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ABSTRACT

This paper estimates economies of scale and scope for 55 major Australian urban utilities over the period 2005/06 to 2008/09. Operating and capital costs are specified as a function of chemical and microbiological compliance, water losses, water quality and service, water main breaks, total connected properties, and urban water supplied. The input variables used to help determine water utility costs include the density of properties served and the sourcing of water from bulk suppliers, groundwater, recycling and surface water. The evidence suggests strong economies of scale at relatively low levels of output (50–75% of mean output). In terms of product-specific economies of scale (increasing an output in isolation), there is substantially stronger evidence that the operating costs of urban water utilities would benefit from increasing chemical compliance, reducing water quality and service complaints, and increasing the number of connected properties, while capital costs would benefit from reducing water losses and the number of water main breaks. For economies of scope, it is clear that there are substantial cost benefits from the joint production of treated quality water delivered across a network with minimal water losses and main breaks. The main cost advantage at all levels of output is decreasing water losses, and this would appear to benefit both operating and capital costs.

JEL classifications: C21, D24, L95.

Keywords: Economies of scale, economies of scope, cost efficiency, urban water utilities.

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1. Introduction

A number of factors have combined to reignite global interest in water policy as it relates to urban water utilities in the 21st century. Starting from their essential nature as natural monopolies operating within network industries, countries around the world with initially similar settings in delivery networks and treatment systems have progressively evolved very different approaches to urban water utilities, especially in the mix of privately and publicly owned entities and the extent of regulatory intervention governing pricing and standards. However, recent circumstances have added impetus to these longstanding developments. These include declining rainfall associated with climate change, pressing needs for maintaining and expanding expensive water supply infrastructure, jurisdictional, sectoral and environmental conflicts over existing surface and groundwater supplies, the expansion of supply options to recycling, desalination, stormwater and managed aquifer recharge, the adoption of water recycling programs and rapid population growth and urbanisation. In response, governments worldwide, including Australia, have refocused on improving the efficient management and delivery of urban water services.

Apart from sharing these developments through the recent catalyst of the National Water Initiative, perhaps one of the most defining features of Australian urban water utilities is the considerable variance in their scale (size) and scope (diversity of outputs). This is an outcome of two separate processes. First, the evolution of the urban water utility sector in this country to sometimes very large, regional and intraregional, publicly owned, corporatized water utilities operating under regulated prices. Second, the continuance of existing arrangements for small water sewerage utilities owned by local councils operating without formal independent price regulation but with some assurances that water services are independent of other council functions. Consider first the different scales of operation. At the wholesale water level, the ACT, the Northern Territory and South Australia each have single urban bulk water supplier, NSW has two, Tasmania and Victoria both three, Queensland several and about twenty in Western Australia. Of these, some are responsible for only urban water, which may or may not be the same entity engaged in the downstream retail business, while others are responsible for both rural and urban bulk water business.

A similar picture emerges at the retail level. Here, urban water services are sometimes very highly concentrated (as in the ACT, Northern Territory and South Australia), whereas Victoria has three metropolitan and 13 regional urban retail businesses, and NSW and Queensland each have three businesses centred on their largest population centres (Sydney and Southeast Queensland) and more than 100 local government or other suppliers. Even among the 73 largest urban water suppliers potentially considered in this analysis, there is an astonishing variability in size, with businesses serving anywhere between ten thousand and 1.7 million households (the several hundred smaller utilities in Australia serve anything from a few hundred to a few thousand households). Now consider scope. For a start, there is very little alignment between urban water supply and urban water drainage services, with most stormwater and drainage remaining the responsibility of local governments or only the largest urban water utilities. Putting this aside, there is a range of behaviour with most utilities providing both water and sewerage services, and a few water or sewerage services only.

Clearly, the substantial variation in the scale and scope of Australia's urban water utilities suggests the potential for economies of scale and scope to impact upon efficient outcomes and thereby provide inferences concerning, among others things, industry practice and the impact of regulation and future industry structure (Fraquell *et al*. 2004; Fraquelli and Moiso 2005). Unfortunately, very few studies of the efficiency of Australia's urban water utilities are known (Woodbury and Dollery, 2004; Coelli and Walding, 2006; Byrnes *et al*., 2010). This is a particularly glaring omission in that urban water regulators elsewhere, especially the UK, have made substantive use of efficiency techniques in guiding policy (Ofwat 2010a, 2010b 2010c). Moreover, none of these concern estimation of economies and scale using the widest sample possible from throughout Australia (Worthington, 2010) [Abbott and Cohen (2009a, 2009b) provide useful general discussion of urban water utility issues, including in Australia]. Accordingly, the purpose of this paper is to estimate economies of scale and scope in Australian urban water utilities

The paper is divided into four main sections. Section 2 briefly discusses the nature of costs in urban water utilities and the theoretical and conceptual sources of any economies of scale and scope. Section 3 deals with the specification of costs and outputs. Section 4 focuses on the cost function specification used to estimate the economies of scale and scope and Section 5 presents the results. The paper ends with some concluding remarks in the final section.

2. The nature of economies of scale and scope in urban water utilities

In general, we can divide the overall costs (or expenditure) required to operate an urban water utility into two areas: operating costs and capital costs. We broadly define operating expenditure as the day-to-day expenditure incurred by the water utility in managing its business while capital expenditure relates to those amounts typically invested in long-lived assets and depreciated over time. Using the NWC's (2010a) indicators and definitions handbook, operating costs (operation, maintenance and administration) include the following: water resource access charges or resource rent taxes, purchases of raw, treated or recycled water, salaries and wages, overheads on salaries and wages, materials/chemicals/energy, contracts, accommodation. They also include items expensed from work in progress (capitalized expense items) and pensioner remission expenses (CSOs) and competitive neutrality (CN) adjustments, they may include but not be limited to, land tax, debits tax, stamp duties and council rates. In contrast, and again using the NWC's own definitions, capital expenditure includes all capital expenditure for new works, renewals or replacements, other expenditure that would otherwise be referred to as capital, and recycling water assets.

Importantly, as in most other business, external parties will almost universally handle some of the services associated with these expenditures whereas others lie along a spectrum of in-house and external third-party providers. For example, NWC (2010) highlights 'alliance' contracts used to deliver operations and maintenance work, customer service, or capital expenditure activities as one feature of water utility operations in Australia that is increasingly prevalent. While individual alliance contracts differ, they typically involve: an agreement between the water utility and an alliance partner(s), the reimbursement by the utility of the alliance partners' direct and indirect expenses, usually including an agreed upon profit margin, forecast expenditure on capital or operating programs, to be agreed upon in advance, and transparent. Alliance arrangements also include reporting from the alliance partners to the utility once programs are underway, along with the sharing of any cost savings or overruns between the utility and alliance partners (NWC 2010).

The actual behavioural stance water utilities take to these expenditures, both operating and capital, is potentially difficult to conceptualise. Australia's urban water utilities are mainly commercialized public sector entities operating in highly regulated quasi-markets. That said, there is often an expectation of profitability, with the anticipation of dividends being paid. As argued by the NWC (2010), the level of dividend payable will reflect government dividend policy, pricing policies, the profitability of the utility and its future cash requirements. Nevertheless, government generally sets dividend policy and it is often outside of the control of the individual utility. In addition, we only observe a stable dividend policy in the largest water utilities, often with very high payout ratios, while in practice few of the smaller water utilities pay dividends at all. Clearly, we cannot blindly apply a profit-maximising objective across the sector. However, one acceptable long-run cost objective for water utilities is to be in a position to produce the desired output (or outputs) either stipulated by regulation and/or required by customers at the lowest possible cost (or cost minimisation). This minimal performance criterion should apply to any economic enterprise desiring the efficient use of resources.

