Productivity and efficiency measurement in the water industry

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Abstract

Over the past twenty years there has been increasing interest in the productivity and efficiency of, and the optimal structures for, the water supply and wastewater industries. In part this interest has manifested itself in the increased use of numerous statistical techniques to determine the productivity and efficiency of the water sector in a variety of countries. The purpose of this paper is threefold. First it briefly reviews the various measures that have been used to gauge the levels of productivity and efficiency in the water sector, with particular reference to input and output data requirements of these measures. Second it summarises the key structural findings that have been determined from this research, particularly with respect to economies of scale and scope, public versus private ownership and the impact of regulation. Third, it considers potential areas for potential future research, such as the effect of environmental management activities (including water conservation) and regulation on productivity and efficiency, the role of wastewater as a potential source of potable water and the relationship between water supply and urban planning.

** The views contained in this paper are those of the author only, and do not represent those of Melbourne Water.*

Part I

1. Introduction

Prior to the 1990s a great deal of analytical work was conducted on measuring the efficiency and productivity performance of various utilities industries; especially in the United States. The bulk of this work was concentrated on the rail and electricity industries; however, additional work was also undertaken on the water supply and wastewater industries. This work was encouraged by debate during the 1970s in the United States on the optimal size of water utilities, the existence of possible economies of scale, the effects of mergers and the relative performance of public versus private water and wastewater businesses.

In general, these studies tended to use econometric techniques to estimate cost functions for the industry and from these estimations comment on the degree of economics of scale and other issues. Analysis of the efficiency and productivity levels of the water supply industry was encouraged by the vast amounts of data that was gathered by utility regulators in the United States during this period. Also significant was the dominance of the industry by integrated monopoly providers. In markets where input and output prices are distorted by the existence of market power, normal means of evaluating the performance of firms such as profit rates become problematic. Such financial indicators might be more an indication of the distortions themselves, than of the firm or industry in question. In these circumstances the evaluation of the performance of firms, and even entire industries, depends more on efficiency and productivity analysis.

Although evaluations on the levels of productivity and efficiency of the United States water supply industry became common in the 1970s and 1980s, this work was not quite as important in the development of the techniques of productivity analysis as was the case of other utilities such as rail and electricity supply. Nonetheless it did play a part in encouraging reform of the industry itself, and in assessing those reforms that did occur. Subsequent reforms of the water supply and wastewater industries through the 1990s – especially the major reforms in the United Kingdom – further encouraged researchers to undertake additional productivity and efficiency studies in a number of countries. These studies used a wide range of methodologies, including partial productivity measures, total factor productivity, data envelopment analysis (DEA), traditional econometric techniques (particularly the estimation of cost functions) and stochastic frontier methods.

The purpose of this paper is threefold. First it briefly reviews the various measures that have been used to gauge the level of efficiency and productivity of the water supply industry, including partial productivity indicators, total factor productivity, DEA, econometric techniques and stochastic frontier techniques, with particular reference given to input and output data requirements of these measures. Second this paper summarises the key structural findings of this research, particularly with respect to economies of scale and scope, public versus private ownership and the impact of regulation. Third, this paper concludes by highlighting areas that may provide a focus for potential future research, such as the effect of environmental management activities (including water conservation) and regulation on productivity and efficiency, the role of wastewater as a potential source of potable water and the relationship between water supply and urban planning.

To this end, the remainder of this paper is structured as follows. Part II is separated into two sections. Section 2 provides a brief summary of the key components of the water industry. Section 3 then details the different measures that have been utilised to assess the efficiency and productivity in the water industry, and briefly considers the data inputs associated with these measures. Part III of the paper examines the key issues that arise from the research that has been undertaken to date. Sections 4 and 5 focus respectively on the issues of economies of scale and scope. Section 6 then considers the effects of public versus private ownership, while Section 7 looks at the impact of regulation on efficiency. Section 8 concludes by summarising the key findings of the research to date, highlights issues where consensus has not yet emerged and considers areas for potential future research.

Part II

2. Industry structure

Industry structures in the water sector vary across the world – in the range of activities that individual businesses undertake, the geographical size and number and nature of customers they service, the extent of private sector involvement, the scope of competition (if any), the nature and extent of regulation, and the bodies upon whom responsibility for overseeing and/or implementing that regulation is placed.

In general, the range of activities that water businesses may undertake include: bulk water collection and storage, bulk water transfer, water treatment, bulk water distribution, reticulation and retail supply, sewerage collection, distribution and treatment, drainage and irrigation. In many instances, water businesses are also responsible for such things as land and resource management, standard setting, regulation and policy development. The range of activities undertaken by water businesses is illustrated in Figure 1 below.

Myriad factors may influence not only the particular activities an individual water business will undertake, but also the manner in which they are undertaken. Water supply activities, for example, will depend upon the nature of the water sources that are available, e.g. surface water, ground water, and/or manufactured water. This in turn will influence the technology utilised to ensure that water is treated to a suitable quality – for example, aeration, DE filtration, rapid sand filtration, slow sand filtration, ultrafiltration and ion exchange. Geography, geology and topography will also play a role, as well as factors such as customer type, demand and density.

In most jurisdictions, particularly in small to medium sized markets, the basic characteristics of the water sector have resulted in water businesses operating as vertically integrated, geographical monopolies in relation to their particular activities (either privately or government owned). In larger metropolitan areas, with bigger markets and a reliance on multiple sources of water, the coexistence of several vertically integrated entities is also common, with each operating as a separate local distribution network in separate parts of the city.

In part such structures are a function of heavy up front capital costs, with water supply and wastewater systems generally involving engineering scale economies which contribute to the creation of natural monopoly conditions. Further, as water has a low value added relative to its transport costs, centralised transmission over long distances through a large national or regional network, as occurs in the case of an electricity grid, is impractical and so systems tend to be highly decentralised. Competition in the industry is generally limited because of this difficulty in long distance transportation and because a large share of the cost of supplying water and collecting sewerage is tied up in distribution networks, which are costly to duplicate. Approximately two-thirds of the cost of water supply is related to the cost of the supply network for water. In contrast around 40 percent of the cost of supplying electricity is related to the transmission and distribution networks (Wallsten and Kosec 2005). The complexity of managing inflows and outflows within the network also impinges on the scope for competition, as do water quality and public health related externalities – the most serious being water contamination which can lead to disease and other health problems (see Garcia, Moreaux and Reynaud 2007). Management of a scare natural resource (water) also plays a role, as does the planning of network extensions; both of which also have important public policy implications.

The existence of natural monopoly characteristics, externalities and welfare concerns create a strong rationale for either government provision or in the case of private delivery for government regulation. Water provision is not highly contestable and the consumer is not able to easily assess whether water is safe to drink. Regulation generally seeks to guard against the extraction of monopoly rents and to ensure adequate water quality, while at the same time guaranteeing the investors a necessary return on long lived assets. Generally, responsibility for such regulation vest either within or separate to the water businesses themselves. In more recent times government authorities in some jurisdictions have separated their commercial activities in water supply and wastewater management from policy and regulatory functions.

