 1.04 percent across all utilities and was largely attributable to efficiency gain, roughly equally split between pure technical efficiency and gains from scale. As in many other highly regulated Australian industries, technological improvements during this period are very small, averaging just 0.22 percent a year. We subsequently employ second-stage regression analysis to quantify the effects of uncontrollable (nondiscretionary) factors on total factor productivity and efficiency change, including the role of different water sources (surface, ground, recycled and bulk water purchases) and utility size. The results indicate that imposed environmental factors only account for a small percentage of the observed variation in efficiency, technology change, and productivity improvements.

JEL classifications: C61, D24, L95.

Keywords: Productivity, technical and scale efficiency, technological progress, Malmquist indices, urban water utilities.

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1. Introduction

Over the last three decades, the Australian urban water utility sector has moved progressively towards a greater appreciation of performance through the reform process, very often at the instigation of national bodies appointed by the Commonwealth or cooperative arrangements between the Commonwealth and the States. In the early 1980s, urban water utilities first began to implement a user-pays water tariff for residential customers while by the early 1990s, the first Australian urban water authorities were being corporatised. Subsequent national-level sources of reform include the Industry Commission (1992) inquiry into water resources, the Council of Australian Governments (COAG) (1994) setting of a strategic framework for the efficient and sustainable reform of the water industry, the COAG (1995) implementation of the National Competition Policy (NCP) and its incentivisation of jurisdictions effectively implanting water reforms within the earlier strategic framework. The reforms also include the COAG (2004) National Water Initiative (NWI) and the establishment of the National Water Commission (NWC) to assist and assess progress on the NWI reforms and COAG (2008) in enhancing the national water reform framework concerning the security of supply of urban water (Productivity Commission (2011, xviii). Most recently, it includes the Productivity Commission (2011) being tasked with examining the case for microeconomic reform in the urban water sector and to identify pathways to achieve improved resources allocation and efficiency and a report prepared by the author for the NWC (Worthington 2011) on efficiency and productivity measurement in urban water utilities from which this paper is derived.

Undoubtedly, urban water utility reform per se and the anticipation of reform has affected the efficiency and productivity of the sector. One suggestion is that the productivity of the sector has significantly improved through expansion of the productivity frontier, suggesting fewer (or the same) resources are now needed to produce the same (or more) outputs. Problematically, this may not be the case. In a world without inefficiency, productivity growth, as measured by productivity indices (an index of output divided by an index of total input usage), is synonymous with technical progress (or shifts in the technology boundary). However, in a world in which inefficiency exists, productivity is no longer technical change unless there is either no technical inefficiency or unless technical inefficiency does not change over time. If these conditions do not hold, then productivity is the net effect of changes in

efficiency (or movements relative to the existing frontier) and shifts in the production frontier (or technical change).

This distinction is important from a policy viewpoint, as changes in productivity growth due to inefficiency suggest different policies to those concerning technical change. For example, in an industry characterised by a high level of inefficiency, it may be a waste to promote efforts aimed at innovation, while a lack of innovation in an efficient industry may result in stagnation. In any case, remarkably little is quantitatively known about the productivity of the Australian urban water utility sector, even less about the spread of productivity levels across the sector, and virtually nothing about whether suggestions of productivity improvements are the result of an increase in efficiency, an increase in technology, or both.

Accordingly, the purpose of this paper is to assess the recent productivity growth of Australian urban water utilities taking into account changes in both efficiency and technology. While not the only study to examine efficiency and/or productivity in Australian urban water utilities (Coelli and Walding, 2006; Byrnes et al. 2010) it is the only one to focus exclusively on productivity, efficiency and technological change at a utility-level using readily available panel data. The paper comprises four sections. Section focuses on the specification used to measure productivity, efficiency, and technological change in Australian urban water utilities. Section 3 deals with the specification of inputs and outputs. Section 4 presents the results. The section ends with some concluding remarks in Section 5.

2. Malmquist indexes of productivity and technical change

The methodology employed to calculate productivity change and decompose it into its technical efficiency and technological component is the nonparametric Malmquist index [for pioneering works see Färe et al. (1992) and Färe et al. (1994)]. The approach has since been applied to a number of service industries, including healthcare (Maniadakis and Thanassoulis, 2000; Ventura et al. 2004), financial services (Worthington, 1999; Mahlberg and Url, 2003; Sturm and Williams, 2004; Lee et al. 2010) and education (Flegg et al. 2004; Johnes et al. 2004; Worthington and Lee 2008).

Following Coelli et al. (1998), Figure 1 illustrates the underpinning theoretical framework. In this diagram, a production frontier representing the efficient level of output (y) that can be produced from a given level of input (x) is constructed, and the assumption made that this frontier can shift over time. The frontiers (F) thus obtained in the current (t) and future ($t+1$) time periods are labelled accordingly. When inefficiency exists, the relative movement of any

given water utility over time will therefore depend on both its position relative to the corresponding frontier (technical efficiency) and the position of the frontier itself (technical change). If we ignore inefficiency, then productivity growth over time will be unable to distinguish between improvements that derive from a water utility ‘catching up’ to the frontier, or those that result from the frontier itself shifting up over time.

[Figure 1 here]

Now, for any given water utility in period t , say, represented by the output/input bundle z_t , the inputs used are x_t and the output is y_t . However, this is technically inefficient as the water utility lies below the production frontier: with the available technology and the same level of inputs, the utility should be able to produce output y_a . In the next period, there is a technology increase such that more outputs can be produced for any given level of inputs: the frontier moves upward to F_{t+1} . This technology increase potentially relates to a large range of changes in engineering and work practices, management, governance.

The only requirement is that it alters the way utilities transform their inputs into outputs and that this technology ultimately becomes available to the entire sector. Assume the output/input bundle is now represented by z_{t+1} with input x_{t+1} and output y_{t+1} . Once again the utility is inefficient, but in reference to the new technology, and should be producing output y_c if it were efficient. The challenge for productivity assessment is to sort these increases in output relative to the level of inputs into that associated with the change in efficiency and that associated with the change in technology.

It is possible using the Malmquist input-orientated productivity index to decompose this total productivity change between two periods into technological (or technical) change and technical efficiency change. Input-orientation refers to the emphasis on the equiproportionate reduction of inputs, within the context of a given level of outputs. There are several reasons for selection this orientation. To start with, as discussed in Worthington (2011), the overwhelming majority of past research into efficiency in urban water utilities employs an input orientation.

As there, we assume that the outputs we later specify are not very amenable to change in the short run. Further, even if able to be changed, there are limits to the ability of the utility to augment these outputs, either because of natural limits to behaviour (i.e. maximum water quality and compliance with chemical and microbiological standards) or limits imposed by regulation and the environment (such as increasing the number of households using the

existing infrastructure). Following Coelli et al. (1998), the input-based Malmquist productivity change index is:

$$M_I^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{D_I^t(y_{t+1}, x_{t+1})}{D_I^t(y_t, x_t)} \times \frac{D_I^{t+1}(y_{t+1}, x_{t+1})}{D_I^{t+1}(y_t, x_t)} \right]^{1/2} \quad (1)$$

where the subscript I indicates an input-orientation, M is the productivity of the most recent production point (x_{t+1}, y_{t+1}) (using period $t + 1$ technology) relative to the earlier production point (x_t, y_t) (using period t technology), D are input distance functions, and all other variables are as previously defined. Values greater than unity indicate positive total factor productivity (TFP) growth between the two periods. An equivalent way of writing this index is:

$$M_I^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{D_I^{t+1}(y_{t+1}, x_{t+1})}{D_I^t(y_t, x_t)} \left[\frac{D_I^t(y_{t+1}, x_{t+1})}{D_I^{t+1}(y_{t+1}, x_{t+1})} \times \frac{D_I^t(y_t, x_t)}{D_I^{t+1}(y_t, x_t)} \right]^{1/2} \quad (2)$$

or $M = E \cdot P$ where M (Malmquist TFP) is the product of a measure of technical progress P as measured by shifts in the frontier measured at period $t + 1$ and period t (the geometric mean of the two ratios in the square bracket corresponding to y_c/y_b and y_b/y_a in Figure 1) and a change in efficiency E over the same period (the term outside the square bracket corresponding to $(y_{t+1}/y_c)/(y_t/y_a)$ in Figure 1).

Using this approach, four efficiency/productivity indices are provided for each water utility along with a measure of technical progress over time. These are: (i) technical efficiency change (i.e. relative to a constant returns-to-scale technology) (EFFCH); (ii) technological change (TECHCH); (iii) pure technical efficiency change (i.e. relative to a variable returns-to-scale technology) (PECH); (iv) scale efficiency change (SECH); and (v) TFP change (TFPCH). Coelli et al. (1998) discuss the linear programs necessary to calculate these indices and the DEAP 2.1 software used in this analysis.