As discussed in Worthington (2010), the principal outputs for most urban water utilities would appear to be the quantity and quality of water produced and distributed and the number of customers served in the distribution network. Efficient production would then entail, among other things, adjusting the scale of production to the most appropriate size for the outputs produced. Sometimes dividing the production process into smaller more specialized production units can result in economies, as evidenced by the division of most urban water utilities into separate departments responsible for water and sewerage services, and sometimes into entirely different entities with not necessarily corresponding networks. On other occasions, enlarging the scale of production can achieve lower unit costs. This can proceed over time through a continuum ranging from the internal provision of services through to full contracting out. Through this process, water utilities overcome indivisibilities in factor inputs, avoid the costs of a lack of capacity, and gain access to economies in the fixed costs of production including purchasing, marketing and administration (including human resources and information technology).

The production process for a specific output (say, the amount of treated water supplied or the number of customers served) is then said to exhibit economies of scale when average cost (AC) (i.e. cost per unit of output) declines over some range (where $AC = TC/Q$) . For long-run average cost (LRAC) to decline, the marginal cost (MC) (i.e. the cost of the last unit produced) must be less than overall average costs (where $MC = \Delta TC/\Delta Q$). If average cost is increasing, then marginal cost must exceed average cost and production then starts to exhibit diseconomies of scale. It is thought that diseconomies of scale arise from a number of sources. These include the increase in input prices as industry constraints on factor availability apply (for example, the bidding up of the price of specialised labour) and the reduction of incentives and effective coordination through the growth of bureaucracy and organisational complexity in large organisations. From a pure engineering viewpoint, there are additional complexities in urban water utilities relating to the often less than proportional increase in production from larger plants and in distribution from larger pipes and pumping stations.

In most industries, average costs are U-shaped in cost–output space, so that the smallest and largest utilities would have equally high costs relative to medium-sized utilities. That is, on either side of the minimum efficient scale (MES) of production, costs are rising so output less than or more than the MES is inefficient from a cost perspective. This would appear to match the simple analysis in Figures 1 and 2where a quadratic function is fitted to a scatter plot of observations using the data to be employed in this analysis. As shown, both operating costs per connected property to the number of properties (Figure 1)and the volume of water supplied (Figure 2) display a somewhat U-shaped pattern, but with apparently little difference in costs as we increase in output, but a substantial variation in costs at relatively low levels of output. Of course, the pattern is not as distinct as may well find in other industries because of the distribution patterns of Australian urban water utilities, with very many small utilities and only a fewer larger utilities distributed along a wide range of output (note: Sydney Water Corporation is the utility located on the extreme right-hand side in all four figures). In practice, there is much variation in the shape of LRAC across industries. One possibility is that economies of scale are negligible and diseconomies dominate at relatively low levels of output. Elsewhere, economies of scale may be extremely important and decline continuously over a wide range until output diseconomies are experienced. This results in cost efficient outputs for output levels equal to and exceeding the MES.

[Figure 1 here]

[Figure 2 here]

In yet other contexts, the LRAC may be virtually horizontal over a wide range of output: economies of scale are quickly exhausted though diseconomies are not encountered until very large levels of output are produced. These L-shaped cost curves are indicative that small, medium, and large-sized water utilities could operate with an approximately equal level of cost efficiency beyond the point of MES where average costs are either flat or only slightly increasing. This would seem to be the case in Figures 1 and 2. As shown, operating costs per connection and urban water supplied decrease at relatively low levels of production over a short range and then increase only slightly with output over a very long range. This contrasts sharply with Figures 3 and 4 where capital costs appear to be declining over a large range of output and then increase relatively sharply over a short range. Of course, while these figures are suggestive, they are only partial indicators of the true shape of the LRAC and highly sensitive to the observations included (especially the outliers).

[Figure 3 here]

[Figure 4 here]

The presence of economies (diseconomies) of scale then rests on the functional relationship between the costs of production and the rate of output per period. In other words, costs = f(output). However, the rate of output is, in turn, a function of the rate of usage of the resource inputs: that is, output = f(inputs). As the production function displays the relationship between input and output flows, once the prices of the inputs (or factor prices) are known, the costs of a specific quantity of output can be calculated. Consequently, the level and behaviour of costs as a utility's rate of output changes (as evidenced by the LRAC) depends on two important factors: (i) the character of the underlying production function and (ii) the prices the utility must pay for its resource inputs. Generally, the first factor determines the shape of the cost function while the second determines the level of costs.

Consider now a water utility using L units of labour (say, management, administrative and operational labour) in combination with K units of capital (both financial and physical) to obtain an output of Q units such that $L + K \rightarrow Q$. Now assume that the amounts of labour and capital are increased by some arbitrary proportion a with the expected proportional increase in output given by b such that $aL + aK \rightarrow bQ$. When the change in output is more than proportional to the change in input ($b > a$), increasing returns to scale are found. For example if the inputs of labour and capital increase by 20%, output rises by 30%. Alternatively, when the change is less than proportional to the change in inputs ($b < a$), the firm experiences decreasing returns to scale. An example here would be the labour and capital inputs increase by 20% but outputs only rise by 10%. Finally, where the change in output is proportional to the change in inputs ($b = a$) constant returns to scale are present. In this case, increasing inputs by 20% would also result in output increasing by 20%.

It is often tempting to use the terms economies (diseconomies) of scale (a cost concept) and increasing (decreasing) returns to scale (a production concept) interchangeably. While strictly incorrect, to yield economies of scale the production function must have some region of increasing returns to scale, and to yield diseconomies of scale it must have a region where there are decreasing returns to scale. In fact, the levels of output where economies (diseconomies) of scale and increasing (decreasing) returns to scale occur will exactly correspond when the firm faces constant input prices as output expands. This is most likely to occur for a relatively small entity in a competitive industry where the input demand by one firm is likely to be small relative to total market demand. In other cases, however, where the firm's demand for inputs is large relative to total industry demand, situations may arise where economies of scale occur at the same time that the firm experiences constant (or even decreasing) returns to scale.

Consider, for example, a water utility with constant returns-to-scale in a decreasing cost industry. If the inputs (L, K) increase by a given proportion (a), output (Q) will expand by the same proportion (b) such that $b = a$ (i.e. constant returns-to-scale). However, if input prices decline as Q rises, it follows that the average costs of producing aQ must be less than the average cost of producing Q, and long-run average costs must fall (i.e. economies of scale). Similar arguments show that production can even exhibit decreasing returns-to-scale and we can still attain economies of scale so long as the impact on average costs by the decline in factor prices sufficiently offsets the increased use of inputs and vice versa.

In the above discussion, a single output (connected properties and water supplied) is considered. Once multiple product production arises, the presence or absence of complementarity between outputs in production (joint production) in a firm becomes important. This diversity of products (goods or services) within a single firm (or superannuation fund in this case), known as 'scope', may provide cost advantages in that a single utility producing a given level of output for product may spend less than a combination of several specialised utility. That is, economies of scope arise when it is cheaper in terms of total cost (*TC*) to produce some level *Q* of output *A* in conjunction with some level of output *B*, rather than each separately, $TC(QA, QB) < TC(QA, 0) + TC(0, QB)$. Among firms, this process often manifests itself in the jargon as leveraging core competences, competing on capabilities, mobilizing invisible assets, diversification into related products, and umbrella branding. In the case of production in water utilities, the production process typically comprises multiproduct attributes because it produces multiple products (qualities and quantities of water, water and sewerage services) through the sharing and joint utilisation of inputs including management and administrative labour, information technology, human resources, piping networks and access, technical knowledge, and so on. We can see this especially clearly in the literature where outputs typically include the volume of water (Norman and Stoker, 1991; Thannassoulis, 2000; Andwandter and Ozuna, 2002; Tupper and Resende, 2004; Coelli and Walding, 2006; Byrnes *et al*., 2010) and the number of connected proprieties (Coelli and Walding, 2006; Saal and Parker, 2006; García-Valiñas and Muñiz, 2007). However, they also can include the length of mains or the service area (Thanassoulis, 2002; Munisamy, 2010), the proportion of non-households supplied with water and/or the average pumping head (Guder *et al*., 2009), and indexes of water quality assessments, service outages, and customer complaints (Woodbury and Dollery, 2004; Byrnes *et al*., 2010).