3. Productivity and efficiency

Monopoly control in the water sector, the importance of regulation and structural reform by various governments have all encouraged the study of the industry's performance by researchers in a range of countries. This work has encompassed analysis of the operations of vertically integrated firms (water supply or wastewater businesses), horizontally integrated firms (i.e. water supply and wastewater businesses), the entire industry or just components (i.e. wholesale and/or retail water supply). In undertaking these examinations, researchers have used a range of productivity and efficiency techniques.

3.1 Measures of productivity and efficiency

One method of determining levels of productivity is to construct index numbers. Broadly speaking these index numbers can be used to indicate the partial or total factor productivity of the industry. Partial productivity measures generally relate to a firm's output to a single input factor. For example, the volume of water supplied per employee is a labour-based partial productivity measure. In the water industry capital productivity measures are difficult to calculate given the difficulty in measuring capital inputs, and the often very long life of the assets. Partial productivity indicators have the advantage of being easy to compute, require only limited data and are intuitively easy to understand. They can, however, be misleading when looking at the change in productivity of a firm or industry. For instance it might be possible for a company to raise productivity with respect to one input at the expense of reducing the productivity of other inputs. Indices of output to labour, for instance, often tend to overstate the growth of total factor productivity (that is the combined productivity of labour, capital and other factors).

A total factor productivity index is the ratio of a total aggregate output quantity index to a total aggregate input quantity index. Total factor productivity growth, therefore, is the difference between the growth of the output and input quantity indices. Various different approaches can be used to measure total factor productivity, which can lead to different empirical results and interpretations. The aggregate input quantity index is the weighted-sum of the respective indices (weighted usually by cost shares) with each index set at unity for some common data point. More specifically the growth in aggregate inputs is the weighted-sum of the growth rates of the individual input quantity indices.

The first important attempt to derive productivity change measurements for the water supply industry was undertaken by Kendrick (1961) as part of his work on productivity trends of the United States as a whole. This work he further refined in subsequent work (1973; 1982; and Kendrick and Grossman 1980). Kendrick did not unbundle water supply and wastewater activities as he did electricity and gas supply but instead subsumed it into his category “local utilities and other public services”. This category, however, was dominated by water and wastewater businesses. The two inputs used were labour and capital. Labour consisted of estimates of labour hours exerted in the industry, and capital was an estimated capital stock index calculated from gross capital expenditure.

The use of total factor productivity indexes have tended to be rare in relation to the water industry simply because they depend upon making intensive use of input and output price data (see Bosworth and Stoneman 1998). This data can be problematic as the industry is generally a monopoly one with government determined prices. Instead the most common approach used in the case of the water supply industry is the estimation of cost functions.

Econometric methods involve the estimation of a cost or production function. The estimated function can then be used to identify changes in productivity or productive efficiency. In the water sector, the first of these was undertaken by Ford and Warford (1969), who estimated cost functions for local authorities and water boards in England and Wales in the mid 1960s. During the 1970s a range of studies that involved the estimation of cost functions were undertaken in the United States (Mann and Mikesell 1976; Morgan 1977; Crain and Zardkoohi 1978; Clark and Stevie 1981). In addition Knapp (1978) estimated cost functions for the English and Welsh wastewater industry. These studies used econometric analyses of cost functions in the industry but did not try to determine the size and causes of productivity change. These econometric analyses were mainly designed to determine the existence of economies of scale in the industry; although a number of the American studies also looked at the issue of public versus private ownership.

The estimation of cost functions has been the most commonly used method of determining the levels of efficiency in the water industry, although a number of techniques have been used in estimating these cost functions. In the determination of cost functions a range of variables need to be used including some variant of cost as the dependent variable (total costs, variable costs or average costs), as well as the level of output and input prices as independent variables. Often other variables that might drive costs are also included (in the case of water this generally means technical characteristics such as customer density, water source, losses, etc). In the context of the water supply industry this raises the issue of what is regarded as an adequate indicator of output and inputs. In a number of cases simple volumes have been used, in others these have been broken down into multiples on the basis of retail versus wholesale sales or on the basis of their source. In terms of inputs the cost of labour is generally a straight forward price but the cost of capital is often more difficult to determine. A brief summary of the range of data used for these cost functions (and for other methodologies) is contained in the Table in the Appendix.

Another approach adopted by a number of studies has been to apply stochastic frontier methodologies to the water supply industry. Parametric techniques can be used to estimate technical efficiency by constructing first the production frontier derived from the best practice firms and then comparing the actual output of firms relative to the best practice firms. The majority are early applications of this approach were with United States data. In the water sector, one of the earliest applications was an analysis of the English and Wales water and sewerage industry by Lynk (1993). Further papers were published later by people such as Bhattacharyya, Harris, Narayanan, and Raffiee (1995b – United States), Cubbin and Tzanidakis (1998 – England and Wales), Estache and Rossi (2002 – Asia Pacific countries), Bottasso and Conti (2003 – England and Wales), Corton (2003 – Peru), Saal and Parker (2004 – England and Wales), Aubert and Renaud (2005 – United States) and Fraquelli and Moiso (2005 – Italy). The range of variables used for these methodologies is similar to that for work focused solely on the estimation of cost functions (see Appendix).

Data envelopment analysis (DEA) was pioneered by Charnes et al (1978) based on the work by Farrell (1957). DEA is a linear programming technique, which estimates organisational efficiency by measuring the ratio of total inputs employed to total output produced for each organisation. This ratio is then compared to others in the sample group to derive an estimate of relative efficiency. DEA identifies the most efficient providers of a good or service by their ability to produce a given level of output using the least number of inputs. Other organisations in the sample group receive an efficiency score determined by the variance in their ratio of inputs employed to outputs produced relative to the most efficient producer in the sample group. DEA is therefore a measure of relative efficiency against the sample group's benchmark best practice. The advantage is that it can be used without input or output prices, which is useful in the case of the water industry where these are often distorted by a lack of competitive forces or political decisions. Instead simply volumes of output (including quality indicators) and inputs can be used. DEA analysis undertaken to date has tended to rely on a small number of variables (e.g. volume of water delivered, the number of properties connection; operating expenditure, capital) (see Lambert, Dichev and Raffiee 1993; Sawkins and Accam 1994; Thanassouloulis 2000, 2002; Coelli and Walding 2005; Garcia-Sanchez 2006), although there are also a number of instances where a greater number of variables have been utilised (see Anwandter and Ozuna 2002; Byrnes, Grosskopf and Hayes 1986; Woodbury and Dollery 2004).

DEA has been used to assess productivity and efficiency levels for the water supply industry at the industry, segment and firm level. The first work of this nature was by Byrnes, Grosskopf and Hayes (1986) who looked at water businesses (both public and private) in the United States. Subsequent work utilising DEA has concentrated on a variety of issues (e.g. Thanassoulis 2000 – water distribution; Thanassoulis 2002 – sewerage services; Woodbury and Dollery 2004 – relative efficiency of NSW local government water authorities), but prevalent amongst them has been the relative efficiency of government owned versus privately owned companies. Studies that have used the DEA approach for this purpose include those by Norman and Stoker (1991 – England and Wales), Lambert, Dichev and Raffiee (1993 – United States), Sawkins and Accam (1994 – Scotland), Cubbin and Tzanidakis (1998 – England and Wales), Thanassouloulis (2000, 2002 – England and Wales), Anwandter and Ozuna (2001 – Mexico) and Garcia-Sanchez (2006 – Spain).

