ECONOMIC DISCUSSION PAPERS

Efficiency Series Paper 01/2008

Assesing Performance in the Management of the Urban Water Cycle

Andrés J. Picazo-Tadeo, Francisco J. Sáez-Fernández y Francisco González-Gómez

Departamento de Economía

Universidad de Oviedo

UNIVERSIDAD DE OVIEDO

DEPARTAMENTO DE ECONOMÍA

PERMANENT SEMINAR ON EFFICIENCY AND PRODUCTIVITY

ASSESING PERFORMANCE IN THE MANAGEMENT OF THE URBAN WATER CYCLE

Andrés J. Picazo-Tadeo[♣], Francisco J. Sáez-Fernández[♠] and Francisco González-Gómez[♦]

Efficiency Series Paper 01/2008

Abstract: This paper proposes the use of directional distance functions and *Data Envelopment Analysis* techniques to assess technical efficiency in the provision of the stages of the urban water cycle in Andalusia, a Southern Spanish region. Evaluating performance in the management of specific stages of the urban water cycle provides utility managers and regulating authorities with relevant information that could remain out of sight with more conventional approaches based on assessing performance at firm level. Among other results, we show that Andalusian water and sewage utilities could achieve important increases in the volume of water delivered without diminishing their production in the remaining services, and with the same quantities of inputs. Potential increases are also important for the volume of sewage collected, thus entailing significant environmental benefits in a territory where water scarcity has seen the efficient management of this natural resource become a pressing obligation.

Key words: *urban water cycle; water and sewage utilities; technical efficiency; Data Envelopment Analysis; directional distance functions.*

[♣] Corresponding author. Departamento Economía Aplicada II, Universidad de Valencia, Spain.
e-mail: andres.j.picazo@uv.es

[♠] Departamento de Economía Internacional y de España, Universidad de Granada, Spain y Fundación Escuela de Negocios de Andalucía.

[♦] Departamento de Economía Aplicada, Universidad de Granada, Spain.

1. Introduction

The assessment of performance is a deep-rooted issue of study in the field of economics. In activities with a large number of competitors and no entry barriers, competition generally stimulates firms to perform efficiently, but when competitive pressure is insufficient, important managerial inefficiencies might occur. The water and sewage industry is characterised by low competition potential and, in most cases, by the existence of institutional regulations that restrict managerial decisions, circumstances that do not encourage water companies to behave efficiently. Thus, measuring efficiency in water and sewage utilities is a practice with a great potential to provide managers and decision makers with valuable information as a sound basis for making strategic choices. This information might help to improve the management of utilities and, moreover, to improve the design of public policies aimed at regulating the water and sewage industry. Furthermore, assessing the performance of utilities located in places where water is a scarce natural resource might be of additional interest from a social viewpoint.

In the water and sewage industry, the measurement of performance has been approached from quite different perspectives, ranging from very simple indicators such as number of workers or operational costs per unit of service provided, to more sophisticated approaches that include computing technological frontiers. Alegre *et al.* (2006) propose a wide array of performance indicators for water supply services, such as water resource indicators, personnel indicators, physical indicators, operational indicators, quality of service indicators and economic and financial indicators. Furthermore, Matos *et al.* (2003) provide several performance indicators for wastewater services.

Over the last two decades, a number of papers have focused on measuring managerial performance in water and sewage utilities using benchmarking techniques, by means of either econometric approaches or nonparametric methods based on *Data Envelopment Analysis* (*DEA*), in the framework of neoclassical production theory and efficiency analysis (González-Gómez and García-Rubio, 2008 reviews the literature). Initial papers computed simple measures of efficiency in line with the seminal proposal by Farrell (1957), while subsequent research has been stimulated by a wider range of motivations. These include assessing the relative performance of public and privately-owned utilities (Lambert *et al.*, 1993; Faria *et al.*, 2005; Kirkpatrick *et al.* 2006; Souza *et al.* 2007; Sabbioni, 2008), the extent of scale and scope economies in the water and sewage industry (Ashton, 2003; Sauer, 2005; Torres and Morrison-Paul, 2006; Garcia *et al.*, 2007), the impact of public regulations on utility performance (Garcia and Thomas, 2003; Aubert and Reynaud, 2005; Mugisha, 2007), the influence of operating environments on efficiency measurement (Picazo-Tadeo *et al.* 2009) and, more recently, the effect of including quality in measuring efficiency in water utilities (Lin, 2005; Saal *et al.*, 2007; Picazo-Tadeo *et al.*, 2008).