3. Specification of inputs and outputs

The data consist of annual observations of 55 major Australian urban utilities over the period 2005–06 (the year of the first National Performance Report) to 2008–09 (the most recent report available) (NWC 2007, 2008, 2009, 2010). This is longest period where the Water Services Association of Australia, in conjunction with the National Water Commission and the parties to the National Water Initiative (the Commonwealth of Australia and the

governments of NSW, Victoria, Queensland, South Australia, ACT, Northern Territory, Tasmania and Western Australia), has provided consistent utility-level data.

Unfortunately, the data for 2009–10 (NWC 2011) was not available at the time of preparing this paper. In the 2008–09 report, 73 utilities from across Australia supplying approximately 17.2 million Australians with their water services provided the some 117 indicators used in the report, compared to 56 water utilities in 2008–09. These indicators cover a wide range of critical performance areas, including safety (health), customer service, asset management, environmental, finance and pricing.

In terms of sampling, we first removed all utilities where data was unavailable for each year over the four-year period. We then removed an additional eighteen reporting water utilities from the sample. To start with, we excluded the seven bulk water suppliers (Fish River Water, Goldenfields Water, Rous Water, Sydney Catchment Authority, Seqwater, Hobart Water, and Melbourne Water) because their productive behaviour differs substantially from the utilities that are the focus of this study. Bulk utilities are utilities that do not have end-use customers of their own; instead, they provide services to other water utilities. These services potentially include the harvesting and storage of water in reservoirs, treating and transferring water from storage to other reticulation networks, and the treating and disposing of (or recycling) of sewage collected from other customers.

Then, given there is a range of behaviour with most utilities providing both potable water and wastewater services and a few providing only either service, we removed institutions that offered wastewater services only (including Wagga Wagga Council, Riverina Water, City of Kalgoorlie–Boulder, and Water Corporation–Bunbury). Fortunately, as the indicators in the report split according to water and wastewater services, we were able to retain utilities offering water services only and use only the water-related indicators for utilities offering both water and wastewater services.

Finally, we removed seven other utilities with substantial amounts of missing data that we were unable to extrapolate, reconstruct or approximate from the data available. One indicator of the scale of missing data is that in the 2006–07 report, the amount of available data was about 60 per cent of the total potential dataset, rising to 80 per cent in 2007–08 and 85 per cent in 2008–09. This has necessarily determined both the sample composition and the specification of inputs and outputs with a view of maximising the sample size. Table 1 lists the 55 utilities included in the analysis along with their location by jurisdiction (state) and the

categorisation in the report by the number of connected properties. The utility names correspond to the abbreviations given in the 2008–09 report.

[Table 1 here]

The inputs and outputs employed follow a production approach to modelling water utility behaviour, that is, utilities combine factors of production and produce outputs in the form of water-related services. In terms of previous work, the approach selected is most consistent with Guder et al. (2009), Garcia-Valina and Muniz (2007), Picazo-Tadeo et al. (2009), Byrnes et al. (2010) and Munisamy (2010). Worthington (2011) provides a complete review of the empirical specifications found in existing studies of urban water utilities. Ideally, it should be possible to identify several different inputs and outputs so that the production process can reflect the different flexibilities may have in using a range of potentially substitutable inputs to produce a variety of outputs. For instance, efficient usage of a particular input will vary by its degree of factor substitutability and price, whereas production of a particular output will be determined by, among other things, the price paid or the weighting assigned by the utility's customers. Unfortunately, the inputs in the NWC reports are not finely specified and so we are unable to identify even capital and labour inputs separately, let alone their prices [as in, say, Filipini et al. (2008) and Reznetti and Dupont (2009)].

Accordingly, our sole input is total operating cost (in \$000s). The NWC (2009) defines operating costs as comprising a range of expenditure water utilities incur on a range of activities, including labour and technology costs, fees for legal and other professional services, and corporate/head office expenditure. Operating expenditure also includes operations and maintenance expenditure on water infrastructure, water and sewage treatment costs, including chemicals and processes to treat water, licence fees paid to entities such as regulators and government departments, and water conservation expenditure including public education, costs associated with the advertisement and enforcement of water restrictions. Unfortunately, outside the most recent report, the indicators do not include the capital expenditure on long-term assets. Importantly, the NWC (2010: makes the following point that helps support both the focus on operating expenditure as an input and the input orientation of this analysis:

Operating expenditure is usually directly recovered from customers through prices, in the year it is incurred. Therefore, increases in operating expenditure are passed on to customers relatively quickly. This is because without the necessary revenue to recover the day-to-day operating expenditure of the business, utilities would be unable to operate their systems.

Equally importantly, this input makes no allowance for the non-discretionary or non-controllable structural and environmental factors that also impact upon the observed behaviour of water utilities, including its size, density, location, and principal sources of water and infrastructure requirements. This is because in this part of the analysis, we employ the method of first estimating the efficiencies using only the set of controllable factors and then gauging the effects on these efficiencies using the set of non-controllable factors. The six non-controllable factors are: (i) PMN, the number of properties served per km of water main (n), (ii) WTR, total urban water supplied (ML), (iii) BLK, the percentage of water sourced from bulk supplier (per cent), (iv) GRD, the percentage of water sourced from groundwater (per cent), (v) REC the percentage of water sourced from recycling (per cent), and (vi) SUR, the percentage of water sourced from surface water (per cent).

We should note that the number of connections is commonly considered as one of the main drivers of operating costs in urban water utilities. We also note that apart from the number of properties served and the volume of water supplied, at least some utilities will have zero values for some of these factors. For example, relatively few utilities source recycled water as an input. However, this is not a theoretical concern, as the purpose of these factors is merely to condition the input environment in which utilities operate, and the positive or negative effects of this imposed environment on operating costs. It is also not an empirical concern in the second-stage regression analysis.

In contrast, we are able to use the reports to specify five categories of discretionary (or controllable) output. The key focus here is on the provision of high-quality water services to the utility's customers, encompassing requirements for clean, potable water reliably delivered with a minimum of waste and interruption. These are: (i) CHC, the percentage of zones where chemical compliance was achieved (per cent), (ii) MBC, the percentage of zones where microbiological compliance was achieved (per cent), (iii) LSI, the inverse of real losses (litres/service connection/day); (iv) WQI, the inverse of water quality and service complaints (per 1000 properties, and (v) WMI, the inverse of water main breaks (per 100 km of water main). Key points to note are that we normalise microbiological and chemical compliance by the number of zones (originally in terms of the number of compliant zones) because the number of zones vary by utility. Further, inverses are used for real losses, water quality and service complaints and water main breaks to ensure that an increase in an output is associated with an improvement in services (i.e. less water wastage and fewer service complaints and main breaks).

[Table 2 here]

Table 2 includes selected descriptive by year and for the entire sample period. By and large, the distributional properties of the panel data for most of the thirteen variables included appear non-normal. Given that the sampling distribution of skewness is normal with mean 0 and standard deviation of $\sqrt{6/n}$ where n is the sample size (0.323 for the panel, 0.647 for each year) OXT, LSI, WQI, WMI, PRP, WTR, PMN, BLK, GRD and REC are significantly positively skewed at the .05 level (one-tailed), suggesting the greater likelihood of higher than lower values. CHC and MBC are negatively skewed indicating the greater probability of lower than higher values.

The kurtosis or degree of excess, for all variables is also large, thereby indicating leptokurtic or fat-tailed distributions (relatively many extreme values). Given the sampling distribution of kurtosis is normal with mean 0 and standard deviation of $\sqrt{24/n}$ where n is the sample size, then all estimates are once again statistically significant at any conventional level (0.647 for the panel, 1.294 for each year). Finally, the calculated Jarque-Bera statistics and corresponding p-values (not shown) are used to test the null hypotheses that the variables are normally distributed. All p -values are smaller than the .01 level of significance suggesting the null hypothesis can be rejected. None of these controllable and non-controllable inputs and controllable outputs is then well approximated by the normal distribution.