Finally, as well as being used to benchmark firms against one another it is possible to use DEA to estimate changes in productivity of individual firms, or the sample as a group, over time. Examples of this approach are the studies by Tupper (2004 – Brazil), Coelli and Walding (2005 – Australia) and Erbetta and Cave (2006 – England and Wales).

Part III

Research on productivity and efficiency in the water sector undertaken to date, and the methodologies utilised, has been diverse. Up until the 1990s the tendency was for studies to concentrate on the issues of the existence of economics of scale in the industry and the effects of public versus private ownership. This was mainly because the main issues at the time were the possible advantages that might be obtained from merging water suppliers into larger units and the existence in the United States of both public and private water suppliers with varying levels of performance.

During the 1990s additional studies were undertaken on a wider range of issues, and across a wider range of countries. The industry in England and Wales attracted a lot of attention due to its privatisation in 1989, with the performance under the new ownership conditions of interest to researchers. Attention there was also drawn to the new regimes of price regulation that were implemented. More broadly, interest also focused on issues associated with the structural separation of the industry. The water supply industry can be broken up or combined in a number of ways. First, it is possible to vertically separate wholesale collection of water and the retail distribution of it to final consumers. Secondly the water supply industry can be horizontally separated (or combined) with sewerage and wastewater disposal. Thirdly, it is common to find water supply companies combined with the responsibilities of planning approvals and water management; particularly if the company is government owned. The effects of the possible separation and combinations all began to attract attention in the 1990s. Finally the issue of economies of scale and the optimal size of water supply units all continued to attract attention during the 1990s and 2000s.

As the reform and restructuring of the water supply industry occurred around the world, productivity and efficiency analysis of the industry spread from the United States, first to the United Kingdom, and then to a number of other countries. In the following sections, this paper focuses on the key themes and findings that emerge from this work, which fall within four broad categories:

- economies of scale;
- economies of scope;
- public versus private ownership; and
- effects of regulation

4. Economies of scale

The first issue taken up by researchers was the possible existence of economies of scale in the industry. Economies of scale arise when the cost per unit falls as output increases. Typically this occurs in circumstances where there are high fixed costs and constant marginal costs, or when there are low fixed costs and declining marginal costs. Research in relation to economies of scale is particularly relevant to the water sector given the diversity in the geographical size and number of customers served by water businesses within and between different countries. Research in relation to economies of scale in the water sector is briefly summarised in chronological order in Table 1 below.

A number of these studies found that significant scale economies exist in water supply (Bhattacharyya, Parker and Raffiee 1994; Renzetti 1999; Ashton 2000a; Garcia and Thomas 2001; Shih, Harrington, Pizer and Gillington 2006; Nauges and van den Berg 2007; though see also Ashton 2003). Some studies, however, raised doubts about the extent of these economies. As early as the paper by Ford and Warford (1969) evidence was detected that diseconomies of scale might exist in the water sector. Fox and Hofler (1985) suggested that while there are economies of scale in distribution, there were diseconomies of scale in the production of water available for delivery. More recent papers, such as Saal, Parker and Weyman Jones (2007), also raise questions about whether these economies of scale exist – finding that the large water and sewerage businesses operating in England and Wales are characterised by diseconomies of scale.

Given the diversity of research findings, specifying areas of clear consensus is fraught. It is, however, possible to provide some tentative conclusions.

The studies that looked at small water businesses generally found that economies of scale could be reaped if they became larger (see for instance Kim 1987; Fabbri and Fraquelli 2000; Antonioli and Fillipini 2001; Mitzutani and Urkami 2001; Fraquelli and Giandrone 2003; Houtsma 2003; Fraquelli and Moiso 2005; Tynan and Kingdom 2005; Sauer 2005; Torres and Morrison Paul 2006; Martins, Fortunato and Coelho 2006). The research, however, often finds that at some level economies of scale were exhausted. There is not consensus on the number of customers or the volume of water supplied, and how it would be affected by various geographical and demographic conditions (e.g. population density and customer type) (see, for example, Ford and Warford 1969; Kim

1987; Kim and Lee 1998; Fabbri and Fraquelli 2000; Garcia and Thomas 2001; Ashton 2003; Fraquelli and Moiso 2005; Torres and Morrison Paul 2006; Nauges and van den Berg 2007), but the sorts of number of connections where economies of scale were found to have been exhausted range from 100,000 (Fraquelli and Giandrone 2003) to 766,000 (Mizutani and Urakami 2001) through to one million (Fraquelli and Moiso 2005).

There is less diversity of view in relation to wastewater activities, in part because these activities have been subject to less research or have been examined in the context of businesses which undertake both water supply and wastewater activities (e.g. Ashton 2000a). Both Knapp (1978) and Renzetti (1999) found that economies of scale exist in the wastewater sector.

5. Economies of scope

Closely related to the question of economies of scale is the issue of economies of scope. Whereas economies of scale relate primarily to the efficiencies associated with the level of production of a single product type, economies of scope relate to efficiencies that accrue from combining processes or activities in the production of multiple outputs.

To some extent the specification of this issue has lacked clarity in the research to date. In some instances, discussion of economies of scope have focused on the question of vertical integration of the various stages of supply as complementary products – for example, on the combination of wholesale water capture and treatment, and final reticulation to the customer (e.g. Garcia and Thomas 2001; Garcia, Moreaux and Reynaud 2007, see also Kim 1987; Kim and Clark 1988). In other cases, the focus has been on the integration of more diverse activities such as the joint undertaking of water supply and wastewater activities (Saal and Parker 2000; Fraquelli and Giandrone 2003; Stone and Webster 2004; Fraquelli and Moiso 2005), and the integration of water supply with other activities such as environmental management, planning, policy development and regulation (see Hunt and Lynk 1995; Fraquelli and Giandrone 2003).

As reform of the water sector may potentially encompass both the integration and/or atomisation of the discrete activities undertaken in the water sector (see Section 2.1), in this paper economies of scope are specified broadly to encompass both issues of vertical integration and the joint undertaking of more diverse activities in the water sector. Studies relating to these issues are briefly summarised in Table 2 below.

First, in relation to vertical integration of water supply activities, Hayes (1987) showed that vertical integration is efficient for small companies but not necessarily for large ones. Similarly, Garcia and Thomas (2001) found that there are significant economies of scope between water production and distribution, with particular reference to reduction of network losses. This result was confirmed by Stone and Webster (2004), with savings most evident for businesses only undertaking water supply. In contrast, Garcia, Moreaux and Reynaud (2007) concluded that separation may be advantageous in some circumstances, and that economies of vertical integration are not significant except for the smallest utilities. While the work in this area is not prolific, it is reasonable to suggest that there is no evidence than vertical separation can bring advantages in terms of efficiency and productivity to relatively small water companies. Further work on the case of larger institutions would be helpful.