Of course, in many cases we simply cannot envisage the situation separate specialised utilities could provide these outputs. This is easy enough with water and sewerage services (the latter not considered in this paper) where most studies assume sizeable economies of scope exist through joint production in the sharing of the various types of labour, pipe-laying machinery, and recycling technology and so on. However, given the network nature of urban water utilities we can have some difficulty imagining separate firms delivering the quantity of water and another quality. We could more readily accept one producing water (as in a bulk supplier) and another distributing it, or separate responsibilities for wholesale, commercial and retail distribution, or for operation and maintenance of the network. However, in any estimation we would usually wish to include several dimensions of output, if only to ensure that we have fully specified the nature and qualities of an output to avoid any misspecification bias.

3. Specification of outputs and costs

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 (NWC 2008, 2009, 2010b). 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 is not available at the time of this anlysis (scheduled for release in April 2011). 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 remove all utilities where data is unavailable for each year over the four-year period. We then remove 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 water and sewerage services, and a few only water or sewerage services, we remove institutions offering sewerage services only (including Wagga Wagga Council, Riverina Water, City of Kalgoorlie–Boulder, and Water Corporation–Bunbury). Fortunately, as the indicators in the data split according to water and sewerage services, we are able to retain utilities offering water services only and use only the water-related indicators for utilities offering both water and sewerage services. Finally, we remove 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% of the total potential dataset, rising to 80% in 2007/08 and 85% 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]

Stochastic cost functions typically regress costs (here separated into operating and capital expenditure) on the quantity and price of the factor inputs used in production (typically capital and labour) and the outputs produced (Fabbri and Fraquelli 2000; Filippini *et al*. 2008). Unfortunately, the data released by the NWC in its reports do not permit full specification of the prices and quantities of the factor inputs. A suitable cost function would then typically specify the quantity of labour employed (where the price is the average wage or salary) along with the amount of energy and chemicals used (average price paid) and some measure of physical capital (say, the dollar value of physical assets) (where the price is the rate of depreciation). See, for example, Norman and Stoker (1991), Bhattacharya *et al*. (1995), Bottasso and Conti (2003), Aubert and Reynaud (2005), Kirkpatrick *et al*. (2006) and Da Silva e Souza *et al*. (2007)]. As this data is not available, it amounts to the assumption that input prices are constant across the urban water utility industry and so the quantity of factor inputs employed in production is proportional to the quantity of operating and capital expenses. Fortunately, Australian urban utilities are arguably price-takers operating in competitive factor markets, at least in terms of labour and financial capital. However, we do include a number of non-price variables that help determine input prices in our specification to account for variation across water utilities.

Moreover, while we should attempt to model the determination of operating and capital costs separately, not least because they are a function of different parameters, information on capital expenditure and the written down replacement cost of fixed water supply assets is only available for the most recent report (2008/09). For this reason, we estimate three separate cost functions. The first specifies total operating cost ($000) as the dependent variable as a function of seven outputs: (i) the percentage of zones where chemical compliance was achieved (%) (CHC), (ii) the percentage of zones where microbiological compliance was achieved (%) (MBC), (iii) the inverse of real losses (L/service connection/d) (LSI), (iv) the inverse of water quality and service complaints (per 1,000 properties) (WQI), (v) the inverse of water main breaks (per 100 km of water main) (WMI), total connected properties (000s) (PRP) and total urban water supplied (ML) (WTR). This is reasonable in that the literature generally accepts these parameters are drivers of water utility costs and that the focus of this section is not on individual level technical efficiencies rather sector wide economies of scale and scope. We also specify five input variables that help determine water utility costs: (i) properties served per km of water main (n) (PMN), (ii) (ii) the percentage of water from bulk suppliers (%) (BLK), (iii) the percentage of water from groundwater (%) (GRD), (iv) the percentage of water from recycling (%) (REC) and (v) the percentage of water from surface water (%) (SUR). Because of the unavailability of data, we specify this operating cost function over the period 2005/06 to 2008/09. The upper panel in Table 2 provides selected descriptive statistics.

[Table 2 here]

The second and third cost functions only use data from 2008/09 when information on capital expenditure and the amount of physical capital is available, with selected descriptive statstics in the lower panel of Table 2. Accordingly, an attempt is made to more finely specify those parameters that determine operating costs from those that determine capital costs. The first model specifies total operating expenses ($000) (OXT) as a function of four outputs (CHC, MBC, WQI and PRP) and five input variables (PMN, BLK, GRD, REC and SUR). The second model specifies total capital cost ($000s) (CXT) as a function of four outputs (LSI, WMI, WTR and PRP) and five input variables (CAP, BLK, GRD, REC and SUR). In general, the first model regards operating costs as a function of water quality, the number of supplied properties, the sources of water the utility employs and the associated requirements for treatment, and the density characteristics of its service area. The focus is short-run, day-to-day operating demands of customers. The second model instead focus on capital expenditure and the efforts the utility takes to expand and maintain a network that minimize water losses and breaks relative to the amount of water supplied and the size of the utility, the amount of capital already invested, and the infrastructure needs of its water resources. The focus is then largely the long-run asset demands of the network.

4. Model specification

We employ a quadratic cost function to estimate these models. This has the advantage of a flexible specification applicable to multifactor production. The cost function is also an appropriate form to take account of the linear, quadratic and cross-product terms found with more than one output. A cost function that allows the economies of scale to vary with different levels of input, x_{i} and output, y_{i} is specified as:

$$C = \alpha_0 + \sum_{i=1}^{m} \alpha_i y_i + 1/2 \sum_{i=1}^{m} \beta_i (y_i)^2 + \sum_{\substack{i,j=1 \\ i \neq j}}^{m} \delta_{ij} y_i y_j + \sum_{i=1}^{n} \gamma_i x_i + \varepsilon_i \qquad (1)$$

where α_0 is the fixed cost term, α_i (i = 1, 2, 3,… m) are the slope coefficients of the linear term for all outputs y_{i} (i = 1, 2, 3,… m), β_i (i = 1, 2, 3,… m) are the slope coefficients of the quadratic terms, δ_{ij} (i = 1, 2, 3,… m, j = 1, 2, 3,… m and $i \neq j$) are the slope coefficients of the cross-product terms, γ_i(i = 1, 2, 3,… n) are the coefficients of the linear term for all inputs x_{i} (i = 1, 2, 3,… n) and C is alternately the total operating (OXT) or capital (CXT) costs of each water utility.

The cost function in (1) allows the estimation of economies of scale and scope. These are defined as ray economies of scale, product-specific economies of scale, global economies of scope and product-specific economies of scope. Under ray economies of scale, the composition of each water utility's output is assumed to remain fixed while the aggregate size of output varies. This provides a measure of scale analogous to the single output case where ray economies (diseconomies) of scale exist if the measure is greater (less) than unity. Product specific economies of scale, however, allow one output to vary, while all other outputs are held constant. Product-specific economies (diseconomies) of scale then exist if the measure is greater (less) than unity. With global economies of scope, the composition of each water utility’s output is again assumed to remain fixed while the aggregate size of output varies. Finally, product-specific economies of scope measure whether the cost of producing the outputs jointly is less than the costs of producing them separately. A value greater than or equal to zero thus indicates that cost advantages accrue through the joint production of outputs.