In this broad body of literature, empirical applications addressing the measurement of technical efficiency have mostly treated water companies as single-output firms producing the service of water delivering. However, as is detailed later on, water and sewage utilities are multi-output firms that can produce one or several of the services integrating the urban water cycle, mainly water treatment and distribution, sewage collection and sewage treatment. Furthermore, when utilities have been considered as multi-output firms, including outputs such as sewage collected or water treated, in addition to the volume of water delivered, global indicators of technical efficiency at firm level have been for the most part computed (Estache and Trujillo, 2003; Tupper and Resende, 2004). Nonetheless, common sense suggests that utilities producing two or more water and sewage services might well not be equally efficient in the management of the different services they provide.

In this context, our paper assesses technical efficiency in the management of the urban water cycle on behalf of the water and sewage industry in Andalusia, a European region located in the south of Spain. Specific indicators of technical performance are computed for each stage or service integrating the urban water cycle. Concerning the methodology, nonparametric *DEA* techniques and directional distance functions are used in the framework of neoclassical production theory.

The potential of *DEA* as a powerful analytical tool to help policy makers to regulate water companies has been highlighted by Thanassoulis (2000a, 2000b). Furthermore, the approach used in this paper allows interesting insights to be added to the usefulness of *DEA* in analysing performance in the water and sewage industry. On the one hand, instead of assessing performance at firm level as conventional *DEA*-based analyses have done, here performance indicators are computed for the different services of the urban water cycle, which is our major contribution to the empirical literature in this field of research. Moreover, scores of performance adjusted for the effect of some features of the environment where utilities operate are also computed. Measuring efficiency at stage level might provide managers and regulating authorities with relevant information since, as noted, utilities do not necessarily have to be equally efficient in the management of all the services they provide. On the other hand, as detailed in the section devoted to methodology, our approach makes it possible to distinguish between the productive resources that are used to produce all the services of water and sewage companies from those which are only used to provide some of these services.

The rest of the paper is organised as follows. Section 2 explains the main insights of the methodology. Section 3 describes some features of the Andalusian water and sewage industry. Section 4 models the multi-output structure of the urban water cycle, while Section 5 is devoted to discussing the results. Finally, Section 6 summarises and concludes.

2. Methodological issues

Microeconomic theory considers production processes as the result of optimisation behaviour. Managerial decisions concerning what to produce and which combination of inputs to use are intended to achieve specific objectives. From a technical view, producers seek to maximise output for a given endowment of resources. When input prices are involved, producers are assumed to allocate resources efficiently from an economic standpoint by using the combination of inputs that minimises the cost of producing a given level of output. However, the firm’s overall objective is to achieve the production plan that maximises profits, at given output and input prices. Even so, not all producers are successful in achieving these objectives, and production, cost and profit frontiers representing best practices need to be computed. These benchmarks allow us to calculate how much individual firms deviate from technical, economic and profit efficiencies.

The underlying theoretical framework in this paper is based on a production function, in which it is assumed that a set of decision-making units make use of a vector of inputs $\boldsymbol{x} \in \Re_{+}^{\mathrm{N}}$ to produce a vector of outputs $\boldsymbol{y} \in \Re_{+}^{\mathrm{M}}$. The *technology* that allows the transformation of inputs into outputs is represented by an output correspondence which is a mapping $\mathrm{P}: \Re_{+}^{\mathrm{N}} \rightarrow \mathrm{P}(\boldsymbol{x}) \subseteq \Re_{+}^{\mathrm{M}}$, where the *output set* $\mathrm{P}(\boldsymbol{x})$ represents the set of all feasible vectors of outputs given a vector of inputs $\boldsymbol{x}$.