Secondly, with regard to economies of scope between water supply and wastewater activities, there is considerable support for the view that there are economies of scope that accrue to a company that operates both jointly. The work by Lynk (1993), Hunt and Lynk (1995), Fraquelli and Giandrone (2003), Fraquelli and Moiso (2005) and Martins, Fortunato and Coeho (2006) endorses this position, though it appears that is more strongly the case for small companies as opposed to large ones. In this regard, Stone and Webster (2004) argue that the horizontal integration of water and sewerage is associated with overall diseconomies of scope, although they also note that there is some evidence of scope economies from the integration of water and sewerage production activities e.g. through the purchase of power for treatment works. Similarly, Saal and Parker (2000) rejected the hypothesis that economies of scope between water and sewerage services exist (although they noted the possibility of some 'quality-driven scope economies' in which an improvement in the quality of one output may reduce the cost of producing another).

Thirdly, research has briefly looked at the degree to whether there are economies of scope between water supply and wastewater activities, and environmental management, planning, policy development and regulation. In many jurisdictions these activities are carried out by the same institution (often local government authorities). Generally one principle of corporatisation is that regulatory and commercial responsibilities of government bodies should be separated. However, if there is little prospect of a corporatised government water company or privatised company being subjected to new entry and competition than there seems to be little to be gained from separation of these responsibilities.

Research is this area is sparse, and to the extent that it exists, it relates primarily to the role of water supply and wastewater businesses in environmental management. This was considered in Lynk (1993) and Hunt and Lynk (1995), which found that economies of scope existed between environmental management and commercial water activities.

In a related manner, Saal, Parker and Weyman-Jones (2007) considered the effects of environmental regulation on the operations of water and sewerage businesses, and concluded that these regulations had enhanced the efficiency of these businesses (see also Saal and Reid 2004).

The limited research in this area is unfortunate because the separation of planning/environmental management from commercial water supply might be a source of inefficiency in this case. This is suggested by Garcia and Thomas (2001), who call for greater research into the relationship between responsibility for reducing undesirable water output and managing water losses, and by Fraquelli and Giandrone (2003), who highlight the reduced costs associated with sewage treatment where pollution load is removed. That said, there is no evidence from the literature of productivity and efficiency analysis that provides any evidence that private companies are at a disadvantage compared to government ones because they are not directly involved in regulatory functions.

6. Ownership

The third major issue has been that of private versus government ownership and the consequent impact on efficiency levels. As Saal and Parker (2001:66) note:

> *"… The argument as to why privatisation may lead to higher corporate performance has been well rehearsed. Capital market pressures are said to produce a superior principal agent relationship in the private sector, leading to management incentives that are more consistent with efficient operations than exists under state ownership … . Public ownership is also associated with political and economic goals that may conflict with the*

> *efficient use of factor inputs … . At the same time, however, the extent of performance improvement resulting from privatisation depends, at least in part, upon shareholders ability to monitor management effort in the pursuit of efficiency gains …"*

Most of the original work on this issue was undertaken in the United States where there are a large number of both public and private water suppliers. Later in the 1990s the issue of whether the privatisation of the English and Welsh water and wastewater businesses improved the productivity and efficiency of the industry was undertaken by a number of researchers.

In the American case the results have been somewhat ambiguous. A number of studies found that there was no discernable difference between government- and privately-owned companies (Feigenbaum and Teeples 1983; Byrnes, Grosskopf and Hayes 1986; Teeples and Glyer 1987, see further Houtsma 2003) (see also for Spain – Garcia-Sanchez 2006; Brazil – da Silva e Souza, Coelho de Faria and Belchiar S Moreira 2007). In contrast, some studies found that private operators are more efficient (Crain and Zardkoohi 1978; Morgan 1977; Raffiee, Harris, Lambert and Collins 1992) and others that public providers are more efficient (Mann and Mikesell 1976; Bruggink 1982; Fox and Hofler 1985; Lambert, Dichev and Raffiee 1993; Bhattacharyya, Parker and Raffiee 1994; Shih, Harrington, Pizer and Gillington 2006).

One study gives a clue as to the possible reason for this discrepancy. Bhattacharyya, Harris, Narayanan and Raffie (1995b) found that government owned firms were more efficient at high levels of output while privately owned ones were more efficient at low levels of output. Perhaps differences in sampled firms and their sizes are a source of the discrepancies in this work. More broadly, however, the conclusion reached by the researchers is that in driving efficiency, ownership is not as important a question as the level of competition in the industry (see for instance Wallsten and Kosec 2005). In the case of the overwhelming majority of private owned companies in the water sector, they are monopolies and not any more the subject of competitive pressures than government owned ones.

In a related theme, a number of analysts (particularly English ones) have looked at the change in efficiency brought about by privatisation. In most instances, the evidence shows limited effects on efficiency from privatisation (see Shaoul 1997; Bosworth and Stoneman 1998; Saal and Parker 2000; Saal and Parker 2001; Saal and Parker 2004) or even a decline in overall efficiency (see Saal, Parker and Weyman-Jones 2007). Further, any improvements following privatization appear to be less than the improvements in productivity that occurred in the period immediately prior to privatisation. Such an outcome is not unique to the water sector; it was common across most of the privatised industries in Britain (Bishop and Thomson 1993), and generally is attributed to the fact that the nationalised industries in Britain had a great deal of scope to improve their levels of efficiency which they subsequently achieved during the period of corporatisation (Shaoul 1997). After privatisation, improvements could still be made but the scope to so was reduced. Further, the privatised companies were still monopolies and it often wasn't until economic regulation was imposed on them that they began to make substantial efficiency gains (see Saal and Parker 2000; Sawkins 2004; Saal and Reid 2004; Saal, Parker and Weyman Jones 2007) (see Section 7 below).

7. *Regulation*

The fourth major issue prevalent amongst the literature is the effect of regulation on the productivity and efficiency of the water sector. Generally, the water sector is subject to considerable environmental, planning, social and economic regulation. These regulations cover issues as diverse as public health (such as drinking water quality standards), pricing (such as rate of return and incentive-based mechanisms) and river and ocean health. At times governments have given responsibility for regulation to government owned companies themselves, or they are subsumed into local government bodies. In some instances, responsibility for regulation is separated from those bodies for undertaking commercial activities in the water sector.

The research which has been undertaken relates primarily to the United States and the United Kingdom (post-privatisation), and is briefly summarised in Table 4 below.

In the case of the United States, the work by Aubert and Reynaud (2005) demonstrates that the type of regulation imposed (e.g. rate of return *cf* price cap) is important in influencing the level of productivity and efficiency of the industry.

More broadly, the work undertaken in the United Kingdom indicates that the productivity and efficiency of the industry improved as a result of the economic and environmental regulatory arrangements that were imposed on the privatised industry in the 1990s. In the most recent study, Saal, Parker and Weyman (2007) (i) found that productivity growth was not significantly different before and after privatization, (ii) posited that environmental regulation had stimulated technical change in the form of new technologies and new production processes and (iii) concluded that a tightening of the regulatory regime had enhanced efficiency (though only returning the businesses to near their pre-privatisation levels). That regulation is associated with improved efficiency is consistent with the findings of Saal and Parker (2004), which found some evidence of a small increase in the rate to total factor productivity growth in the aftermath of a substantial tightening of regulation in 1995 (see also Saal and Parker 2000; Saal and Reid 2004, though note also Saal and Parker 2001), and Erbetta and Cave (2006) which found that the post-privatisation regulatory environment seemed to reduce allocative inefficiency, and that a change in regulatory approach from 1995 was associated with a general and input-specific high significant effect as far as technical efficiency is concerned.