The method for calculating these measures is as follows. First, the average incremental cost, *AIC*(y_i)) for producing output y_i is defined as:

$$AIC(y_i) = \frac{C(y) \quad C(y_{N\ i})}{y_i} \qquad i = 1, 2, 3, \ldots \text{m.} \tag{2}$$

where *C*(*y*) is the total cost of producing the four outputs and $C(y_{N-1})$ is the total cost of producing zero units of the *i*th output. In the case of a single product, the economies of scale are measured by the average incremental cost divided by the marginal cost. The product-specific economies of scale for y_i, $E(y_i)$ are specified as:

$$E(y_i) = \frac{AIC(y_i)}{MC(y_i)} \tag{3}$$

where $MC(y_i) = \partial C / \partial y_i$ is the marginal cost of producing y_i units of output. Ray economies of scale exist when the quantities of the product are increased proportionately and are presented as:

$$E(RAY) = \frac{C(y)}{\sum_{i=1}^{m} y_i \times MC(y_i)} \tag{4}$$

If $E(y_i)$ or *E*(*RAY*) is greater than one (less) than one then economies of scale (diseconomies of scale) exists for output y_i. Second, economies of scope can be divided into global economies of scope (*GES*) and product-specific economies of scope (*S*) and these are defined as:

$$GES(y_i) = \frac{\sum_{i=1}^{m} C(y_i) \quad C(y)}{C(y)} \tag{5}$$

The product-specific economies of scope are calculated as:

$$S(y_i) = \frac{C(y_i) + C(y_{N-i}) - C(y)}{C(y)} \qquad (6)$$

5. 5. Results

Table 3 presents the estimated coefficients, standard errors and p-values of the three quadratic cost functions: namely, operating expenditure for 2005/06–2008/09 in columns 2–4, operating expenditure for 2008/09 in columns 5–7, and capital expenditure for 2008/09 in columns 8–10. The table also include R^2 as a measure of goodness-of-fit and the F-statistic of the null hypothesis that the slope coefficients are jointly zero. To start with, it is obvious that the models will inevitably include multicollinearity as the explanatory variables contain a linear combination of outputs together with squared and cross-product terms. Accordingly, it is generally difficult to interpret the estimated slopes for the individual coefficients.

[Table 3 here]

The values of R^2 in Table 3 generally indicate that the models explain a significant proportion of the operating and/or capital expenditure in the sampled water utilities, ranging from 98.6–99.0%. The null hypotheses of no output effects are jointly tested in addition with various tests of no linear, quadratic and output cross-product effects with Chi-squared test statistics (statistics not shown). We reject all hypotheses at the 1% level of significance, thus indicating that all of the explanatory variables (including their squares and cross-products) should be included when estimating operating and capital cost functions for Australian urban water utilities.

The estimated quadratic cost functions in Table 3 are used to estimate the marginal costs (MC) and average incremental costs (AIC) for each of the water utility outputs outputs for levels of mean output from 50% to 300% (i.e. 100% is the mean output in the sample data) in Table 2. For instance, over the period 2005/06–2008/09, the mean water utility has chemical compliance (CHC) of 89.70%, microbiological compliance (MBC) of 95.58%, inverse water losses per connection per day (LSI) of 1.607 (87.7 litres per connection per day), inverse water quality and service complaints (per 1,000 properties) (WQI) of 25.83 (17.5 complaints per 1,000 properties), inverse water main breaks (per 100 km of water main) (WMI) of 8.64 (21.5 breaks per 100 km of water main), and 127.53 thousand total connected properties.

[Table 4 here]

Consider the marginal costs of operations over 2005/06–2008/09 in the upper panel of Table 4. As shown, the marginal costs of microbiological compliance decline from 50–75% of mean output and from 50–300% for both water quality and service complaints and the number of connected properties. Interestingly, the marginal cost of an additional connected property for a utility three times larger than the mean ($67.53) is twelve times smaller than a utility with only 50% of the mean number of connected properties ($843.33). The results for 2008/09 are similar. In general, there are decreasing marginal costs in water quality and services complaints, chemical compliance and the volume of water delivered at relatively low levels of output. There are also decreasing marginal costs across a wide range of output for the number of connected properties, and the number of water main breaks, and decreasing marginal capital costs up to 150% of mean output. A similar picture emerges for the average incremental costs in Table 5.

The negative values for marginal costs in Table 4 are potentially confusing. In theory, if all inputs are normal and their prices positive, then total variable cost necessarily increases with output, i.e. marginal cost is everywhere positive. One obvious problem with our analysis is that we were unable to specify individual factors and prices due to a lack of data. Accordingly, the assumption of constant cost over the sector may not hold and this could account for negative marginal costs (i.e. larger water utilities may have substantially lower factor prices than smaller utilities). Putting this aside, there are several other reasons why we may technically observe negative marginal costs.

First, consider the production of treated water. Even if we can design the treatment plant to operate optimally at any level of output, it is unlikely that we can design it to operate optimally at all levels at the same time. In particular, it may well be that the plant requires additional maintenance when operated at less than its ideal level. The maintenance cost saved could then outweigh the increased cost of the other variable factors required to produce closer to the plant's ideal level, resulting in a negative marginal cost. Second, input prices may be negative, especially in the presence of joint production. This is particularly pertinent when we consider the specification of outputs in this analysis. For example, by decreasing water main breaks (an increase in WMI) water utilities will also jointly produce lower water losses (an increase in LSI) and potentially fewer water service complaints (an increase in WQI). Similarly, production aimed at improving chemical (CHC) and microbiological (MBC) compliance with surely also lower the number of complaints relating to water quality (an increase in WQI). Accordingly, the specific factors of production underlying our operating and capital costs (not specified) may have a negative price, thereby also accounting for the estimated negative marginal costs.

[Table 5 here]

The product-specific (E) and ray (RAY) economies of scale for operating and capital costs are in Table 6. As defined earlier, the point estimates represent the degrees of ray economies (diseconomies) of scale: if the point estimate is greater than unity, then ray economies of scale exist across the output set. As shown by the shaded cells, ray economies (the proportional augmentation of output holding composition constant) exist from 50% to 75% of the mean output over the sample period for operating expenses in the period 2005/06–2008/09 and for capital costs in 2008/09. This suggests that much of the sector as a whole is currently experiencing economies of scale and there is a clear incentive to expand the production of all outputs at low levels to exploit existing potential scale economies. However, at some level between 75% and 100% of current mean output, diseconomies of scale affect operating and capital costs in Australia's urban water utilities if we hold the composition of output constant.

[Table 6 here]

Table 6 also includes the product-specific economies of scale. These are the scale economies that exist were an output increased in isolation. As shown for operating costs in the period 2005/06–2008/09, for CHC these are from 75–300% of mean output, 50–75% for MBC, 175–300% for LSI, WQI and PRP and 200–300% for WMI. These indicate that water utilities can obtain economies of scale by increasing individual outputs up to very high levels (only calculated here to 300% of current mean output). For capital costs in 2008/09, the evidence suggests that there are product-specific economies of scale for LSI from 225–300%, from 75–300% for LSI and at 50% for WTR. Of course, we must treat the results using the 2008/09 data with care, for although the models potentially reflect better the cost drivers of operating and capital expenditure, we only have a small cross section of observations to estimate from.

[Table 7 here]

Table 7 includes the product-specific and global economies of scope. As shown in the upper panel, global economies of scope increase (though at a diminishing rate) from 50–300% of current mean output. This indicates that there are costs advantages of providing the outputs as specified at all conceivable levels of output. However, the clearer separation of operating and capital costs in the middle and lower panel in Table 7, respectively, indicate that product-specific and global economies of scope prevail in operating costs at relatively low levels (50–75%). The suggestion is that water utilities do not have to be very large at all before it makes cost sense to produce these outputs in a single organisation (even if it were possible to disentangle, say, treatment from system maintenance). In contrast, there are global economies of scope in capital costs for all conceivable levels of outputs, but only product-specific economies of scope (again for all conceivable levels of output) in LSI. One implication is that by increasing LSI (lowering the amount of water losses) water utilities can decrease costs at all levels of output. Otherwise, they can increase the economies of scope in capital costs by increasing output in its current composition, again at all levels.