That said, the non-parametric, non-stochastic methodology employed in this analysis does not rely upon conventional asymptotic distributional assumptions, and it is only in the case of the most extreme outliers that a particular utility would be excluded. Drawing on the coefficient of variation (CV), it is clear that the most variable inputs and outputs for major water utilities are operating expenditure (OXT), the number of connected properties (PRP) and the amount of water supplied (WTR). In contrast, the least variable inputs or outputs are chemical and microbiological compliance (CHC and MBC) and the number of properties served per km of water main (PMN)

[Table 3 here]

[Table 4 here]

Tables 3 and 4 provide similar descriptive statistics for the 55 major urban water utilities by jurisdiction (state) and type (size and location), respectively. As shown, relatively more of the sample utilities are located in NSW (44 per cent), followed by VIC (29 per cent) and then WA

(11 per cent). In terms of other characteristics, mean operating expenditures are higher in SA (\$113 925) and QLD (\$53 325) and lower in NT (\$14 075) and NSW (\$29 850). The coefficients of variation suggests that NSW and WA have the most variable water utility sectors in the terms of expenditure patterns, while ACT and SA (each with only one utility in the sample) have the least variable. This primarily relates, of course, to the sector structure imposed in each state and does not imply any difference in efficiency or productivity. There is also substantial variation in the types of urban water utility included in the sample. The typical metropolitan large (ML) utility, for instance, incurs operating expenditures of about \$132 million in delivering nearly 146 thousand ML of treated water to its more than half a million densely clustered customers, with water almost equally supplied by bulk providers and surface water. In stark contrast, the average non-metropolitan other (NMO) water utility incurs expenditures of just \$6 million in providing approximately 5 thousand ML of treated water to its 14 thousand relatively dispersed customers, principally relying on surface water, followed by bulk and groundwater almost equally.

4. Empirical results

Table 5 presents the geometric mean changes in efficiency, technology and productivity growth by urban water utility. Using this information, three primary issues are addressed in the computation of Malmquist indices of productivity growth over the sample period. The first is the measurement of productivity growth over the period. The second is to decompose changes in productivity growth into what are generally referred to as a ‘catching-up’ effect (technical efficiency change) and a ‘frontier shift’ effect (technological change). The third is that the ‘catching-up’ effect is further decomposed to identify the main source of improvement, through either enhancements in pure technical efficiency or increases in scale efficiency.

Three points should be emphasised concerning the efficiency, technology and productivity growth indexes before proceeding. First, the indexes (and any resulting percentage changes) are relative. Put differently, a water utility may be more or less efficient, or more or less productive, but only in reference to the other utilities included in the sample, not the population.

At the same, productivity growth is also a relative concept: a larger water utility may be more productive (producing more outputs), but its productivity growth may still be low (when related to inputs). Second, the technique employed places no emphasis on particular inputs

and outputs. On one level, this means that if a water utility chooses to focus, say, on avoiding water losses as against ensuring chemical or microbiological compliance, or minimising customer complaints as against water main breaks, its efficiency is only assessed relative to best-practice water utilities making similar sorts of decisions.

[Table 5 here]

As shown in column 10 in the last row of Table 5, there was an annual mean growth in TFP of just 1.04 per cent over the period 2005–06 to 2008–09 across the urban water utility sector. Given that productivity growth is the sum of technical efficiency and technological change, we can ascertain the major cause of productivity growth by comparing the values of the efficiency change and technological change.

Put differently, the productivity growth can be the result of efficiency gains, technological improvements, or both. In the case of urban water utilities, the overall improvement in productivity over the period is composed of an average efficiency increase (movement towards the frontier) of 4.73 per cent, and average technological progress (upward shift of the frontier) of 0.22 per cent annually. We can further decompose the technical efficiency into pure technical efficiency and scale efficiency and this indicates a 2.11 per cent increase in the former and a 2.23 per cent improvement in the latter. Clearly, across all of the urban water utilities in the sample, the improvement in productivity over the period is the result of improvements in efficiency rather than any expansion in the frontier relating inputs to outputs. One suggestion is that in relative terms, the sector as a whole is relatively inefficient, that many utilities have been catching up with best practice in the sector and that technological improvements have been rather sluggish.

Further, the efficiency improvements are roughly equal between improvements in the ability to combine inputs and outputs in optimal proportions without altering the scale of operations and the benefits from increasing the scale or size of operations. As relative sample-specific measures, it is difficult to compare these findings with other studies. However, in some respects it would appear that the efficiency and productivity outcomes have changed markedly in the sector. For example, in a study of Australia's 18 largest water utilities over the period 1995–09 to 2002–03, Coelli and Walding (2006) calculated a mean total factor productivity decrease of –1.2 per cent in the sector, including a technical efficiency gain but with technological regress. However, these figures obscure very different results across a number of urban water utilities ranked by EFFCH, TECHCH, PECH, SECH and TFP in the column to the right of their scores. LIS (Lismore City Council), for example, had a mean

productivity growth of 2.98 per cent (first-ranked) which was composed of a 12.76 per cent improvement in efficiency (moving towards the efficient frontier) and, like the other utilities, a relatively small 0.23 per cent technological gain (movement in the frontier) ($TFPCH = EFFCH \times TECHCH$).

In turn, the technical efficiency gain almost equally resulted from improvement in pure technical efficiency (3.42 per cent) (optimising the relationships between inputs and outputs without increasing the scale of operation) and through scale efficiency (3.73 per cent) ($EFFCH = PECH \times SECH$) (the gains solely attributable to increasing the scale of operations). That is, LIS improvised its technical efficiency by better combining its inputs and producing outputs and by getting larger (more inputs and outputs) and taking advantage of the increasing returns to scale found in this sector. By way of comparison, RIV (Riverina Water) was ranked second in terms of productivity growth (2.71 per cent), again mostly as result of an improvement in technical efficiency (12.41 per cent).

However, whereas LIS improved its technical efficiency almost equally through the increase in pure technical and scale efficiency, RIV increased its efficiency almost wholly based on pure technical efficiency (13.9 per cent) with little improvement in efficiency from the change in scale (0.89 per cent). Put differently, RIV got better at using its existing inputs to produce outputs but did not grow larger in terms of its scale of operations. Lastly, BAT (Bathurst Regional Council) was third-ranked with productivity growth of 2.54 per cent, again mostly attributable to improvements in technical (mostly pure technical) efficiency but with a relatively larger component attributable to technological progress (0.26 per cent).

Together, these results appear to confirm what we know about firm-level productivity growth: impressive rates of growth can occur from a low base as utilities eliminate inefficiency, but productivity growth is more difficult to sustain as utilities make efforts to remove inefficiencies and reliance is placed on the technological improvements potentially available to the entire sector. As the engineering relationships prevailing in the sector have likely changed little in the past few years, utilities must then place emphasis on areas like workplace and reporting practices, financial coordination, and so on.

At the other end of the scale are urban water utilities with a low rate of TFP growth over the period. For example, while TFP fell in no utility over the period, the three lowest-ranked, IPS, QUE and AQW (Ipswich Water, Queanbeyan City Council and ACTEW, respectively), all made only small efficiency gains (largely through scale efficiency) combined with the only modest improvements in technology (as in the rest of the sector). However, rather than

suggesting overall poor performance, this instead indicates that these utilities were generally operating close to the best-practice frontier and so with limited efficiency improvement potential, and that their opportunities for gain were therefore limited to the small technological gains available to the sector. We gain further insights by examining the changes in pure technical and scale efficiency for these utilities.

Consider pure technical efficiency. Some water utilities have clearly improved by moving towards their best practice frontier—increasing outputs relative to inputs subject to the available technology and scale— and this helped improve TFP growth, including PAS (Power and Water - Alice Springs), DUB (Dubbo City Council) and CLA (Clarence Valley Council). Others have moved towards the frontier largely through an increase in the scale of operations, including GWM (GWM Water), WSA (Western Water) and WKB (Water Corporation – Kalgoorlie–Boulder). Together, these findings indicate the diversity of practices and behaviour that urban water utilities have implemented to improve their efficiency during the sample period.

The second part of the analysis employs a second-stage regression approach where the efficiency, technology and productivity scores from the first part are regressed against the non-controllable environmental factors thought to impact upon the measured results. Potentially, this provides an indication of how these factors impact upon efficiency outcomes and whether any allowance should be made when considering these measures. As shown in Table 5, the environmental factors only account for a small percentage of the variation in efficiency technology and productivity; between 6.5 per cent (scale efficiency change) and 14.3 per cent (technological change). In terms of EFFCH (technical efficiency change) and its significant determinants, efficiency improvements are generally lower in utilities with a higher PMN (the number of properties served per km of water main), a possible indicator of congestion effects, and in utilities sourcing a relatively higher proportion of water from surface (SUR) followed by bulk (BLK) water. With technological change (TECHCH) the significant determinants are not the characteristics of the utility (PRP, WTR, PMN), rather the sources of water, this time, groundwater (GRD) followed by surface water (SUR).

[Table 6 here]

Though the magnitude of these influences are small, we use the estimated model to predict efficiency, technology and productivity change in these utilities ‘washed’ of the inclusion of non-controllable inputs. We then identify only those utilities in the upper quartile of all utilities that performed significantly better in efficiency, technology and productivity

outcomes than suggested by their non-controllable inputs and an equivalent set of utilities in the lower quartile that performed significantly worse than suggested by their non-controllable features. This effectively leaves out the 50 per cent of urban water utilities whose adjusted and unadjusted performances are not substantially different. Table 7 includes the result of the analysis, comprising the residual between the actual and expected performance and an indication of whether the utility performed relatively better ('Better') or worse ('Worse') to the combined sector and environmental benchmark.