It is also assumed that the technology satisfies the usual properties initially suggested by Shephard (1970), including the possibility of inaction, no free lunch, free disposability of inputs and strong disposability of outputs. In addition, the output set is considered to be a convex set, i.e. any convex combination of two technologically feasible productive plans is also technologically feasible.

Based on this characterisation of the technology, the directional output distance function allows us to compute the maximum attainable expansion of each element of the vector of outputs along a direction previously specified by the researcher, for given consumption of resources and technology (Färe and Grosskopf, 2000 summarise the theory and main applications of directional distance functions; see also Färe and Grosskopf, 2004). Formally, the directional output distance function is defined as:

$$\vec{\mathrm{D}}_{\mathrm{O}}\left[\boldsymbol{x}, \boldsymbol{y}; \boldsymbol{g}_{y}=\left(g_{y_1}, \ldots, g_{y_M}\right)\right]=Sup\left\langle\varphi:\left[\boldsymbol{y}+\varphi\left(g_{y_1}, \ldots, g_{y_M}\right)\right] \in P(\boldsymbol{x})\right\rangle, \qquad (1)$$

$\boldsymbol{g}_y$ being the vector that determines the direction in which each output is expanded, e.g. g_{y1} indicates in which direction output y_1 expands. Moreover, the expression *Sup* denotes the maximum φ such that the resulting productive plan belongs to the production possibilities set.

In what follows, in order to accommodate the general definition of the distance function to the aim of evaluating the technical performance of specific stages of the urban water cycle, we will make use of a direction that allows for a particular output to be expanded while maintaining the production of the remaining outputs constant, always for given consumption of inputs and technology. With this direction vector, the directional output distance function becomes:

$$\vec{\mathrm{D}}_{\mathrm{O}}\left[\boldsymbol{x},\left(y_i, \boldsymbol{y}_{-i}\right); \boldsymbol{g}_{y}=(1, \boldsymbol{0})\right]=Sup\left\langle\varphi:\left[\left(y_i, \boldsymbol{y}_{-i}\right)+\varphi(1, \boldsymbol{0})\right] \in P(\boldsymbol{x})\right\rangle, \qquad (2)$$

where i denotes the output to be expanded, while $-i$ stands for the remaining outputs.

This expression measures the maximum potential expansion of output *i*, e.g. the service produced in a particular stage of the water urban cycle, without additional consumption of productive resources, while controlling for the production of the other outputs, i.e. without diminishing the service produced in the remaining stages.

In this paper we also make a basic distinction between allocatable production factors or inputs that are only used to produce a particular output but not the others and unallocatable production factors, which are used in the production of all outputs (Nin *et al.*, 2003). This distinction is motivated by the fact that in our dataset we have information on inputs which are used only in particular stages of the urban water cycle, but also for production factors which are used as inputs in all the stages of the urban water cycle and it is not possible to differentiate the quantities used in each stage.

As regards the empirical computation of the directional distance function involved in expression (2), as noted in the introduction, nonparametric *DEA* techniques are used. *DEA* was pioneered by Charnes *et al.* (1978) in a paper that used mathematical programming to pursue Farrell's approach to efficiency measurement. Since then, hundreds of papers have employed this technique to address the issue of efficiency measurement in different economic activities (a couple of recent reviews of the empirical literature are Gattoufi *et al.*, 2004 and Emrouznejad *et al.*, 2008).

Essentially, *DEA* evaluates the performance of peer units allowing a *surface* representing the technological frontier to be built over a set of data, which allows the behaviour of a decision-making unit to be compared with best observed practices in terms of an indicator of performance. This technique is a flexible approach to efficiency measurement that has some important advantages over the econometric approach. On the one hand, it allows the technological frontier to be constructed without imposing a parametric functional form on technology or on deviations from it (inefficiencies). On the other hand, the flexibility of *DEA* allows a wide range of indicators of performance, each focusing on different aspects of production processes, to be readily computed. Conversely, the deterministic nature of conventional *DEA*, when compared with stochastic approaches to efficiency measurement, is the main drawback of this technique. Further details on *DEA* can be found in Cooper *et al.* (2004).