6. Concluding remarks

This paper employed stochastic functions of operating and capital costs to calculate product-specific economies of scale and scope and ray and global economies of scale and scope, respectively for 55 major urban water utilities over the four-year period 2005–06 to 2008–09. The section comprised two separate but complementary analyses. The first focused only on scale and scope economies in operating expenditure over the full four-year period 2005–06 to 2008–09. The second analysis considered scale and scope economies in both operating and capital expenditures, but because the written down replacement cost of capital was only available for 2008–09, it was not possible to accurately specify separate operating and capital cost equations for the full four-year period. Accordingly, the results for economies of scale and scope in operating expenditure over the whole four-year period are relatively more robust than the single cross section used to evaluate scale and scope economies in operating and capital expenditure for 2008–09 only. Nevertheless, the technique employed incorporates allowance for stochastic variation (mismeasurement, misspecification, unexpected outcomes, etc.) that could potentially arise when using a single year of data.

First, in terms of economies of scale, the evidence suggests that there are strong economies of scale at relatively low levels of output (up to 75 per cent of mean output or about 90 000 connected properties). One implication is that horizontal aggregation will provide efficiency gains, especially if the composite utilities are located in close proximity and if the increase in scale is without significant investment in network costs. In the sample, 11 utilities are currently too large (experiencing diseconomies of scale) with connected properties in excess of 125 000 properties while 44 utilities have less than 65 000 connected properties of which 25 have less than 30 000 connected properties (both experiencing economies of scale). It is, of course, important to recall that the sample only includes utilities with at least ten thousand connected properties, and so it is likely that increasing economies of scale also prevail for the several hundred smaller water utilities in the Australian population, but not included in this analysis.

In terms of product-specific economies of scale (increasing an output in isolation), there is evidence that there are scale economies in chemical compliance, water quality and service complaints, and the number of connected properties. That is, the average costs of each of these outputs become lower as production increases. Further, there are product-specific economies of scale in capital costs for water losses and water main breaks. That is, the average costs of reducing water losses and water main breaks also become lower as production increases. However, it would appear that these only come about at relatively high levels of output (125 per cent and higher) and so are unobtainable for all but the very largest utilities in the sample.

Second, in terms of economies of scope it is clear that there are substantial cost benefits from the joint production of the outputs included in this analysis. The presence of scope economies typically provide some support for vertical integration as here where wholesale water storage and acquisition, treatment, delivery and retail services are included in single entities. Nevertheless, we should remember that the focus of this report is on potable water, so we have not considered the economies of scope that potentially exist between water and wastewater services.

Of course, the analysis does have a number of limitations and these both qualify the findings in this paper and suggest future directions for research. First, the sample only includes the largest urban water utilities in Australia, and while these service the majority of Australian households, the results are not directly reflective of the many hundreds of smaller urban water utilities. Unfortunately, there is no nationally consistent dataset readily available for these smaller entities. An equally important consideration is that the evidence for economies of scale and scope in capital expenditure is less robust than that for operating expenditure as the former is only able to employ a single year of data (2008–09). This qualifies the interpretation of the relevant results.

Second, the focus in this analysis is on water services not water and wastewater services, even though the majority of water utilities provide both. While it is possible to separate the services provided by water utilities in water and sewerage services at least as far as correctly specifying their respective cost functions using the available data, it is likely that utilities benefit from the economies of scope between water and sewerage. For example, both are network services and have similar input requirements. There is also the real potential for the production of one type of output to affect the other.

For example, improving the treatment of sewage will have benefits for water quality drawn from surface sources, while treated sewage can also provide an input into water services in the form of recycled water. Fortunately, there is an emerging body of literature applying efficiency measurement techniques to wasterwater services from which direction can be obtained [see, for example, Estache and Trujillo (2003), Tupper and Resende (2004), Erbetta and Cave (2006) and Nauges and van den Berg (2008)].

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Figure 1. Operating expenditure per connected property ($) (y-axis) and total connected properties (000s) (x-axis), 2008/09

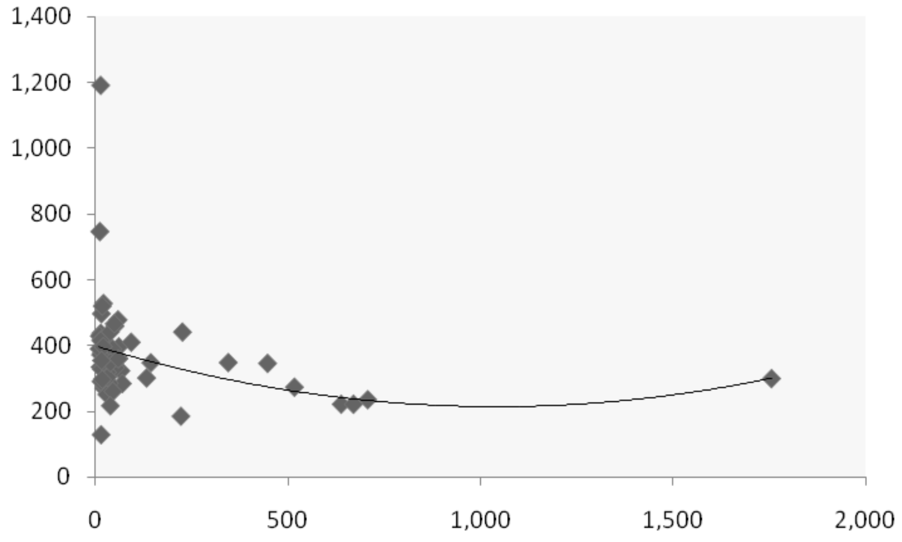

Figure 2. Operating expenditure per connected property ($) (y-axis) and total urban water supplied (ML) (x-axis), 2008/09

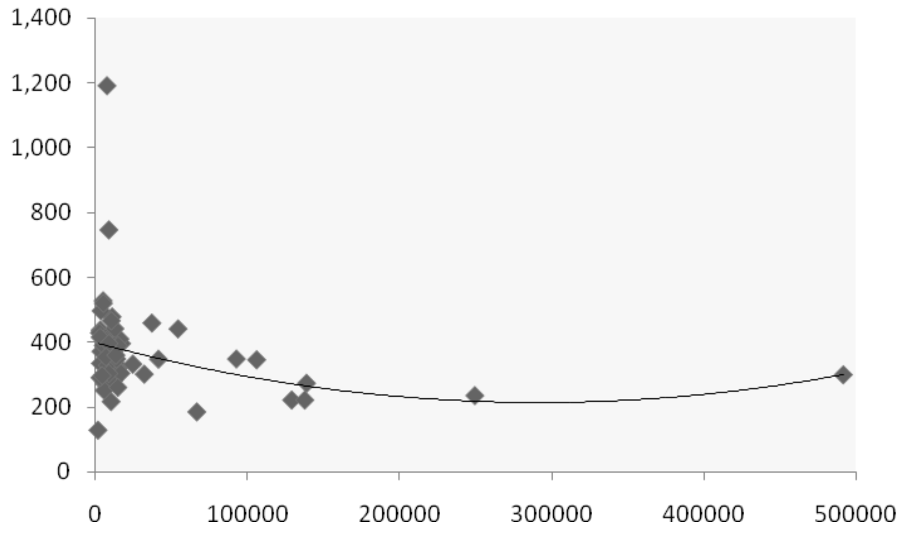

Figure 3. Capital expenditure per connected property ($) (y-axis) and total connected properties (000s) (x-axis), 2008/09