However, given the relative paucity of the research that has been undertaken to date in this area, it appears that there is still substantial scope for additional research. In particular the impact of environmental regulation of the industry in productivity and efficiency has so far attracted little attention.

8. Conclusion

In recent years interest has grown both in the reform of the structure of water supply around the world and the undertaking of the productivity and efficiency performance of water utilities. In this paper we have reviewed the various measures that have been used to gauge the levels of productivity and efficiency in the water sector and summarises some of the key structural findings.

The work that has been undertaken to date does suggest some general characteristics in the industry. First of all there are economies of scale in the industry but there is also evidence that at some point these are exhausted. As well there is some evidence that there are economies of scope between water supply and wastewater disposal, but again these are greatest for small institutions. Vertical integration between bulk water supply and distribution also involves economies with smaller sized companies. In the case of larger institutions further work is needed.

Regarding the issue of ownership the results from the United States are ambiguous and no clear conclusions can be made. In the case of water supply perhaps corporatisation of government operations can bring about many of the productivity performance improvements that privatisation can and in the case of privatisation the sector is one where monopoly conditions are common and so improvements in performance can only be brought about with economic regulation.

Research on such things as the effect of environmental management activities (including water conservation) the role of wastewater as a potential source of potable water and the relationship between water supply and urban planning is at this stage woefully inadequate and considerable amounts of research needs to be undertaken in these areas in the future if policy makers are going to b bale to make informed decision about the integration or separation of these functions from commercial activities in the sector..

Figure 1: Water supply and waste water industry – key activities

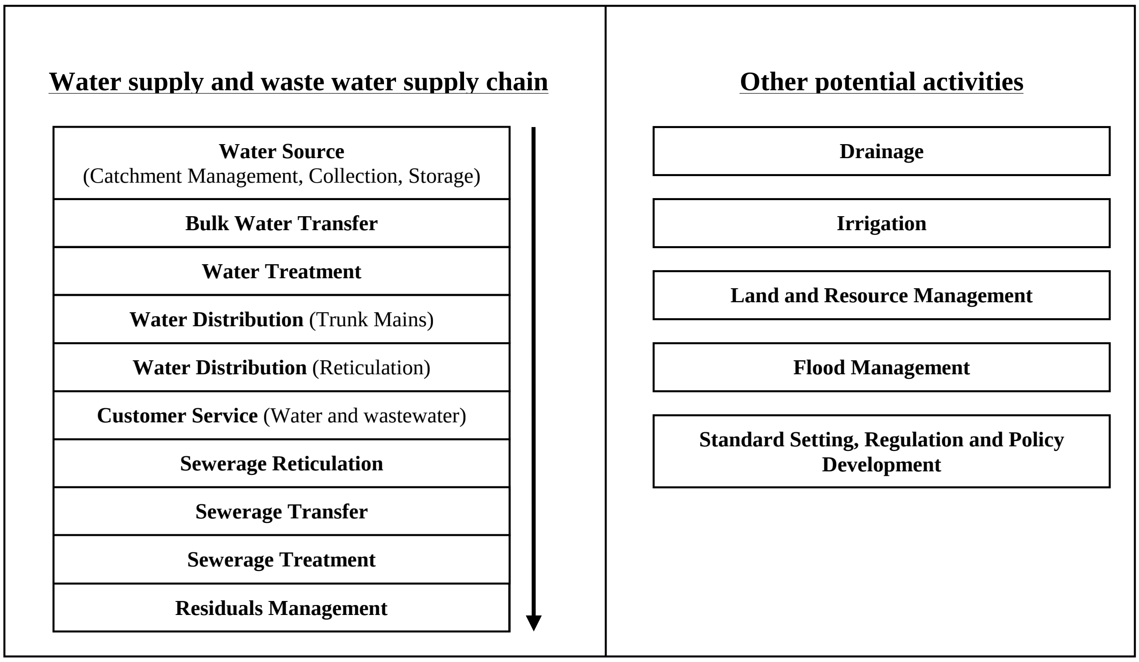

Table 1: Studies of economics and diseconomies of scale

AUTHOR(S)	DATE	COUNTRY	RESULTS
Ford and Warford	1969	England & Wales	Diseconomies of scale may exist.
Knapp	1978	England &Wales	Strong economies of scale in wastewater treatment.
Fox and Hofler	1985	USA	Economies of scale in distribution. Diseconomies in production of water.
Kim	1987	USA	Some economies of scale for non-residential water supply, some diseconomies of scale for residential.
Kim and Clark	1988	USA	No significant economies of scale in overall operation, some economies of scale for non-residential, some diseconomies for residential.
Bhattacharyya, Parker and Raffiee	1994	USA	Economies of scale for water utilities (though scope of activities unclear).
Kim and Lee	1998	Korea	Economies of scale for most businesses.
Renzetti	1999	Canada	Economies of scale for water supply and sewerage treatment.
Fabbri and Fraquelli	2000	Italy	Economies of scale exist but are exhausted at some level, diseconomies of scale at higher levels of water delivery.
Ashton	2000a	England & Wales	Economies of scale for water and sewerage.
Saal and Parker	2000	England and Wales	Diseconomies of scale for water and sewerage.
Antonioli and Fillipini	2001	Italy	Economies of scale of output and density, no evidence of economies of larger service areas.
Mizutani and Urakami	2001	Japan	Many small companies that could reap economies of scale, optimal size around 766,000 connections.
Garcia and Thomas	2001	France	Significant economies of scale up to certain level, then diseconomies will arise.
Ashton	2003	England &Wales	Slight diseconomies of scale for water supply.
Fraquelli and Giandrone	2003	Italy	Economies of scale for small plant, exhausted around 15 million cubic metres, 100,000 connections.
Houtsma	2003	USA	Economies of scale, charges fall for population in excess of 10,000, also beyond 125,000 connections.
Stone and Webster Consultants for OFWAT	2004	England & Wales	Diseconomies of scale for water and sewerage about 2 million water connections and 2.3m for sewerage, economies of scale for small water only companies about 350,000 connections.
Fraquelli and Moiso	2005	Italy	Some economies of scale up to 90 million cubic metres (i.e. 1m connections), diseconomies of scale thereafter.
Sauer	2005	Germany	Economies of scale for small rural water supply and sewerage businesses.
Tynan and Kingdom	2005	33 countries	Economies of scale for small utilities under 125,000 connections, some cases of diseconomies of scale above that but also some cases of none.
Torres and Morrison Paul	2006	USA	Economies of scale for small utilities when mergers lead to greater densities, diseconomies of scale for large regional ones where area serviced is large and diverse.
Shih, Harrington, Pizer and Gillington	2006	USA	Economies of scale for community water systems.
Martins, Fortunato and Coelho	2006	Portugal	Small companies can reap economies of scale, large utilities appear to have moderate overall diseconomies of scale.
Nauges and van den Berg	2007	Brazil, Columbia, Moldova, Vietnam	Economies of scale in water supply and sewerage sector in three countries (but no clear evidence in Brazil).
Saal, Parker and Weyman-Jones	2007	England &Wales	Diseconomies of scale found amongst more than half of the large water and sewerage utilities.