Using *DEA* on a sample of $k = 1,\ldots,K$ decision-making units, the directional output distance function of expression (2) for decision-making unit k' and output i comes from the solution to the following programming problem:

$$
\begin{array}{lll}
\vec{D}_O\left[\boldsymbol{x}^{k'},\left(y_i^{k'},\boldsymbol{y}_{-i}^{k'}\right);\boldsymbol{g}_y=\left(1,\boldsymbol{0}\right)\right]=Max_{z^k,\varphi_i^{k'}}\ \varphi_i^{k'} & & \\
\text{subject to:} & & \\
x_n^{k'} \geq \sum_{k=1}^{K} z^k x_n^k & n \notin A & (i) \\
x_{ni}^{k'} \geq \sum_{k=1}^{K} z^k x_{ni}^k & n \in A & (ii) \\
y_i^{k'} + \varphi_i^{k'} \leq \sum_{k=1}^{K} z^k y_i^k & i \in m \text{ and i} \notin \text{–i} & (iii) \\
y_{-i}^{k'} \leq \sum_{k=1}^{K} z^k y_{-i}^k & -i \in m & (iv) \\
z^k \geq 0 & k=1,\ldots,K & (v) \\
\sum_{k=1}^{K} z^k = 1 & & (vi)
\end{array}
\qquad (3)
$$

z^k being a set of intensity variables determining the efficient combination of decision-making units firm k' is compared to. Moreover, x_n^k and y_m^k stand for observations on input n and output m of firm k, respectively. Lastly, A stands for the set of allocatable production factors and x_{ni} denotes the level of allocatable input n used in the production of output i.

In expression (3), the set of constraints in *(i)* and *(ii)* guarantee that at its projection on the technological frontier, decision-making unit k' will make use of no less inputs, both allocatable and unallocatable, than the efficient productive plan it is compared with. Also, restrictions in *(iii)* and *(iv)* ensure that under the efficient production plan, firm k' produces no more outputs than the technological reference at the frontier. Finally, variable returns to scale have been imposed through restriction *(vi)* (Banker *et al.*, 1984).

By considering variable returns to scale, each firm in the sample can be compared with firms of a similar size. In this way, the computed scores of performance measure what in this literature is known as *pure technical inefficiency,* derived from wrong managerial decisions for a given scale of production, thus excluding inefficiencies derived from a inadequate scale. In our view, this constitutes an appropriate assumption in the case of the water and sewerage industry where the size of utilities is restricted by demand conditions.

Based on computations from program (3), the technical efficiency for decision-making unit k' and output *i*, i.e. the service produced in a particular stage of the urban water cycle, can be assessed by merely comparing the observed level of that output with the level that would result if the firm were behaving efficiently. Formalising:

$$\text{Stage-specific technical efficiency}_{\mathrm{i}}^{\mathrm{k'}} = \frac{y_i^{k'}}{\left(y_i^{k'} + \varphi_i^{k'}\right)} \tag{4}$$

By construction, this indicator can take values greater than zero and smaller than or equal to one. A value equal to one means technical efficiency, while the greater the distance from one, the lower the level of technical efficiency.

When several decision-making units within a sample are compared to each other to assess their relative performance, it is implicitly assumed that they operate under a similar production setting. However, in addition to the skills in managing production activities, firms' performance may be influenced by a set of features which are beyond the control of their managers. In the provision of water and sewage services, the nature of technical interactions between inputs and outputs may be particularly influenced by the environments in which utilities operate (Fabbri and Fraquelli, 2000; Burns *et al.*, 2005). In order to account for this circumstance, in this paper we have also computed a measure of stage-specific technical efficiency controlling for some of the characteristics of the environment where water utilities in our sample operate.