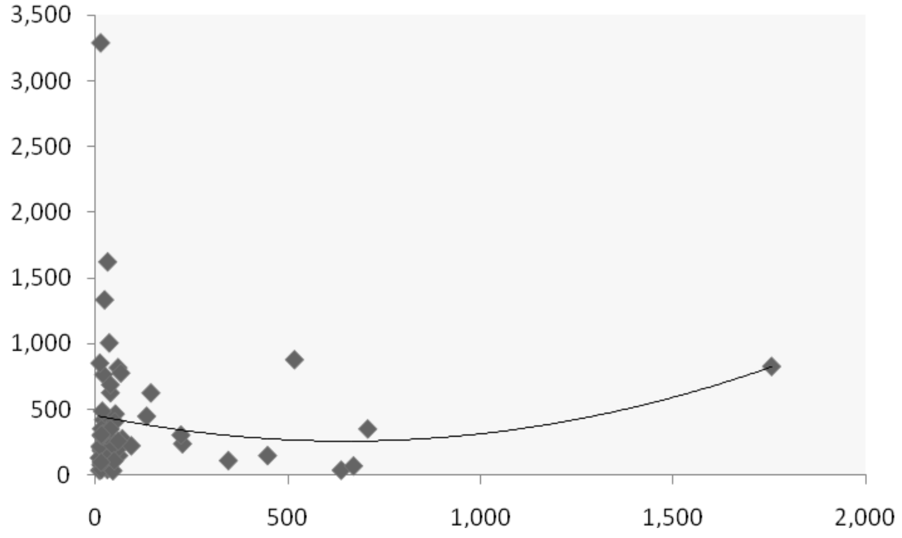

Figure 4. Capital expenditure per connected property ($) (y-axis) and total urban water supplied (ML) (x-axis), 2008/09

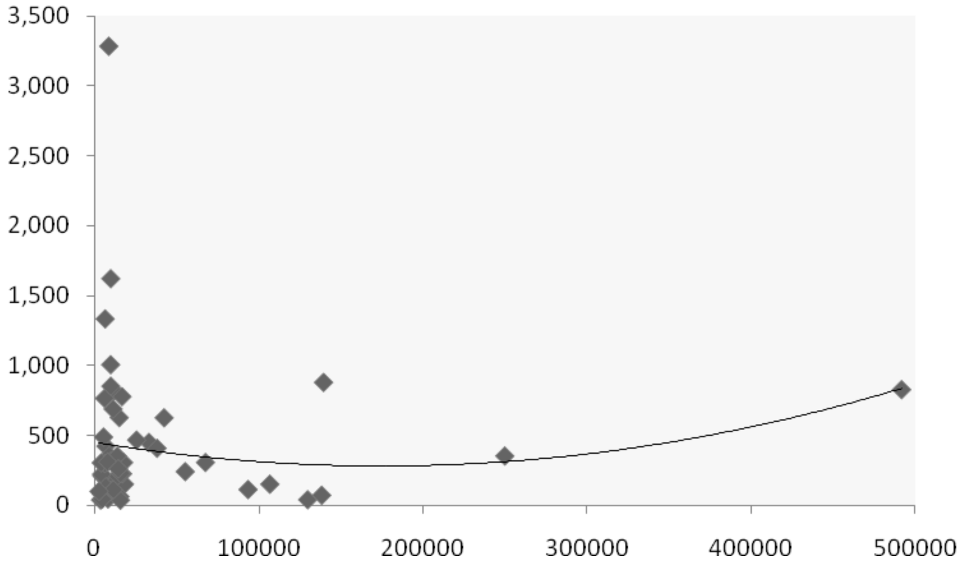

Table 1. Sampled urban water utilities

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 Regional	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 cost function variables

	Variable	Mean	Max.	Min.	Std. dev.	Skew.	Kurt.
2005/06–2008/09 (n = 220)	OXT	35189.770	601724.600	1920.000	74903.750	4.968	32.095
	CXT	–	–	–	–	–	–
	CHC	89.705	100.000	0.000	21.218	-2.857	11.391
	MBC	95.578	100.000	0.000	13.805	-4.427	25.785
	LSI	1.607	12.500	0.260	1.230	4.290	33.258
	WQI	25.827	263.158	0.010	39.318	2.948	13.351
	WMI	8.637	92.593	1.075	9.446	4.441	33.244
	PRP	127.532	1755.000	9.990	274.849	4.063	22.081
	WTR	37396.340	528260.000	1426.000	79052.580	4.216	23.343
	PMN	40.309	84.000	5.000	16.629	0.780	3.229
	CAP	–	–	–	–	–	–
	BLK	28.616	100.000	0.000	42.320	0.907	1.913
	GRD	14.413	100.000	0.000	28.407	2.046	5.788
	REC	3.404	43.428	0.000	6.289	3.677	20.256
	SUR	53.388	100.000	0.000	41.631	-0.220	1.287
2008/09 (n = 55)	OXT	38945.390	524745.000	1920.000	79807.490	4.462	26.309
	CXT	32143.725	454445.389	410.132	69802.258	4.914	27.156
	CHC	89.755	100.000	0.000	21.459	-2.963	12.087
	MBC	97.815	100.000	50.000	7.883	-4.661	26.617
	LSI	1.685	8.333	0.260	1.243	3.148	16.282
	WQI	30.263	263.158	0.937	49.861	2.819	11.391
	WMI	9.373	92.593	1.248	13.161	4.904	30.591
	PRP	130.695	1755.000	9.990	281.586	4.032	21.786
	WTR	36005.260	491968.000	2061.000	77542.600	4.297	23.826
	PMN	40.550	84.000	5.460	16.815	0.792	3.278
	CAP	689623.891	10433975.000	29256.000	1582023.599	4.979	17.001
	BLK	30.783	100.000	0.000	43.337	0.782	1.698
	GRD	14.520	100.000	0.000	27.180	2.033	5.968
	REC	3.664	43.428	0.000	6.792	3.956	22.608
	SUR	50.769	100.000	0.000	41.087	-0.136	1.290

Notes: OXT Total operating cost ($000s), CXT Total capital cost ($000s), CHC Percentage of zones where chemical compliance was achieved (%), MBC Percentage of zones where microbiological compliance was achieved (%), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1,000 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), CAP Written down replacement cost of fixed water supply assets ($000s), BLK Percentage of water sourced from bulk supplier (%), GRD Percentage of water sourced from groundwater (%), REC Percentage of water sourced from recycling (%), SUR Percentage of water sourced from surface water (%)