Table 2: Studies of economies of scope

AUTHOR(S)	DATE	COUNTRY	RESULTS
Hayes	1987	USA	Vertical integration is efficient for small companies, but not large ones.
Kim and Clark	1988	USA	Economies of scope for joint production of residential and non-residential water.
Lynk	1993	England & Wales	Greater inefficiencies in water only companies than water and sewerage companies, economies of scope for water and sewerage, economies of scope, water supply and environmental.
Hunt and Lynk	1995	England & Wales	Economies of scope between regulation (environmental services) and water supply (though not sewerage); evidence of economies of scope between water and sewerage.
Saal and Parker	2000	England and Wales	No evidence of economies of scope between water and sewerage services.
Garcia and Thomas	2001	France	Positive degree of economies of scope (i.e. reduced network leaks), significant economies of scale.
Fraquelli and Giandrone	2003	Italy	Vertical integration seems to produce significant scope economies; removed pollution load has a significant role in explaining variability of costs.
Stone and Webster Consultants for OFWAT	2004	England & Wales	Diseconomies of scope for water and sewerage; economies of scope for vertical integration of water.
Martins, Fortunato and Coelho	2006	Portugal	Economies of scope between water and sewerage except for the largest businesses.
Garcia, Moreaux and Reynaud	2007	USA	Disintegration may lead to cost savings, specialization of inputs and assets can lead to savings.

Table 3: Studies of public versus private ownership

AUTHOR(S)	DATE	COUNTRY	RESULTS
Mann and Mikesell	1976	USA	Public more efficient than private.
Morgan	1977	USA	Private more efficient than public.
Crain and Zardkoohi	1978	USA	Private more efficient than public.
Bruggink	1982	USA	Public more efficient than private.
Feigenbaum and Teeples	1983	USA	No significant differences in efficiency between public and private.
Fox and Hofler	1985	USA	Similar technical efficiency between the two types but private firms are more allocatively inefficient.
Byrnes, Grosskopf and Hayes	1986	USA	No evidence of difference in efficiency between public and private.
Teeples and Glyer	1987	USA	No evidence of difference in efficiency between public and private.
Raffiee, Harris, Lambert and Collins	1992	USA	Private more efficient than public.
Lambert, Dichev and Raffiee	1993	USA	Public more efficient than private.
Bhattacharyya, Parker and Raffiee	1994	USA	Public more efficient than private.
Bhattacharyya, Harris, Narayanan and Raffiee	1995b	USA	Small: private more efficient, large: public more efficient.
Shaoul	1997	England & Wales	Improvements in productivity occurred before not after privatization.
Bosworth and Stoneman	1998	England & Wales	Labour productivity rose by 2.2 %, under corporatised government ownership and 0.03 under privatization.
Saal and Parker	2000	England & Wales	Privatization did not improve cost efficiency, regulation did.
Saal and Parker	2001	England & Wales	Improvement in TFP performance after privatization but less than pre-privatization period.
Estache and Rossi	2002	Asia Pacific countries	Efficiency is not significantly different in private companies than in public ones.
Houtsma	2003	USA	Claims of private companies being ‘substantially more efficient’ found to be not valid, and that unlikely customers of private companies received ‘comparable services’ to those of public companies.
Saal and Parker	2004	England & Wales	Productivity improvement after regulation in 1995, not privatization in 1989.
Wallsten and Koser	2005	USA	No evidence of difference between public and private.
Garcia-Sanchez	2006	Spain	No evidence of difference in efficiency between public and private.
Shih, Harrington, Pizer and Gillington	2006	USA	Public systems lower costs than private.
da Silva e Souza, Coelho de Faria and Belchiar S Moreira	2007	Brazil	No evidence of a difference in efficiency between public and private.
Saal, Parker and Weyman-Jones	2007	England & Wales	Improved productivity after regulation not privatization, although some efficiency gains amongst more inefficient businesses.

Table 4: Studies of the effects of regulation

AUTHOR	DATE	COUNTRY	RESULTS
Saal and Parker	2000	England & Wales	Privatization did not improve cost efficiency, regulation did.
Saal and Parker	2001	England & Wales	Productivity results not consistent with hypothesis that the regulatory system became more effective in generating efficiency gains
Saal and Reid	2004	England & Wales	Regulation led to an improvement in productivity
Saal and Parker	2004	England & Wales	Productivity improvement after regulation in 1995, not privatization in 1989.
Aubert and Reynaud	2005	USA	Efficiency influenced by regulatory structure, most efficient are those with rate of return regulation in which regulator gathers extensive information
Erbetta and Cave	2006	England & Wales	Post-privatisation regulatory environment seemed to reduce allocative inefficiency, and change in regulatory approach from 1995 associated with a general and input-specific high significant effect on technical efficiency
Saal, Parker and Weyman-Jones	2007	England & Wales	Improved productivity after amended regulation imposing stricter financial regime, not privatization

Appendix A – Productivity and efficiency studies: methodology and variables utilised

AUTHOR	DATE	COUNTRY	METHODOLGY	VARIABLES
Antonioli and Fillipini	2001	Italy, 32 water districts, 1991-95	Multivariate variable cost function	VC; cubic meters of water distributed; labour, length of pipes (size of system), number of customers (extent of system), water loss, water wells (capital stock), other costs
Anwandter and Ozuna	2002	Mexico, 110 utilities, 1995	DEA	Water supply, primary treatment, secondary treatment; personnel (numbers), electricity, materials, chemicals, outside services, other costs, specific wastewater treatment costs
Ashton	2000a	England and Wales, 10 water and sewerage companies, 1989-1997	Variable cost function, translog	VC; number of connected households; labour (yearly staff costs), consumables (power, materials, taxes, direct costs and servicing, fixed assets (yearly spending on tangible fixed assets plus depreciation); time
Ashton	2000b	England and Wales, 10 water and sewerage companies, 1987-1997	Cost function	OC; number of connected households (adjusted); labour (level of staff costs divided by FTEs, consumables (power, materials and taxes), other costs (service charges and other direct costs)
Ashton	2003	England and Wales, 10 water and sewerage companies, 1991-1996	Variable cost function, translog	VC; water supplied to households annually; labour (total labour cost divided by FTEs), non-labour variable costs (rents, materials and power costs), capital (operational assets), density (households/length of mains); time
Aubert and Reynaud	2005	Wisconsin, 211 utilities, 1998-2000	Stochastic cost function	VC; volume of water sold, number of customers; labour, electricity, chemicals, operation supplies, maintenance (variable costs), net base of assets (capital); purchase water from other utility; use surface water; average depth of pumping wells (technical characteristics)
Bhattacharyya, Harris, Narayanan and Raffiee	1995a	Nevada, 1992, 26 utilities	Hedonic cost function	VC; volume of water supplied annually; labour (hours), energy, volume of water produced by or available for delivery, stock of capital; population density, ownership, percentage of metered connections, number of connections per mile of distribution pipe length, water input source (technical characteristics)
Bhattacharyya, Harris, Narayanan and Raffiee	1995b	United States, 190 public and 31 private utilities 1992	Stochastic cost frontier	VC; volume of water; energy, labour, materials; water input produced or available for delivery, stock of capital; water input source (surface, ground, both), system loss, age of distribution pipelines, number of emergency breakdowns, length of distribution pipeline, customer type (residential, commercial) (technical characteristics)
Bhattacharyya, Parker and Raffiee	1994	United States, 225 public and 32 private water companies, 1992	Variable cost function, translog	VC; volume of water, price (total revenues/output); labour, energy, materials; fixed capital; number of distribution system breakdowns (technical characteristics)
Bosworth and Stoneman	1998	England & Wales, 10 water and sewerage companies, 1979-89 and1989-95	TFP index	Valued added measure of output. labour, chemicals, other, no capital
Bottasso and Conti	2003	England and Wales, 10 water and sewerage companies, 12 water only companies, 1995-2001	Stochastic variable cost frontier	OC; water delivered; labour, operating expenditure, capital stock, sewerage dummy; length of mains, average pumping head, proportion of river sources on total water sources, population density, volume of water introduced into the distribution system (technical characteristics)
Bruggink	1982	United States, 1960	Cobb-Douglas cost function	VC; water supplied. labour, capital
Byrnes, Grosskopf and Hayes	1986	United States, 68 government and 59 private companies, 1978	DEA	Water distributed.; ground water, surface water, purchased water, miles of pipeline, labour (p/t and f/t), storage capacity