In doing so, the four-stage procedure proposed by Fried *et al.* (1999) is employed. Using this approach to incorporate exogenous factors into a *DEA*-based model of performance evaluation, the first stage would be to calculate the directional distance function frontier technology according to standard production theory, thus ignoring external factors. The second stage consists of regressing potential increases or slacks in outputs as dependent variables on a set of exogenous variables representing the features of the operating environment likely to affect performance. This would make it possible to separate managerial inefficiency from inefficiency due to the features of the operating setting which cannot be controlled by management. Formally, this regression is:

$$\text{Output slack}_m^k = f\left(E_m^k, \beta_m, \mu_m^k\right) \tag{5}$$

where $E^k{}_m$ is a vector of exogenous variables representing the features of the operating environment for firm *k* affecting the production of output *m*, β_m is a vector of coefficients and, finally, $\mu^k{}_m$ is a disturbance term.

The estimated parameters in stage two are used in a third stage to predict output slacks for each decision-making unit in the sample based on their observed exogenous variables. These predictions are then utilised to adjust the observed outputs with the purpose of netting them out from the effect of the operating environment. Formally, the predicted slacks for firm *k* and output *m* are computed as:

$$\text{Predicted output slack}_m^k = f\left(E_m^k, \hat{\beta}_m\right), \tag{6}$$

where $\hat{\beta}_m$ are the estimated coefficients from expression (5).

Furthermore, the adjusted outputs are calculated as:

$$\mathrm{y}_m^{k\ adjusted} = \mathrm{y}_m^k - Min^{k' \in (1,\ldots,K)}\left(\text{Predicted output slack}_m^{k'}\right) + \text{Predicted output slack}_m^k \tag{7}$$

In expression (7), the minimum predicted slack is used to reset all outputs to the level of outputs of the most favourable operating environment, thus preventing adjusted outputs from becoming negative. The fourth and final stage consists of using the adjusted data to re-run the *DEA* model under the initial input-output specification and generate new measures of inefficiency netted out from the effect of external operating environments.

3. The Andalusian water and sewage industry

Andalusia is a Spanish region located in southern Europe which occupies around 15 per cent of the surface area of the Iberian Peninsula and which is currently facing increasing desertification and an alarming shortage of water. The demand for water has risen substantially over the last decade as a result of extraordinary urban development and population growth. The growing influx of tourists and also many European citizens who establish their second home on the Spanish Mediterranean coast has promoted new urban and recreational uses for water in Andalusia, such as watering gardens and golf courses, which compete with traditional uses. Likewise, the increase in the average temperature and the decrease in rainfall appear to confirm the predictions of theories regarding climate change and the desert is advancing gradually from the southeast, thus reducing the supply of water. The strong demand for water and the restrictions affecting supply make studying water management efficiency a particularly important issue in Andalusia for utility managers, policy makers and the general public as a whole.

As regards the institutional side of the water and sewage industry in Andalusia, Spanish legislation stipulates that town halls are responsible for providing urban water cycle services, although the law has permitted them to transfer water utility management to private companies since 1985. In the second half of the 1980s, many town halls in Andalusia decided to privatise the various stages of the urban water cycle, particularly those highly in debt or with more complex water demand, many of which were located in tourist destinations on the coast. A great deal of privatisation also took place in the 1990s and is still occurring today. Private companies or public-private partnerships, with both public and private capital, current provide water services to nearly three million people, practically 40 per cent of the population of Andalusia.

The second business strategy that has considerable altered the structure of the water and sewage industry in Andalusia since the mid 1980s was the creation of business consortia and associations. The latter were the result of agreements between small towns, generally located in the least populated areas in the region, that decided to create one sole company to provide integral cycle services to all. The creation of consortia has also been a common business practice among the towns in the largest urban areas in the region. This managerial strategy was strongly supported by local and regional governments on the grounds that it would lead to significant gains in efficiency and productivity. However, the scarce empirical evidence on this issue does not support the existence of a relationship between efficiency and consortia of utilities in the Andalusian water and sewage industry (Picazo-Tadeo *et al.*, 2008).