[Table 7 here]

Unsurprisingly, urban water utilities that performed relatively better (poorly) in Table 6 also generally perform relatively better (poorly) in Table 7, largely because of the small amount of variance in performance attributable to uncontrollable inputs. However, consideration of the binary outcome of 'Better' or 'Worse' performance across the five measures particularly helps identify utilities that may be deserving of more attention. For example, utilities that performed relatively better than suggested by their environment (at least four of the five measures) are BAT (Bathurst Regional Council), BRI (Brisbane Water) and CHW (Central Highlands Water). Those that performed relatively poorly relative to their imposed environment (again in at least four of the five measures) are WSP (Westernport Water), WAY (Water and Waste Services–Mackay Regional Council), LOW (Lower Murray Water) and EGW (East Gippsland Water).

5. Concluding remarks

This paper examined the productivity growth of major Australian urban water utilities over the period 2005–06 to 2008–09. Using Malmquist indices, productivity growth was decomposed into technical efficiency and technological change. The results indicate that annual productivity growth averaged 1.04 per cent across all utilities, with a range of 0.09–2.98 per cent, and was largely attributable to efficiency gains (that is reducing inputs relative to outputs based on observed industry best practice). There appears to have been very little gain from technological improvements (0.17–0.29 per cent) and this is suggestive of a slow pace of best-practice improvement in the sector. Unfortunately, it is not possible using this analysis to identify the impediments to these technological changes.

One possibility is that it is increasingly difficult to improve the quantity and quality of water services beyond some physical engineering limit, which the sector has perhaps already met. Another possibility is that the demands for capital expenditure for expanding and modifying expensive infrastructure are having adverse impacts on utility operations. For instance, diverting funding, attention and effort away from operations to fund and build up capital works implies fewer financial, intellectual and managerial resources are available for innovation in water utility operations and so the efficient frontier will not expand as rapidly as it might otherwise.

A somewhat likely prospect in a sector as highly regulated as urban water is also that the costs associated with regulation in the sector, including compliance costs, costs associated with price distortions and resulting production losses, and costs associated with delayed or deferred investment have an adverse effect. Nevertheless, one possible empirical factor is the focus in this report on potable water where there has been arguably less technological progress in recent years or at least over the short run. This contrasts with wastewater treatment processes where there are perhaps more opportunities for technological improvements to play a role. It would then be necessary to specify both potable water and wastewater in a single study to full account for the different sorts of technological advances the urban water sector has made.

Nonetheless, apart from identifying the slow pace of technological progress in the sector and the moderate but steady growth in sector efficiency, there are a number of useful lessons here for the utilities themselves. Clearly, this technique helps identify other utilities to which they can benchmark. In this regard, it would be most useful for utilities to investigate practices in

those utilities that perform relatively better than their operating environment would suggest. Further, it would be useful for those utilities that generally perform worse than their environment to investigate practices in both similar urban water utilities and the sector as a whole.

References

- Byrnes J, Crase L, Dollery BE and Villano R 2010, 'The relative economic efficiency of urban water utilities in regional New South Wales and Victoria', *Resource and Energy Economics* 32(3): 439–455
- Coelli T and Walding S 2006, 'Performance measurement in the Australian water supply industry: A preliminary analysis', in Coelli T and Lawrence D (Eds), *Performance Measurement and Regulation of Network Utilities*, Edward Elgar, Cheltenham, 29–62.
- Coelli, T., Prasada Rao, D.S., and Battese, G. E. (1998). *An introduction to efficiency and productivity analysis*. Boston: Kluwer.
- Council of Australian Governments (COAG) 1994, Council of Australian Governments' Communiqué 25 February 1994—Water Resource Policy, available at <http://www.coag.gov.au/>, accessed April 2011.
- Council of Australian Governments (COAG) 1995, Agreement to Implement the National Competition Policy and Related Reforms, Attachment A of Council of Australian Governments Meeting 11 April 1995, available at <http://www.coag.gov.au/>, accessed April 2011.
- Council of Australian Governments (COAG) 2004, Intergovernmental Agreement on a National Water Initiative between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory, available at <http://www.coag.gov.au/>, accessed April 2011.
- Council of Australian Governments (COAG) 2008, Council of Australian Governments' Meeting 29 November 2008—Climate Change and Water, available at <http://www.coag.gov.au/>, accessed April 2011.
- Färe, R., Grosskopf, S., Lindgren, B. and Roos, P. (1992). Productivity changes in Swedish pharmacies 1980–1989: A non-parametric Malmquist approach. *Journal of Productivity Analysis*, 3(1-2), 85–101.
- Färe, R., Grosskopf, S., Norris, M. & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review*, 84(1), 66–83.
- Filippini M, Hrovatin N and Zoric J 2008, 'Cost efficiency of Slovenian water distribution utilities: An application of stochastic frontier methods', *Journal of Productivity Analysis* 29(2): 169–182.
- Flegg, A.T., Allen, D.O., Field K., & Thurlow, T.W. (2004). Measuring the efficiency of British universities: A multi-period data envelopment analysis. *Education Economics*, 12(3), 231–249.
- García-Valinas MA and Muniz MA 2007, 'Is DEA useful in the regulation of water utilities? A dynamic efficiency evaluation', *Applied Economics* 39(2): 245–252.
- Guder J, Kittlau B, Moll R, Walter M and Zschille M 2009, 'The performance of German water utilities: A first non-parametric analysis', DIW Berlin (German Institute for Economic Research) and Dresden University of Technology Efficiency Analysis Working Papers. WP-EA-20, available at <http://tu-dresden.de/>, accessed May 2010.
- Industry Commission (IC) 1992, *Water Resources and Waste Water Disposal*, Report No. 26, Canberra, July.
- Johnes, J., Johnes, G., Thanassoulis, E., Lenton, P., & Emrouznejad, A. (2004). *An exploratory analysis of the cost structure of higher education in England*, Department of Education and Skills, Research Report RR641, Available at <http://www.dfes.gov.uk/>. Accessed June 2006.

- Lee, B., Worthington, A.C. and Leong, W.H. (2010) Malmquist indices of pre- and post-deregulation productivity, efficiency and technological change in the Singaporean banking sector, *Singapore Economic Review*, 55(4), 599–618.
- Mahlberg, B., & Url, T. (2003). Effects of the single market on the Austrian insurance industry. *Empirical Economics*, 28(4), 813–838.
- Maniadakis, N., and Thanassoulis, E. (2000). Assessing productivity changes in UK hospitals reflecting technology and input prices. *Applied Economics*, 32(12): 1575–1589.
- Munisamy S 2010, 'Efficiency and ownership in water supply: Evidence from Malaysia', Proceedings of the 12th International Business Research Conference, 8–9 April, Dubai, United Arab Emirates, available at <http://www.wbiconpro.com/>, accessed May 2010.
- National Water Commission 2008, National Performance Report 2006–07—Urban Water Utilities, available at <http://www.nwc.gov.au/>, accessed April 2011.
- National Water Commission 2009, National Performance Report 2007–08—Urban Water Utilities, available at <http://www.nwc.gov.au/>, accessed April 2011.
- National Water Commission 2010a, National Performance Report 2008–09—Urban Water Utilities, available at <http://www.nwc.gov.au/>, accessed April 2011.
- National Water Commission 2010b, National Performance Framework 2009–10—Urban Water Performance Report Indicators and Definitions Handbook, available at <http://www.nwc.gov.au/>, accessed April 2011.
- National Water Commission 2011, National Performance Report 2009–10—Urban Water Utilities, available at <http://www.nwc.gov.au/>, accessed April 2011.
- Picazo-Tadeo AJ, Sáez-Fernández FJ and González-Gómez F 2008, 'Does service quality matter in measuring the performance of water utilities?', *Utilities Policy* 16: 30–38.
- Productivity Commission 2011, *Australia's Urban Water Sector*, Draft Report, Canberra.
- Renzetti S and Dupont DP 2009, 'Measuring the technical efficiency of municipal water suppliers: The role of environmental factors', *Land Economics* 85(4): 627–36.
- Sturm, J.E., and Williams, B. (2004). Foreign bank entry, deregulation and bank efficiency: Lessons from the Australian experience. *Journal of Banking and Finance*, 28(7), 1775–99.
- Ventura, J., Gonzalez, E., and Carcaba, A. (2004). Efficiency and program-contract bargaining in Spanish public hospitals. *Annals of Public and Cooperative Economics*, 75(4), 549–73.
- Worthington, A.C. (1999). Malmquist indices of productivity change in Australian financial services. *Journal of International Financial Markets, Institutions and Money*, 9(3), 303–320.
- Worthington, A.C. 2011, *Productivity, efficiency, and technological progress in Australia's urban water utilities*, Waterlines Report Series, National Water Commission, Canberra (forthcoming).
- Worthington, A.C. (2011) A review of frontier approaches to efficiency and productivity measurement in urban water utilities, *Griffith Business School Discussion Papers in Economics*, No. 2010-10. ISSN 1836-8123.
- Worthington, A.C. and Lee, B.L. Efficiency, technology and productivity change in Australian universities, 1998–2003, *Economics of Education Review*, Vol. 27, No. 3, 2008, pp. 285–298.