Table 3. Estimated cost functions

	Operating expenditure 2005/06–2008/09			Operating expenditure 2008/09			Capital expenditure 2008/09		
Variable	Coef.	Std. error	p-val.	Coef.	Std. error	p-val.	Coef.	Std. error	p-val.
CONS.	2.85E+05	7.85E+04	0.000	–	3.66E+05	0.868	9.20E+06	4.46E+06	0.047
CHC	–75.008	151.898	0.622	397.240	2504.130	0.875	–	–	–
MBC	579.137	270.384	0.034	1138.092	3550.244	0.750	–	–	–
LSI	11804.460	9272.236	0.205	–	–	–	36145.080	16628.240	0.037
WQI	–273.638	183.248	0.137	–119.665	966.062	0.902	–	–	–
WMI	828.060	484.660	0.089	–	–	–	1045.508	1326.943	0.436
PRP	–497.313	903.460	0.583	–546.242	705.028	0.444	–2687.601	1041.254	0.014
WTR	1.379	2.510	0.584	–	–	–	9.026	3.750	0.022
$.5 \times CHC^2$	–0.610	2.043	0.766	–7.785	5.227	0.145	–	–	–
$.5 \times MBC^2$	–8.699	3.570	0.016	–16.259	17.872	0.369	–	–	–
$.5 \times LSI^2$	–517.658	288.620	0.075	–	–	–	–6022.853	2298.697	0.013
$.5 \times WQI^2$	–1.323	0.708	0.063	–1.150	1.605	0.479			
$.5 \times WMI^2$	7.595	4.445	0.089	–	–	–	–12.590	18.538	0.502
$.5 \times PRP^2$	–2.435	1.119	0.031	0.032	0.111	0.778	–30.266	11.621	0.013
$.5 \times WTR^2$	0.000	0.000	0.002	–	–	–	–0.001	0.000	0.013
CHC×MBC	1.265	1.098	0.251	–0.211	23.956	0.993	–	–	–
CHC×LSI	1.077	24.058	0.964	–	–	–	–	–	–
CHC×WQI	5.933	2.048	0.004	5.530	11.671	0.639	–	–	–
CHC×WMI	–2.367	4.568	0.605	–	–	–	–	–	–
CHC×PRP	–4.091	3.847	0.289	1.744	6.636	0.794	–	–	–
CHC×WTR	0.003	0.009	0.704	–	–	–	–	–	–
MBC×LSI	–66.832	95.938	0.487	–	–	–	–	–	–
MBC×WQI	0.255	2.760	0.927	–3.118	20.583	0.881	–	–	–
MBC×WMI	–8.597	4.653	0.066	–	–	–	–	–	–
MBC×PRP	9.621	8.287	0.247	5.794	2.577	0.031	–	–	–
MBC×WTR	–0.010	0.023	0.671	–	–	–	–	–	–
LSI×WQI	–46.699	30.984	0.134	–	–	–	–	–	–
LSI×WMI	–118.633	125.545	0.346	–	–	–	–1249.505	646.443	0.061
LSI×PRP	–26.709	63.612	0.675	–	–	–	501.954	251.346	0.054
LSI×WTR	–0.130	0.198	0.512	–	–	–	–2.600	1.400	0.072
WQI×WMI	–9.288	5.009	0.065	–	–	–	–	–	–
WQI×PRP	0.638	1.091	0.559	0.470	0.627	0.458	–	–	–
WQI×WTR	–0.004	0.004	0.320	–	–	–	–	–	–
WMI×PRP	10.369	18.299	0.572	–	–	–	83.019	76.173	0.283
WMI×WTR	–0.022	0.052	0.678	–	–	–	–0.132	0.222	0.556
PRP×WTR	0.010	0.004	0.008	–	–	–	0.137	0.052	0.012
CAP	–	–	–	–	–	–	0.115	0.041	0.009
PMN	271.688	83.320	0.001	286.587	207.650	0.176	–	–	–
BLK	–3097.165	760.069	0.000	250.072	2668.655	0.926	–92452.080	44718.650	0.046
GRD	–3106.105	756.327	0.000	245.928	2673.185	0.927	–92420.640	44733.180	0.046
REC	–3200.504	745.960	0.000	415.026	2748.360	0.881	–92678.890	44795.400	0.046
SUR	–3128.429	754.924	0.000	206.572	2683.464	0.939	–92504.950	44751.500	0.046
R-squared	0.986	–	–	0.986	–	–	0.990	–	–
F-statistic	317.342	–	0.000	131.297	–	0.000	173.727	–	0.000

Notes: CHC Percentage of zones where chemical compliance was achieved (%), MBC Percentage of zones where microbiological compliance was achieved (%), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1,000 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), CAP Written down replacement cost of fixed water supply assets ($000s), BLK Percentage of water sourced from bulk supplier (%), GRD Percentage of water sourced from groundwater (%), REC Percentage of water sourced from recycling (%), SUR Percentage of water sourced from surface water (%). CONS. Constant.

Table 4. Marginal costs (MC)

	Level	MC(CHC)	MC(MBC)	MC(LSI)	MC(WQI)	MC(WMI)	MC(PRP)	MC(WTR)
Operating expenditure 2005/06–2008/09	50%	–166.935	378.188	–17214.407	331.933	–917.584	843.833	–0.579
	75%	–180.616	170.341	–17422.390	323.390	–901.184	766.203	–0.956
	100%	–194.298	–37.507	–17630.374	314.846	–884.783	688.572	–1.333
	125%	–207.979	–245.354	–17838.357	306.303	–868.383	610.942	–1.710
	150%	–221.660	–453.201	–18046.340	297.759	–851.983	533.311	–2.086
	175%	–235.342	–661.048	–18254.323	289.216	–835.582	455.681	–2.463
	200%	–249.023	–868.896	–18462.306	280.672	–819.182	378.051	–2.840
	225%	–262.705	–1076.743	–18670.289	272.129	–802.782	300.420	–3.217
	250%	–276.386	–1284.590	–18878.272	263.585	–786.382	222.790	–3.593
	300%	–303.749	–1700.285	–19294.238	246.498	–753.581	67.529	–4.347
Operating expenditure 2008/09	50%	25.230	–151.200	–	235.389	–	739.542	–
	75%	–149.458	–548.792	–	226.690	–	740.573	–
	100%	–324.146	–946.384	–	217.990	–	741.604	–
	125%	–498.834	–1343.976	–	209.290	–	742.634	–
	150%	–673.522	–1741.568	–	200.590	–	743.665	–
	175%	–848.210	–2139.160	–	191.891	–	744.696	–
	200%	–1022.898	–2536.752	–	183.191	–	745.727	–
	225%	–1197.586	–2934.344	–	174.491	–	746.758	–
	250%	–1372.274	–3331.936	–	165.792	–	747.789	–
	300%	–1721.650	–4127.121	–	148.392	–	749.850	–
Capital expenditure 2008/09	50%	–	–	–44807.463	–	3929.703	4580.587	1.741
	75%	–	–	–47345.328	–	3900.201	3591.677	–3.534
	100%	–	–	–49883.192	–	3870.698	2602.768	–8.809
	125%	–	–	–52421.057	–	3841.195	1613.858	–14.084
	150%	–	–	–54958.922	–	3811.693	624.949	–19.359
	175%	–	–	–57496.786	–	3782.190	–363.961	–24.633
	200%	–	–	–60034.651	–	3752.688	–1352.870	–29.908
	225%	–	–	–62572.515	–	3723.185	–2341.780	–35.183
	250%	–	–	–65110.380	–	3693.683	–3330.689	–40.458
	300%	–	–	–70186.109	–	3634.677	–5308.508	–51.007

Notes: CHC Percentage of zones where chemical compliance was achieved (%), MBC Percentage of zones where microbiological compliance was achieved (%), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1,000 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). Level is % of sample mean output.