4. Modelling the water urban cycle: sample and data description

One basic step when assessing efficiency with *DEA* techniques is the modelling of the production structure and the selection of the variables to represent output and production factors, which is not always an easy decision. As noted in the introduction, water and sewage utilities are multi-output firms that can provide one or several of the services or stages that integrate the urban water cycle (*Figure 1*). The first of such services is the chemical treatment of water previously collected in reservoirs or extracted from the subsoil, in order to make it suitable for urban consumption. The second stage involves distributing the water that has been previously treated to various urban users: households, industry, services or for public use. In this stage, part of the water that is piped into the delivery network is lost along the way and, therefore, fails to reach final consumers. Although this unaccounted-for water may, at least partly, return to reservoirs or the subsoil and be recollected, retreated and redistributed, it is costly since it has already incurred in costs such as pumping or treatment expenses.

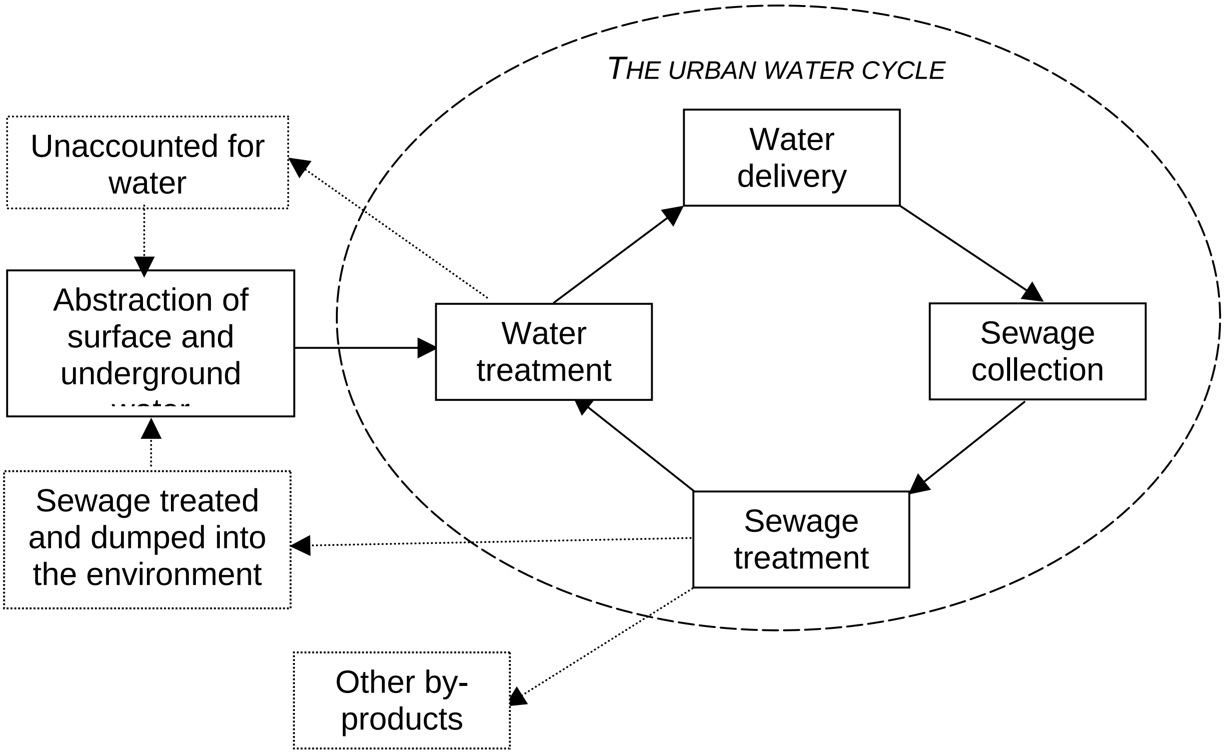

Figure 1. **The urban water cycle**

In the third stage of the urban water cycle, sewage is collected by the sewerage network, which also collects the rainfall on towns and cities. Finally, the fourth stage of the urban water cycle consists of treating the sewage that has been collected in order to either return it to the environment, minimising pollution, or to be reutilised for different purposes, such as watering gardens or golf courses and city cleaning, depending on how thorough the purification process is. In addition, other sub products are generated during this fourth stage, including sludge that can be used as a fertiliser in agriculture.