Figure 1: Efficiency, technology and productivity change

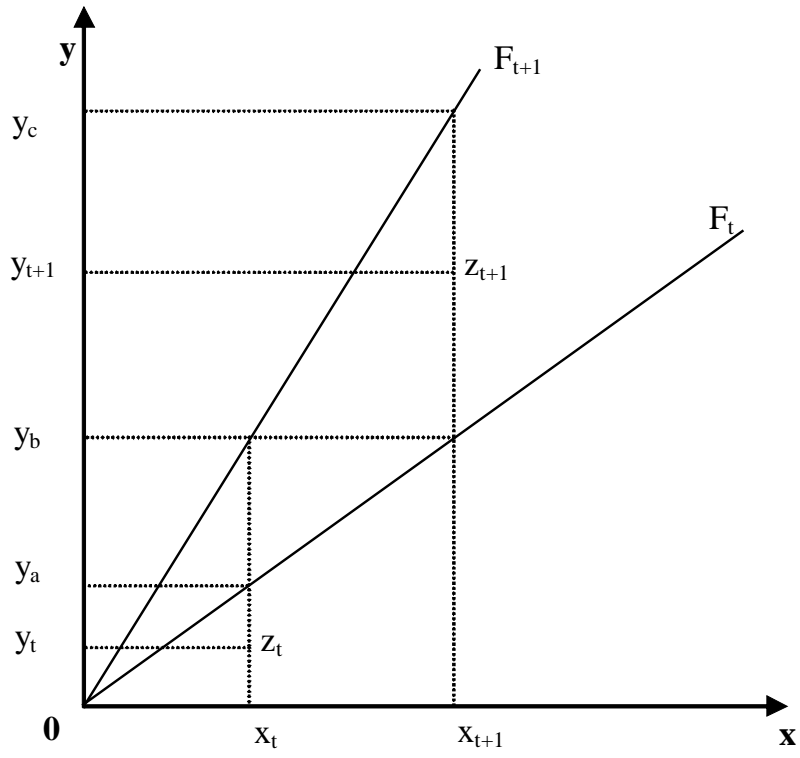


Table 1: Sampled urban water utilities

Code	Utility	Jurisdiction	Type
ACW	ACTEW	ACT	ML
ALB	Albury City Council	NSW	NML
AQW	Aqwest – Bunbury Water Board	WA	NMO
BAL	Ballina Shire Council	NSW	NMO
BAR	Barwon Water	VIC	ML
BAT	Bathurst Regional Council	NSW	NMO
BEG	Bega Valley Shire Council	NSW	NMO
BRI	Brisbane Water	QLD	ML
BYR	Byron Shire Council	NSW	NMO
CGW	Central Gippsland Water	VIC	MO
CHW	Central Highlands Water	VIC	MO
CIT	City West Water	VIC	ML
CLA	Clarence Valley Council	NSW	NMO
COF	Coffs Harbour City Council	NSW	NML
COL	Coliban Water	VIC	MO
DUB	Dubbo City Council	NSW	NMO
EGW	East Gippsland Water	VIC	NML
GCW	Gold Coast Water	QLD	ML
GFW	Goldenfields Water	NSW	NMO
GOS	Gosford City Council	NSW	MO
GOU	Goulburn Valley Water	VIC	MO
GWM	GWMWater	VIC	NML
HWC	Hunter Water Corporation	NSW	ML
IPS	Ipswich Water	QLD	MO
KMP	Kempsey Shire Council	NSW	NMO
LIS	Lismore City Council	NSW	NMO
LOG	Logan Water	QLD	MO
LOW	Lower Murray Water	VIC	NML
MCW	MidCoast Water	NSW	NML
NEW	North East Water	VIC	NML
ORC	Orange City Council	NSW	NMO
PAD	Power and Water – Darwin	NT	NML
PAS	Power and Water – Alice Springs	NT	NMO
PMQ	Port Macquarie Hastings Council	NSW	NML
QUE	Queanbeyan City Council	NSW	NMO
RIV	Riverina Water	NSW	NML
SAW	SA Water – Adelaide	SA	ML
SEW	South East Water Ltd	VIC	ML
SGW	South Gippsland Water	VIC	NMO
SHL	Shoalhaven City Council	NSW	NML
SWC	Sydney Water Corporation	NSW	ML
TAM	Tamworth Regional Council	NSW	NMO
TWE	Tweed Shire Council	NSW	NML
WAN	Wannon Water	VIC	NML
WAY	Water and Waste Services (Mackay)	QLD	NML
WCA	Water Corporation – Albany	WA	NMO
WCG	Water Corporation – Geraldton	WA	NMO
WKB	Water Corporation – Kalgoorlie–Boulder	WA	NMO
WMN	Water Corporation – Mandurah	WA	NML
WPT	Water Corporation – Perth	WA	ML
WSA	Western Water	VIC	NML
WSP	Westernport Water	VIC	NMO
WSR	Wingecarribee Shire Council	NSW	NMO
WYS	Wyong Shire Council	NSW	MO
YAR	Yarra Valley Water	VIC	ML

Notes: ACT Australian Capital Territory, NSW New South Wales, NT Northern Territory, QLD Queensland, SA South Australia, VIC Victoria, WA Western Australia, ML Metropolitan Large 100 000+ connected properties, MO Metropolitan Other 50–100 000 connected properties, NML Non-metropolitan Large 20–50 000 connected properties, NMO Non-metropolitan Other 10–20 000 connected properties.

Table 2: Selected descriptive statistics of controllable and non-controllable inputs and controllable outputs by year

		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
2005-06 to 2008-09 n=220	Mean	35189.770	89.705	95.578	1.607	25.827	8.637	127.532	37396.340	40.309	28.616	14.413	3.404	53.388
	Maximum	601724.600	100.000	100.000	12.500	263.158	92.593	1755.000	528260.000	84.000	100.000	100.000	43.428	100.000
	Minimum	1920.000	0.000	0.000	0.260	0.010	1.075	9.990	1426.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	74903.750	21.218	13.805	1.230	39.318	9.446	274.849	79052.580	16.629	42.320	28.407	6.289	41.631
	CV	2.129	0.237	0.144	0.766	1.522	1.094	2.155	2.114	0.413	1.479	1.971	1.848	0.780
	Skewness	4.968	-2.857	-4.427	4.290	2.948	4.441	4.063	4.216	0.780	0.907	2.046	3.677	-0.220
	Kurtosis	32.095	11.391	25.785	33.258	13.351	33.244	22.081	23.343	3.229	1.913	5.788	20.256	1.287
2005-06 n=55	Mean	30862.070	89.089	92.104	1.468	21.914	9.486	124.425	40069.560	39.992	26.856	13.141	3.027	56.943
	Maximum	407983.100	100.000	100.000	4.762	111.111	50.000	1706.000	528260.000	82.000	100.000	100.000	36.351	100.000
	Minimum	3475.296	0.000	0.000	0.287	0.010	1.818	10.000	1983.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	61669.760	23.189	18.945	0.892	26.010	8.842	271.919	83590.430	16.731	42.387	29.333	5.785	43.311
	CV	1.998	0.260	0.206	0.608	1.187	0.932	2.185	2.086	0.418	1.578	2.232	1.911	0.761
	Skewness	4.522	-2.687	-3.096	1.621	1.543	2.388	4.100	4.135	0.709	1.018	2.163	3.828	-0.364
	Kurtosis	26.802	9.689	13.136	5.535	4.660	9.975	22.429	22.804	3.114	2.104	6.053	21.292	1.298
2006-07 n=55	Mean	33835.540	89.087	95.991	1.524	23.975	7.316	126.446	38189.950	40.272	28.802	15.027	3.452	52.524
	Maximum	476992.400	100.000	100.000	3.846	200.000	33.333	1721.000	509930.000	83.000	100.000	100.000	33.891	100.000
	Minimum	3543.384	0.000	0.000	0.336	0.010	1.075	11.000	1426.000	6.000	0.000	0.000	0.000	0.000
	Std. Dev.	70892.260	21.826	15.218	0.900	35.694	6.570	275.073	80717.740	16.732	42.134	29.222	6.018	41.715
	CV	2.095	0.245	0.159	0.591	1.489	0.898	2.175	2.114	0.415	1.463	1.945	1.743	0.794
	Skewness	4.776	-2.761	-5.129	0.989	2.839	1.994	4.072	4.180	0.821	0.892	2.022	2.899	-0.158
	Kurtosis	29.153	10.985	30.928	3.110	12.679	7.207	22.164	23.028	3.246	1.922	5.656	13.414	1.289
2007-08 n=55	Mean	37116.060	90.888	96.403	1.751	27.156	8.373	128.563	35320.610	40.422	28.025	14.963	3.470	53.318
	Maximum	601724.600	100.000	100.000	12.500	200.000	50.000	1737.000	481701.000	83.000	100.000	100.000	41.308	100.000
	Minimum	3608.500	0.000	50.000	0.429	1.060	1.471	11.000	1535.000	6.000	0.000	0.000	0.000	0.000
	Std. Dev.	86699.410	18.686	10.095	1.713	42.329	8.012	278.293	76253.390	16.692	42.486	28.588	6.660	41.281
	CV	2.336	0.206	0.105	0.978	1.559	0.957	2.165	2.159	0.413	1.516	1.911	1.919	0.774
	Skewness	5.294	-2.971	-3.210	4.698	2.645	2.977	4.046	4.237	0.799	0.943	1.959	3.756	-0.230
	Kurtosis	34.129	12.920	12.855	29.473	9.883	14.726	21.928	23.353	3.269	1.969	5.479	20.369	1.309
2008-09 n=55	Mean	38945.390	89.755	97.815	1.685	30.263	9.373	130.695	36005.260	40.550	30.783	14.520	3.664	50.769
	Maximum	524745.000	100.000	100.000	8.333	263.158	92.593	1755.000	491968.000	84.000	100.000	100.000	43.428	100.000
	Minimum	1920.000	0.000	50.000	0.260	0.937	1.248	9.990	2061.000	5.460	0.000	0.000	0.000	0.000
	Std. Dev.	79807.490	21.459	7.883	1.243	49.861	13.161	281.586	77542.600	16.815	43.337	27.180	6.792	41.087
	CV	2.049	0.239	0.081	0.738	1.648	1.404	2.155	2.154	0.415	1.408	1.872	1.853	0.809
	Skewness	4.462	-2.963	-4.661	3.148	2.819	4.904	4.032	4.297	0.792	0.782	2.033	3.956	-0.136
	Kurtosis	26.309	12.087	26.617	16.282	11.391	30.591	21.786	23.826	3.278	1.698	5.968	22.608	1.290