Table 5. Average incremental costs (AIC)

	Level	AIC(CHC)	AIC(MBC)	AIC(LSI)	AIC(WQI)	AIC(WMI)	AIC(PRP)	AIC(WTR)
Operating expenditure 2005/06–2008/09	50%	–158.476	768.231	3197.256	–107.671	369.268	–554.055	1.089
	75%	–200.209	862.778	–1106.346	–24.688	139.872	–337.240	0.944
	100%	–241.943	957.325	–5409.947	58.296	–89.524	–120.426	0.799
	125%	–283.677	1051.872	–9713.549	141.279	–318.920	96.388	0.655
	150%	–325.410	1146.419	–14017.151	224.262	–548.316	313.203	0.510
	175%	–367.144	1240.966	–18320.753	307.246	–777.712	530.017	0.365
	200%	–408.878	1335.513	–22624.355	390.229	–1007.108	746.831	0.220
	225%	–450.611	1430.060	–26927.957	473.212	–1236.504	963.646	0.075
	250%	–492.345	1524.607	–31231.558	556.196	–1465.900	1180.460	–0.070
	300%	–575.813	1713.701	–39838.762	722.162	–1924.692	1614.089	–0.359
Operating expenditure 2008/09	50%	409.855	1062.492	–	–1.970	–	–176.471	–
	75%	416.162	1024.692	–	56.877	–	8.415	–
	100%	422.470	986.892	–	115.724	–	193.300	–
	125%	428.777	949.092	–	174.571	–	378.186	–
	150%	435.085	911.292	–	233.419	–	563.071	–
	175%	441.392	873.492	–	292.266	–	747.957	–
	200%	447.699	835.693	–	351.113	–	932.842	–
	225%	454.007	797.893	–	409.961	–	1117.728	–
	250%	460.314	760.093	–	468.808	–	1302.613	–
	300%	472.929	684.493	–	586.503	–	1672.384	–
Capital expenditure 2008/09	50%	–	–	13741.348	–	3010.360	–397.308	9.896
	75%	–	–	2539.483	–	3992.785	747.839	10.331
	100%	–	–	–8662.383	–	4975.211	1892.986	10.766
	125%	–	–	–19864.249	–	5957.637	3038.133	11.201
	150%	–	–	–31066.115	–	6940.063	4183.279	11.637
	175%	–	–	–42267.980	–	7922.489	5328.426	12.072
	200%	–	–	–53469.846	–	8904.914	6473.573	12.507
	225%	–	–	–64671.712	–	9887.340	7618.719	12.942
	250%	–	–	–75873.578	–	10869.766	8763.866	10.465
	300%	–	–	–98277.309	–	12834.618	11054.159	14.247

Notes: CHC Percentage of zones where chemical compliance was achieved (%), MBC Percentage of zones where microbiological compliance was achieved (%), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1,000 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). Level is % of sample mean output.

Table 6. Product-specific (E) and ray (RAY) economies of scale

	Level	E(CHC)	E(MBC)	E(LSI)	E(WQI)	E(WMI)	E(PRP)	E(WTR)	E(RAY)
Operating expenditure 2005/06–2008/09	50%	0.949	2.031	–0.186	–0.324	–0.402	–0.657	–1.880	7.476
	75%	1.108	5.065	0.064	–0.076	–0.155	–0.440	–0.988	12.007
	100%	1.245	–25.524	0.307	0.185	0.101	–0.175	–0.600	–29.701
	125%	1.364	–4.287	0.545	0.461	0.367	0.158	–0.383	–4.741
	150%	1.468	–2.530	0.777	0.753	0.644	0.587	–0.244	–2.253
	175%	1.560	–1.877	1.004	1.062	0.931	1.163	–0.148	–1.372
	200%	1.642	–1.537	1.225	1.390	1.229	1.975	–0.078	–0.940
	225%	1.715	–1.328	1.442	1.739	1.540	3.208	–0.023	–0.692
	250%	1.781	–1.187	1.654	2.110	1.864	5.299	0.019	–0.533
	300%	1.896	–1.008	2.065	2.930	2.554	23.902	0.083	–0.348
Operating expenditure 2008/09	50%	16.245	–7.027	–	–0.008	–	–0.239	–	–0.568
	75%	–2.784	–1.867	–	0.251	–	0.011	–	–0.393
	100%	–1.303	–1.043	–	0.531	–	0.261	–	–0.179
	125%	–0.860	–0.706	–	0.834	–	0.509	–	–0.177
	150%	–0.646	–0.523	–	1.164	–	0.757	–	–0.146
	175%	–0.520	–0.408	–	1.523	–	1.004	–	–0.121
	200%	–0.438	–0.329	–	1.917	–	1.251	–	–0.101
	225%	–0.379	–0.272	–	2.349	–	1.497	–	–0.086
	250%	–0.335	–0.228	–	2.828	–	1.742	–	–0.073
	300%	–0.275	–0.166	–	3.952	–	2.230	–	–0.055
Capital expenditure 2008/09	50%	–	–	–0.307	–	0.766	–0.087	5.686	28.427
	75%	–	–	–0.054	–	1.024	0.208	–2.923	39.507
	100%	–	–	0.174	–	1.285	0.727	–1.222	–357.388
	125%	–	–	0.379	–	1.551	1.883	–0.795	–20.354
	150%	–	–	0.565	–	1.821	6.694	–0.601	–8.796
	175%	–	–	0.735	–	2.095	–14.640	–0.490	–5.089
	200%	–	–	0.891	–	2.373	–4.785	–0.418	–3.361
	225%	–	–	1.034	–	2.656	–3.253	–0.368	–2.398
	250%	–	–	1.165	–	2.943	–2.631	–0.259	–1.803
	300%	–	–	1.400	–	3.531	–2.082	–0.279	–1.129

Notes: CHC Percentage of zones where chemical compliance was achieved (%), MBC Percentage of zones where microbiological compliance was achieved (%), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1,000 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). Level is % of sample mean output.

Table 7. Product-specific (S) and global (GES) economies of scope

	Level	S(CHC)	S(MBC)	S(LSI)	S(WQI)	S(WMI)	S(PRP)	S(WTR)	GES
Operating expenditure 2005/06–2008/09	50%	0.922	0.848	0.934	0.904	0.918	0.805	0.906	5.397
	75%	0.898	0.739	0.924	0.859	0.890	0.646	0.864	5.099
	100%	0.883	0.609	0.928	0.816	0.870	0.450	0.824	4.800
	125%	0.875	0.462	0.943	0.775	0.855	0.221	0.786	4.500
	150%	0.874	0.297	0.969	0.734	0.846	–0.040	0.750	4.196
	175%	0.879	0.114	1.005	0.693	0.842	–0.332	0.715	3.886
	200%	0.890	–0.084	1.050	0.653	0.843	–0.653	0.680	3.570
	225%	0.907	–0.300	1.104	0.613	0.848	–1.003	0.647	3.247
	250%	0.928	–0.532	1.167	0.572	0.857	–1.383	0.614	2.914
	300%	0.985	–1.048	1.318	0.490	0.886	–2.233	0.547	2.216
Operating expenditure 2008/09	50%	2.625	2.908	–	2.374	–	3.230	–	7.868
	75%	7.293	8.827	–	5.937	–	10.570	–	21.850
	100%	–28.689	–37.723	–	–20.700	–	–47.996	–	–85.900
	125%	–6.951	–9.794	–	–4.436	–	–13.027	–	–20.799
	150%	–4.850	–7.219	–	–2.755	–	–9.913	–	–14.507
	175%	–4.222	–6.557	–	–2.157	–	–9.213	–	–12.623
	200%	–4.044	–6.492	–	–1.880	–	–9.275	–	–12.088
	225%	–4.079	–6.717	–	–1.746	–	–9.717	–	–12.188
	250%	–4.244	–7.131	–	–1.690	–	–10.414	–	–12.678
	300%	–4.855	–8.398	–	–1.722	–	–12.427	–	–14.501
Capital expenditure 2008/09	50%	–	–	1.000	–	0.997	0.974	0.985	2.976
	75%	–	–	1.001	–	0.995	0.943	0.969	2.951
	100%	–	–	1.004	–	0.992	0.900	0.946	2.918
	125%	–	–	1.008	–	0.989	0.845	0.918	2.876
	150%	–	–	1.013	–	0.986	0.778	0.883	2.826
	175%	–	–	1.019	–	0.983	0.700	0.843	2.767
	200%	–	–	1.026	–	0.979	0.609	0.796	2.700
	225%	–	–	1.034	–	0.974	0.506	0.743	2.625
	250%	–	–	1.043	–	0.970	0.392	0.714	2.541
	300%	–	–	1.066	–	0.960	0.126	0.548	2.347

Notes: CHC Percentage of zones where chemical compliance was achieved (%), MBC Percentage of zones where microbiological compliance was achieved (%), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1,000 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). Level is % of sample mean output.