Clark and Stevie	1981	United States, 12 utilities over 10 years	Cost function	C; capital cost of treatment plant, design capacity of treatment plant, annual water use, per capita annual use, population density, geographical service area
Coelli and Walding	2005	Australia, 18 water services businesses, 1995/96 to 2002/03	DEA	Number of properties connected, volume of water delivered; operating expenditure, capital expenditure
Corton	2003	Peru, 34 companies, 1999	Stochastic cost frontier	C; volume of water produced; length of pipeline, operating expenditure
Crain and Zardkoohi	1978	United States, 88 public and 24 private companies, 1978	Translog cost function	Water produced; production costs (operating, maintenance and administration), labour, (f/t and p/t), capital (net book value)
Cubbin and Tzanidakis	1998	England and Wales, 29 companies, 1992/93	Stochastic cost function & DEA	Water delivered; operating expenditure, length of mains, proportion of water delivered to non-households
da Silva e Souza, Coelho de Faria and Belchiar S Moreira	2007	Brazil, 149 public and 15 private companies, 2002	Stochastic frontier techniques	AC; volume of water produced. capital, labour; population density, region
Erbetta and Cave	2006	England and Wales, 10 water and sewerage companies, 1993-2005	DEA	Volume of delivered potable and non-potable water, number of household and non-household water connections, number of household and non-household sewerage connections, physical amount of waste water; labour, other operating expenditure, capital expenditure
Estache and Rossi	2002	Asia Pacific, 50 water companies in 29 countries, 22 of which involve private participation, 1995	Stochastic cost frontier	OC; operational costs, annual salary, number of clients, daily production, number of connections, population density in area served, percentage of water from surface sources, number of hours of water availability per day, percentage of metered connections, qualitative treatment variables (chlorination, desalination)
Europe Economics	1998	England and Wales, 10 water and sewerage companies, 19 water only companies, 1992/93 and 1997/98	Partial productivity	Operating expenditure per output
Fabbri and Fraquelli	2000	Italy, 173 utilities, 1991	Hedonic translog cost function	C; number of consumers, density (population & pipelines), water purchased, water treated. Labour, energy, capital-materials
Feigenbaum and Teeples	1983	United States, 57 private and 262 public companies, 1970s	Hedonic cost functions, translog	C; volume of water delivered, labour, energy, capital, water available for delivery, level of water treatment, percentage of water metered, metered customers per length of pipe, storage capacity, average size of metered account
Ford and Warford	1969	England and Wales, 1965-66, 67 local authorities, 75 water boards and 20 water companies	Cost function	AVC; daily volume of water supply, operating expenditure, density, service area
Fox and Hofler	1985	USA, 156 public and 20 private utilities	Stochastic frontier techniques	Volume of water produced annually, miles of pipelines. manhours, treatment capacity, percent of water distributed to non-residents, region. Also considered surface water collected as percentage of total surface and groundwater, potable water purchased, storage capacity, user charge revenues, tests of water quality, tests for organic contamination
Fraquelli and Giandrone	2003	Italy, 103 urban wastewater treatment plants, 1996	Cobb-Douglas cost function	C; volumes treated, quality. labour, materials, amount of pollution removed, sludge ratio, average number of workers, number of inhabitants served, expenses per ton of sludge mass disposed, filter pressing, centrifuging, cogeneration, agricultural use
Fraquelli and Moiso	2005	Italy, 18 regions, 30 years	Stochastic cost frontier, translog	C; water delivered. labour, electricity, materials, services and capital; network length, losses, time, density (population/network length)
Garcia and Thomas	2001	France, 55 utilities, 1995, 96, 97	Multi-product translog cost function	VC; retail volumes, wholesale volumes; labour, electricity, materials, capital; number of customers, number of municipalities supplied, network length, production capacity,