Notes: OXT Total operating cost (\$000s), CHC Percentage of zones where chemical compliance was achieved (per cent), MBC Percentage of zones where microbiological compliance was achieved (per cent), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1000 properties), WMI Inverse water main breaks (per 100 km of water main), PRP Total connected properties – water supply (000s), WTR Total urban water supplied (ML), PMN Properties served per km of water main (n), BLK Percentage of water sourced from bulk supplier (per cent), GRD Percentage of water sourced from groundwater (per cent), REC Percentage of water sourced from recycling (per cent), SUR Percentage of water sourced from surface water (per cent)

Table 3: Selected descriptive statistics of controllable and non-controllable inputs and controllable outputs by jurisdiction

		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
ACT n=1	Mean	43033.960	100.000	100.000	2.008	33.839	2.883	141.000	45678.750	46.769	0.000	0.000	6.072	93.928
	Maximum	50019.980	100.000	100.000	2.857	52.632	3.429	144.000	52470.000	47.074	0.000	0.000	8.558	96.209
	Minimum	35833.510	100.000	100.000	1.603	7.246	2.083	139.000	40749.000	46.000	0.000	0.000	3.791	91.442
	Std. Dev.	5839.995	0.000	0.000	0.581	19.635	0.647	2.160	5464.214	0.514	0.000	0.000	2.549	2.549
	CV	0.136	0.000	0.000	0.289	0.580	0.224	0.015	0.120	0.011	0.000	0.000	0.420	0.027
NSW n=24	Mean	29850.330	87.929	91.501	1.425	21.680	12.851	103.470	30843.180	38.040	28.540	10.612	3.037	57.811
	Maximum	601724.600	100.000	100.000	4.082	263.158	92.593	1755.000	528260.000	84.000	100.000	98.224	43.428	100.000
	Minimum	3475.296	0.000	0.000	0.336	0.010	2.237	9.990	2851.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	100558.100	22.824	18.904	0.845	42.986	12.442	343.430	99842.630	16.699	41.949	23.049	7.902	40.645
	CV	3.369	0.260	0.207	0.593	1.983	0.968	3.319	3.237	0.439	0.000	0.000	2.602	0.703
VIC n=16	Mean	36425.700	92.780	99.028	2.051	36.730	4.559	138.281	36408.730	37.891	29.738	5.963	3.873	60.352
	Maximum	148070.000	100.000	100.000	12.500	200.000	14.286	670.000	172797.000	80.000	100.000	39.020	17.079	100.000
	Minimum	1920.000	62.857	84.091	0.287	5.587	1.075	13.000	1426.000	22.000	0.000	0.000	0.000	0.000
	Std. Dev.	42629.710	9.950	2.600	1.793	34.183	2.743	204.466	47728.040	18.346	42.078	10.439	4.971	38.751
	CV	1.170	0.107	0.026	0.874	0.931	0.602	1.479	1.311	0.484	0.000	0.000	1.283	0.642
SA n=1	Mean	113925.200	87.500	100.000	1.495	138.491	4.172	507.173	150776.600	56.341	0.000	0.000	13.789	86.129
	Maximum	141056.400	100.000	100.000	1.613	166.667	4.762	516.690	163577.000	57.365	0.000	0.000	15.522	89.671
	Minimum	97788.770	83.333	100.000	1.287	111.111	3.704	498.000	139129.400	55.000	0.000	0.000	10.329	84.330
	Std. Dev.	18777.100	8.333	0.000	0.148	31.623	0.447	8.016	12547.200	1.064	0.000	0.000	2.439	2.500
	CV	0.165	0.095	0.000	0.099	0.228	0.107	0.016	0.083	0.019	0.000	0.000	0.177	0.029
QLD n=5	Mean	53325.570	96.132	98.599	1.702	21.092	6.135	166.175	43283.560	55.115	62.662	1.115	3.858	32.170
	Maximum	154411.800	100.000	100.000	4.348	76.923	11.111	446.950	140458.000	75.000	100.000	12.344	12.247	100.000
	Minimum	14932.520	78.788	87.879	0.709	0.010	2.012	30.000	10374.000	37.000	0.000	0.000	0.000	0.000
	Std. Dev.	48309.440	6.439	3.083	0.893	22.154	2.326	156.897	42582.550	14.553	46.155	3.237	4.372	44.398
	CV	0.906	0.067	0.031	0.524	1.050	0.379	0.944	0.984	0.264	0.000	0.000	1.133	1.380
NT n=2	Mean	14075.220	35.417	91.667	0.549	1.572	2.492	29.924	22701.270	33.839	0.000	52.105	3.962	43.919
	Maximum	23285.530	100.000	100.000	0.926	3.003	6.495	50.731	37504.070	38.474	0.000	94.955	10.417	89.656
	Minimum	7397.071	0.000	33.333	0.260	0.821	1.248	11.000	8802.000	30.000	0.000	9.402	0.914	0.000
	Std. Dev.	6140.925	44.040	23.570	0.214	0.783	1.665	19.571	14620.930	4.070	0.000	43.815	3.566	46.960
	CV	0.436	1.243	0.257	0.391	0.498	0.668	0.654	0.644	0.120	0.000	0.000	0.900	1.069
WA n=6	Mean	30746.780	100.000	100.000	1.376	5.259	8.493	129.934	45957.850	41.906	16.639	55.474	0.877	25.752
	Maximum	166108.200	100.000	100.000	3.333	15.152	23.743	707.000	249756.000	54.972	99.963	100.000	3.146	100.000
	Minimum	3532.340	100.000	100.000	0.556	0.010	1.923	12.000	3362.000	29.884	0.000	0.000	0.000	0.000
	Std. Dev.	54902.770	0.000	0.000	0.879	3.619	5.998	254.368	88834.180	9.023	38.006	43.123	1.254	36.825
	CV	1.786	0.000	0.000	0.639	0.688	0.706	1.958	1.933	0.215	0.000	0.000	1.430	1.430

Notes: OXT Total operating cost (\$000s), CHC Percentage of zones where chemical compliance was achieved (per cent), MBC Percentage of zones where microbiological compliance was achieved (per cent), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1000 properties), WMI Inverse water main breaks (per 100 km of water main), PRP Total connected properties – water supply (000s), WTR Total urban water supplied (ML), PMN Properties served per km of water main (n), BLK Percentage of water sourced from bulk supplier (per cent), GRD Percentage of water sourced from groundwater (per cent), REC Percentage of water sourced from recycling (per cent), SUR Percentage of water sourced from surface water (per cent)

Table 4: Selected descriptive statistics of controllable and non-controllable inputs and controllable outputs by type

		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
ML n=11	Mean	132781.800	98.490	99.260	1.505	48.656	3.779	517.106	146531.300	62.860	46.545	8.373	4.161	40.129
	Maximum	601724.600	100.000	100.000	3.333	166.667	7.692	1755.000	528260.000	84.000	100.000	57.333	15.522	96.209
	Minimum	34007.000	83.333	80.000	0.709	3.215	1.163	125.000	31868.000	37.000	0.000	0.000	0.000	0.000
	Std. Dev.	127335.400	4.398	3.190	0.508	40.930	1.683	435.034	128130.800	14.595	48.849	17.031	4.524	40.985
	CV	0.959	0.045	0.032	0.337	0.841	0.445	0.841	0.874	0.232	0.000	0.000	1.087	1.021
MO n=8	Mean	21205.380	90.688	99.675	2.168	14.848	6.548	61.380	16361.810	41.526	37.547	2.387	2.520	57.421
	Maximum	38127.950	100.000	100.000	4.348	41.667	25.000	93.000	28170.000	73.000	100.000	23.643	8.151	99.352
	Minimum	15000.380	70.270	97.222	0.287	0.010	2.326	51.000	11334.000	26.000	0.000	0.000	0.000	0.000
	Std. Dev.	4413.357	9.595	0.875	1.138	11.847	5.964	7.950	4616.332	14.803	40.604	4.560	2.660	40.323
	CV	0.208	0.106	0.009	0.525	0.798	0.911	0.130	0.282	0.356	0.000	0.000	1.056	0.702
NML n=16	Mean	11519.870	89.739	95.418	1.881	25.571	10.288	33.835	12452.300	32.947	12.872	8.377	2.706	76.038
	Maximum	23285.530	100.000	100.000	8.333	200.000	50.000	50.731	37504.070	47.000	99.963	77.585	17.079	100.000
	Minimum	5370.912	33.333	50.000	0.260	0.010	1.587	20.000	5108.000	17.000	0.000	0.000	0.000	0.000
	Std. Dev.	4502.625	17.890	10.608	1.247	34.635	8.498	8.770	7296.858	8.391	32.090	17.782	4.716	33.441
	CV	0.391	0.199	0.111	0.663	1.354	0.826	0.259	0.586	0.255	0.000	0.000	1.742	0.440
NMO n=20	Mean	6043.803	84.453	92.043	1.220	17.867	10.824	14.685	5741.148	33.310	27.779	27.374	3.898	40.948
	Maximum	16456.000	100.000	100.000	12.500	263.158	92.593	21.000	10435.000	57.582	100.000	100.000	43.428	100.000
	Minimum	1920.000	0.000	0.000	0.336	0.010	1.075	9.990	1426.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	2465.574	29.578	20.141	1.400	44.255	12.341	2.630	2326.698	11.449	42.249	39.247	8.758	41.031
	Mean	132781.800	98.490	99.260	1.505	48.656	3.779	517.106	146531.300	62.860	46.545	8.373	4.161	40.129

Notes: OXT Total operating cost (\$000s), CHC Percentage of zones where chemical compliance was achieved (per cent), MBC Percentage of zones where microbiological compliance was achieved (per cent), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1000 properties), WMI Inverse water main breaks (per 100 km of water main), PRP Total connected properties – water supply (000s), WTR Total urban water supplied (ML), PMN Properties served per km of water main (n), BLK Percentage of water sourced from bulk supplier (per cent), GRD Percentage of water sourced from groundwater (per cent), REC Percentage of water sourced from recycling (per cent), SUR Percentage of water sourced from surface water (per cent).

Table 5: Geometric mean changes in efficiency, technology, and productivity by utility

Utility	EFFCH	Rank	TECHCH	Rank	PECH	Rank	SECH	Rank	TFPCH	Rank
ACW	3.150	48	0.232	15	0.885	49	3.560	22	0.731	46
ALB	7.298	11	0.225	19	7.298	6	1.000	35	1.640	13
AQW	0.537	54	0.251	5	0.537	54	1.000	35	0.135	53
BAL	5.421	29	0.223	22	5.421	15	1.000	35	1.207	24
BAR	4.239	40	0.209	37	1.516	29	2.797	27	0.888	40
BAT	9.839	6	0.258	4	9.839	3	1.000	35	2.542	3
BEG	6.343	16	0.229	18	6.343	12	1.000	35	1.455	16
BRI	7.982	10	0.236	12	7.982	5	1.000	35	1.886	7
BYR	3.158	47	0.223	22	0.797	50	3.964	18	0.705	48
CGW	6.771	13	0.225	19	6.771	10	1.000	35	1.526	14
CHW	9.791	7	0.239	11	9.791	4	1.000	35	2.338	5
CIT	4.772	35	0.223	22	1.724	27	2.768	28	1.066	32
CLA	6.796	12	0.275	3	6.937	9	0.980	46	1.869	8
COF	8.315	9	0.221	25	2.173	24	3.827	20	1.834	9
COL	5.936	20	0.212	34	6.112	13	0.971	48	1.258	23
DUB	5.734	24	0.287	2	5.895	14	0.973	47	1.645	12
EGW	3.603	45	0.205	44	1.153	33	3.125	24	0.739	45
GCW	4.098	41	0.232	15	2.622	22	1.563	33	0.951	38
GFW	5.816	23	0.241	9	3.362	20	1.730	30	1.400	19
GOS	3.907	42	0.200	48	1.000	39	3.907	19	0.783	44
GOU	3.633	44	0.242	8	3.771	18	0.963	49	0.880	42
GWM	10.006	5	0.176	55	1.000	39	10.006	1	1.764	11
HWC	3.118	49	0.233	14	1.226	31	2.542	29	0.726	47
IPS	0.545	53	0.209	37	0.573	53	0.951	50	0.114	54
KMP	1.951	51	0.250	6	1.966	25	0.993	45	0.487	51
LIS	12.761	1	0.234	13	3.417	19	3.734	21	2.985	1
LOG	6.425	15	0.179	54	2.243	23	2.864	26	1.148	28
LOW	3.273	46	0.194	51	0.721	51	4.537	16	0.636	49
MCW	3.650	43	0.241	9	1.217	32	2.999	25	0.879	43
NEW	4.342	39	0.218	27	2.701	21	1.608	32	0.947	39
ORC	6.499	14	0.231	17	7.173	7	0.906	54	1.499	15
PAD	5.826	22	0.246	7	4.030	17	1.446	34	1.432	17
PAS	4.346	38	0.290	1	4.346	16	1.000	35	1.262	22
PMQ	8.890	8	0.200	48	1.932	26	4.600	14	1.780	10
QUE	0.435	55	0.218	27	0.462	55	0.942	51	0.095	55
RIV	12.414	2	0.218	27	13.966	1	0.889	55	2.710	2
SAW	4.819	33	0.217	30	1.034	37	4.660	13	1.046	33
SEW	6.099	19	0.208	41	1.281	30	4.760	11	1.268	21
SGW	4.694	37	0.219	26	1.064	36	4.410	17	1.029	35
SHL	5.638	26	0.211	35	1.635	28	3.448	23	1.192	26
SWC	5.365	31	0.214	31	1.139	34	4.709	12	1.146	29
TAM	6.272	17	0.225	19	6.708	11	0.935	52	1.412	18
TWE	11.749	3	0.214	31	7.111	8	1.652	31	2.515	4
WAN	10.034	4	0.214	31	10.768	2	0.932	53	2.149	6
WAY	1.000	52	0.210	36	1.000	39	1.000	35	0.210	52
WCA	6.180	18	0.209	37	1.122	35	5.508	5	1.293	20
WCG	4.958	32	0.209	37	0.977	45	5.075	10	1.036	34
WKB	5.830	21	0.206	43	1.018	38	5.726	3	1.203	25
WMN	4.792	34	0.185	53	0.900	48	5.326	8	0.888	40
WPT	5.699	25	0.204	45	1.000	39	5.699	4	1.163	27
WSA	5.443	28	0.202	46	0.950	46	5.731	2	1.100	30
WSP	2.965	50	0.197	50	0.645	52	4.595	15	0.583	50
WSR	4.762	36	0.207	42	0.901	47	5.284	9	0.988	37
WYS	5.481	27	0.187	52	1.000	39	5.481	6	1.025	36
YAR	5.419	30	0.201	47	1.000	39	5.419	7	1.087	31
Mean	4.727		0.220		2.116		2.234		1.040	

Notes: EFFCH Technical efficiency change, TECHCH Technological change, PECH Pure technical efficiency change, SECH Scale efficiency change, TFPCH Total factor productivity change. Utility changes are geometric means. Sample mean is arithmetic mean of utility geometric means. Utility names in Table 2.