				stocking, pumping capacity, network losses (volumes distributed less volumes sold)
Garcia, Moreaux and Reynaud	2007	Wisconsin, 171 vertically integrated, and 23 non-vertically integrated companies, 1997-2000	Cost function, and DEA	VC; volume of water supply, volume of water sold, labour, energy, chemicals, operation supplies, maintenance, water purchased; network length, number of users, capacity (pumping and storage); water losses
Garcia-Sanchez	2006	Spain, 24 towns, 1999	DEA	Water supplied, connections, analyses performed; staff, treatment plants, pipe network (length)
Hayes	1987	United States, 475 utilities, 1970, 1976	Multi-product cost function	C; retail water, wholesale water; operating expenditure, capital expenditure
Houtsma	2003	Californian water industry 1995-2003	Statistical analysis of data	Operating expenditure, operating revenue, salaries per connection, non-salary expenses, number of employees, number of connections
Hunt and Lynk	1995	England and Wales, 10 water and sewerage companies, 1979/80-1987-88	Multi-product cost function	Water supplied, sewerage services, environmental service; labour costs; region; annual operating expenditure
Kim and Lee	1998	Korea 1989-1994, 42 local water corporations	Multi product translog cost function	Volume of water supplied; labour, capital, materials; employment density, population density.
Kim	1987	USA, 1973, 60 utilities	Multi product translog cost function	TC, residential water, non-residential water; labour, capital, energy, capacity utilisation rates, service distance
Kim and Clark	1988	USA, 1973, 60 utilities	Multi product translog cost function	TC; residential water supplied, non-residential water supplied; labour, capital, energy, capacity utilisation rates, service distance (distance between treatment plant and service area)
Knapp	1978	England & Wales, 173 wastewater companies, 1972/73	Multi-product cost function	AC; average operating cost; sewerage flow, purification, proportion of biochemical oxygen demand, average strength of influent and effluent; biological filtration dummies; rate of dry weather flow to total sewage flow; ratio of trade effluent to total sewage flow; total sewage flow per head of population; number of years since works commenced operation
Lambert, Dichev and Raffiee	1993	United States, 238 public and 33 private companies, 1989	DEA	Wholesale and retail water delivered; labour, energy used, materials used, capital value
Lynk	1993	England and Wales, 10 water and sewerage companies, 28 water only companies, 1979/80 – 1987/88	Stochastic cost functions	Volume of daily water supply, sewerage service (trade effluent), environmental services, annual operating cost, labour, region
Mann and Mikesell	1976	United States, 1973	Cost function	AVC
Martins, Fortunato and Coelho	2006	Portugal 249 wand sewerage companies, 16 water only companies, 17 sewerage only companies, 2002	Multi-product cost function	C; volume of water supplied; operation and management costs, interest charges, raw water acquisitions expense, other general expenses, network length, density
Mizutani and Urakami	2001	Japan 112 water supply companies, 1994	Translog cost function	TC; volume of water supplied; labour, energy, materials, capital; network length, utilization (volume delivered/volume of intake); purification; residential water delivery/total consumption; water source (dam and underground)
Morgan	1977	United States, 1970	Cost function	VC
Nauges and van den Berg	2007	Brazil 26 companies, Columbia 228 companies, Moldova 39 companies,	Multi-product translog cost function	C; water of water produced; wastewater collected; contracted out services costs, energy, labour, other; network, average duration of supply; volume of water sold/volume

		Vietnam 67 companies		produced, percentage of metered connections, number of towns serviced; number of pipe breaks; population served and proportion of volume of water sold to residential customers
Norman and Stoker	1991	England and Wales, 28 water only companies, 1987/88	DEA	Potable water, properties supplied, average pumping head, length of mains, average peak; manpower costs, power costs, chemical costs, other costs
Raffiee, Narayanan, Harris and Collins	1992	United States, 238 public and 33 private water utilities	Cost function	C; Volume of water produced. cost of operation, maintenance, administration and debt service payments, labour, energy, materials, capital
Renzetti	1999	Canada, Ontario municipal water and sewerage companies	Translog cost	C; residential and non residential water supplied, sewage treatment; labour, energy, capital; average level of household incomes; number of households, number of firms; climate effect on residential demand
Saal and Parker	2000	England and Wales, 10 water and sewerage companies 1985-1999	Translog multiple output cost function	Resident water supply population, population connected to sewerage treatment works; water quality (water quality compliance local/average); sewerage quality (river and bathing water quality local/average); labour, capital, other costs
Saal and Parker	2001	England and Wales, 10 water and sewerage companies, 1985-99	Multi-product translog cost function	Quality adjusted water supplied, wastewater collected; labour, non-capitalised employment, capital stock, other costs
Saal and Parker	2004	England and Wales, 10 water and sewerage companies, 1985-99	Translog cost function of operating costs.	C; quality adjusted output of water and wastewater; labour, non-capitalised employment, capital stock, other costs
Saal and Reid	2004	England and Wales, 10 water and sewerage companies, 1993-2003	Translog cost function of operating costs.	C; volume of water delivered net of leakage; water capital stock; sewerage capital stock; labour, other input costs; drinking water quality; percentage of secondary treatment of sewerage; number of water connected properties; number of sewerage connected properties, density (population per kilometer of mains)
Saal, Parker and Weyman-Jones	2007	England and Wales, 10 water and sewerage companies, 1985-2000	Stochastic frontier techniques	Water customers, connections with sewerage customers, physical water supply, physical sewerage load; quality adjustment indices (water and sewerage); capital stock, current cost operating profits less current cost deprecation, infrastructure renewal expenditures, non-capitalised employment, labour
Sauer	2005	Germany, rural water companies, 2000/01	Cost function	C. Water supplied.; labour, energy, chemicals; share of groundwater intake, equity, number of supplied connections, and length of supply network
Sawkins and Accam	1994	Scotland, nine regional and three island councils, 1984/85 and 1992/93	DEA	Water supplied, population served, length of mains; staff costs, other operating costs
Sawkins	1996	England and Wales, 10, water and sewerage companies, 1989-1994	Financial data	Return on shares, return on market portfolio
Schmit and Boisvert	1997	New York, 359 water companies, 1987-1992	Hedonic cost function	C; population density, water system population, water system hookups, average daily water production, system design capacity, community residential electricity rate; operation and maintenance costs, treatment process
Shaoul	1997	England and Wales, 10 water and sewerage companies, 1985-1995	Cost and financial ratios	Unit costs, value added
Shih, Harrington, Pizer and Gillington	2006	United States, 1246 water suppliers, 1995, 2000	Cost function-log linear	C; ground water, surface water, purchased water; labour, capital, materials, energy, outside services, other
Stone and Webster Consultants for OFWAT	2004	England and Wales, ,10 water and sewerage companies, 38 water only companies, 1992/3-2002/3	Multi-product hedonic translog cost function	C & VC; volumes of water delivered, number of properties connected for water supply, number of properties connected for sewerage, equivalent population served; labour, power, capital, other

Thanassoulis	2000	England and Wales, 10 water and sewerage companies, 1994	DEA	Operating expenditure, number of supply connections, length of main, amount of water delivered, measured water, unmeasured water, expenditure on bursts
Thanassoulis	2002	England and Wales, 10 water and sewerage companies, 1994	DEA	Sewerage operating expenditure; resident population, length of sewer pipes, size of area served, capacity of pumping in sewerage network
Teeples and Glyer	1986	South California, 119 companies, 1980	Cost function	C; own water, purchased water; labour, energy, capital materials
Teeples and Glyer	1987	South California, 119 companies, 1980	Cost function	C; own water, purchased water; labour, energy, capital materials; connections (adjusted); water storage capacity; connections per mile of line, percentage of connections metered, hydrants per connection or gallon delivered, water treatment index, percentage of water purchased
Torres and Morrison Paul	2006	United States, 225 water companies, 1996	Multi-product variable cost function	VC; wholesale water, retail water, purchased water, labour, electricity, storage, production capacity, percentage of distributed water from groundwater sources, number of customers, size of service area, expenditure on chemicals
Tupper and Resende	2004	Brazil, 20 water and sewerage, companies, 1996-2000	DEA	Water produced, sewerage treated, population served (water and sewerage); labour, operational costs, other operational costs
Tynan and Kingdom	2005	33 countries, 270 water and sewerage companies	Standard econometric model	N/A
Wallsten and Koser	2005	United States, 377,629 water companies, 1997-2003		
Woodbury and Dollery	2004	Australia, New South Wales, 1997/98-1999/2000	DEA	Number of assessments (services to properties), annual water consumption, water quality index (compliance with chemical and physical requirement and microbiological requirements, water service index (water quality complaints, service complaints and average customer outage); management costs, maintenance and operation costs, energy and chemical costs, capital replacement costs

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