Table 6: Regression analysis of efficiency, technology and productivity

Dependent variable	EFFCH			TECHCH			PECH			SECH			TFPCH		
	Coef.	Std. error	p-value	Coef.	Std. error	p-value	Coef.	Std. error	p-value	Coef.	Std. error	p-value	Coef.	Std. error	p-value
PRP	0.0069	0.0076	0.36	-0.0001	0.0001	0.32	0.0035	0.0062	0.5756	0.0048	0.0082	0.5649	0.0012	0.0016	0.4784
WTR	0.0000	0.0000	0.46	0.0000	0.0000	0.28	0.0000	0.0000	0.6711	0.0000	0.0000	0.6843	0.0000	0.0000	0.6027
PMN	-0.0486	0.0257	0.06	-0.0002	0.0003	0.51	-0.0656	0.0325	0.0487	0.0071	0.0233	0.7620	-0.0117	0.0056	0.0426
BLK	0.0727	0.0143	<0.01	0.0022	0.0001	0.00	0.0520	0.0151	0.0012	0.0251	0.0117	0.0373	0.0163	0.0032	0.0000
GRD	0.0631	0.0172	<0.01	0.0024	0.0001	0.00	0.0552	0.0218	0.0147	0.0229	0.0117	0.0556	0.0145	0.0037	0.0003
REC	0.0431	0.0453	0.34	0.0021	0.0004	0.00	0.0774	0.0629	0.2247	0.0236	0.0453	0.6047	0.0088	0.0114	0.4423
SUR	0.0789	0.0109	<0.01	0.0023	0.0001	0.00	0.0609	0.0147	0.0001	0.0245	0.0099	0.0172	0.0180	0.0024	0.0000
R-squared	0.065	-	-	0.143	-	-	0.116	-	-	0.065	-	-	0.076	-	-
Wald F-statistic	21.864	-	<0.001	352.085	-	0.01	8.305	-	0.006	4.814	-	0.033	17.493	-	0.000
Ramsay F-statistic	0.725	-	0.390	1.429	-	0.23	2.937	-	0.093	1.283	-	0.263	0.031	-	0.861

Notes: White heteroskedasticity-consistent standard errors. EFFCH Technical efficiency change, TECHCH Technological change, PECH Pure technical efficiency change, SECH Scale efficiency change, TFPCH Total factor productivity change, PRP Total connected properties – water supply (000s), WTR Total urban water supplied (ML), PMN Properties served per km of water main (n), CAP Written down replacement cost of fixed water supply assets (\$000s), BLK Percentage of water sourced from bulk supplier (per cent), GRD Percentage of water sourced from groundwater (per cent), REC Percentage of water sourced from recycling (per cent), SUR Percentage of water sourced from surface water (per cent)

Table 7: Efficiency, technology and productivity scores adjusted for influence on non-controllable inputs

	EFFCH		TECHCH		PECH		SECH		TFPCH	
	Resid.	Rel.	Resid.	Rel.	Resid.	Rel.	Resid.	Rel.	Resid.	Rel.
ACW	-2.424	Worse	0.011		-2.336	Worse	0.641		-0.504	Worse
ALB	1.378	Better	0.004		3.891	Better	-1.760	Worse	0.320	Better
AQW	-3.899	Worse	0.014	Better	-2.460	Worse	-1.558		-0.866	Worse
BAL	0.237		0.009		2.787	Better	-1.815	Worse	0.082	
BAR	-1.600		-0.017	Worse	-2.126		-0.084		-0.413	
BAT	3.968	Better	0.037	Better	6.467	Better	-1.736	Worse	1.232	Better
BEG	0.435		-0.003		2.122	Better	-1.555		0.120	
BRI	3.264	Better	0.027	Better	6.683	Better	-2.729	Worse	0.904	Better
BYR	-1.720		0.009		-1.769		1.137		-0.346	
CGW	0.303		0.001		2.618	Better	-1.725	Worse	0.073	
CHW	3.421	Better	0.016	Better	5.528	Better	-1.748	Worse	0.918	Better
CIT	0.809		0.013		1.398		-0.725		0.240	
CLA	-0.274		0.050	Better	1.874		-1.591		0.271	Better
COF	2.197	Better	0.000		-1.472		1.067		0.469	Better
COL	-0.064		-0.007		2.301	Better	-1.808	Worse	-0.069	
DUB	-0.075		0.061	Better	2.236	Better	-1.663	Worse	0.339	Better
EGW	-3.148	Worse	-0.019	Worse	-3.390	Worse	0.477		-0.780	Worse
GCW	-0.231		0.021	Better	1.086		-1.823	Worse	0.044	
GFW	-1.152		0.019	Better	-1.458		-0.802		-0.161	
GOS	-0.685		-0.013		-0.476		0.778		-0.200	
GOU	-2.655	Worse	0.017	Better	-0.287		-1.652		-0.543	Worse
GWM	3.769	Better	-0.048	Worse	-3.467	Worse	7.356	Better	0.371	Better
HWC	-2.527	Worse	0.010		-1.961		-0.469		-0.530	Worse
IPS	-4.836	Worse	-0.003		-2.229		-1.916	Worse	-1.053	Worse
KMP	-3.559	Worse	0.014	Better	-2.265		-1.494		-0.762	Worse
LIS	7.430	Better	0.019	Better	0.857		0.913		1.823	Better
LOG	1.468	Better	-0.033	Worse	0.359		-0.189		0.088	
LOW	-2.349	Worse	-0.028	Worse	-3.334	Worse	1.901	Better	-0.615	Worse
MCW	-2.763	Worse	0.017	Better	-2.919	Worse	0.290		-0.559	Worse
NEW	-1.808	Worse	-0.005		-1.668		-1.058		-0.427	Worse
ORC	1.630	Better	0.013		2.608	Better	-1.716	Worse	0.447	Better
PAD	0.278		0.017	Better	0.602		-1.060		0.165	
PAS	-0.289		0.052	Better	0.681		-1.459		0.213	
PMQ	2.778	Better	-0.021	Worse	-1.749		1.822	Better	0.419	Better
QUE	-4.092	Worse	0.006		-1.009		-1.996	Worse	-0.872	Worse
RIV	6.565	Better	-0.020	Worse	9.459	Better	-1.515		1.370	Better
SAW	-0.683		-0.002		-2.058		1.151	Better	-0.155	
SEW	0.677		0.008		-0.102		0.425		0.167	
SGW	-1.782	Worse	-0.005		-3.226	Worse	1.759	Better	-0.426	Worse
SHL	-0.784		-0.012		-2.485	Worse	0.731		-0.248	
SWC	-0.914		-0.003		-0.383		-0.814		-0.191	
TAM	0.061		0.001		2.748	Better	-1.714	Worse	0.015	
TWE	6.095	Better	-0.006		3.854	Better	-1.142		1.262	Better
WAN	3.768	Better	-0.014		6.202	Better	-1.655		0.736	Better
WAY	-4.793	Worse	-0.012		-2.323	Worse	-1.755	Worse	-1.083	Worse
WCA	1.141		-0.026	Worse	-2.399	Worse	2.938	Better	0.157	
WCG	0.226		-0.029	Worse	-2.585	Worse	2.579	Better	-0.035	
WKB	0.380		-0.014		-1.819		2.960	Better	-0.009	
WMN	-0.274		-0.029	Worse	-1.278		2.430	Better	-0.208	
WPT	1.419	Better	-0.019	Worse	-1.141		2.640	Better	0.170	
WSA	-0.595		-0.015	Worse	-2.513	Worse	2.938	Better	-0.229	
WSP	-2.635	Worse	-0.022	Worse	-3.096	Worse	1.847	Better	-0.650	Worse
WSR	-1.318		-0.011		-2.707	Worse	2.564	Better	-0.356	
WYS	0.431		-0.029	Worse	-1.555		2.522	Better	-0.070	
YAR	-0.137		-0.002		-0.427		1.045		-0.049	

Notes: EFFCH Technical efficiency change, TECHCH Technological change, PECH Pure technical efficiency change, SECH Scale efficiency change, TFPCH Total factor productivity change. Upper (lower) quartile cut-offs for difference between actual and adjusted efficiency/productivity are EFFCH 1.259 (-1.751), TECHCH 0.013 (-0.015), PECH 1.998 (-2.294), SECH 1.144 (-1.659), TFPCH 0.255 (-0.419). Better – environment-adjusted performance in upper quartile, Worse – environment-adjusted performance in lower quartile. Utility names in Table 2.