Although each stage of the urban water cycle is clearly different from the rest, they are evidently interrelated: each stage starts with the result of the immediately preceding stage. For instance, water distribution as a function of water and sewage companies starts with the water input coming from the stage of water treatment; likewise, sewage treatment begins with the sewage collected during the stage of sewage collection. This interrelationship is the main reason that explains the vertical integration of water and sewage services. Nevertheless, current empirical evidence regarding the efficiency improvements derived from the joint provision of different water and sewage services is not conclusive (some papers that deal with this issue include Saal and Parker, 2000, Sauer and Frohberg, 2007 and Garcia *et al.*, 2007).

The modelling of the production structure in the Andalusian water and sewage industry carried out in this paper is based on the available information in a dataset collected from a comprehensive survey carried out by the authors with support and funding from the *Agencia Andaluza del Agua* of the regional government of Andalusia, referring to the year 2001. Surveys were initially conducted on 65 water and sewage utilities covering all the utilities in the region. However, a lack of responses or deficient information on some relevant variables reduced our sample to 35 utilities, which provide services to more than one hundred towns and cities and nearly four million citizens, covering nearly fifty per cent of the inhabitants of the region. In addition, we would like to highlight that although the number of utilities in our sample may seem excessively small, it includes nearly 55 % of the population, that is, 35 out of the 65 water and sewage utilities operating in the region, thus allowing for reliable inferences.
The stages of the urban water cycle in our empirical application are modelled as shown in *Table 1*. In the first place, let us indicate that the stages of treatment and delivery of water are modelled jointly. The variable representing output in this stage is the amount of water delivered (measured in cubic meters), which has been previously chemically treated to make it suitable for human consumption. Specific production factors that can be unmistakeably allocated to this stage of the urban water cycle are the variable input raw water (also measured in cubic meters) and the fixed production factor delivery network (in kilometres). Moreover, unallocatable inputs or, in other words, inputs used in all stages of the urban water cycle that our source of data does not allow to assign to

the production of a particular stage, are labour (measured as the number of workers) and operational costs (in thousands of euros), which are both considered as variable production factors.

Table 1. Characterisation of the productive process in the urban water cycle

Stage	Output	Inputs	
		Stage-specific inputs	Unallocatable inputs
Water treatment and delivery	Water delivered	Raw water Delivery network	Labour Operational costs
Sewage collection	Sewage collected	Water delivered Sewerage network	Labour Operational costs
Sewage treatment	Sewage treated	Sewage collected	Labour Operational costs

The reason for considering the stages of treatment and delivery of water jointly in our empirical modelling is that the vast majority of utilities in Andalusia perform these services in an integrated way, so that the amount of raw water coincides exactly with the amount of water treated for all utilities in our sample. Given the nature of the performance indicators used in this paper, this feature would prevent us from identifying inefficiencies if the stage of water treatment were modelled separately, considering the volume of water treated as the output of this stage and raw water as an intermediate input.

In the second place, the stage of sewage collection is modelled considering the volume of sewage collected (also measured in cubic metres) as the variable representing the service produced. Furthermore, stage-specific inputs are the volume of water delivered, as an intermediate input, and the sewerage network (kilometres) as a fixed input, while unallocatable production factors are labour and operational costs. As previously noted, each stage of the urban water cycle starts with the result of the immediately precedent stage, so that the amount of water delivered is considered as an intermediate input specific to the stage of sewage collection. Let us, however, go more deeply into the practical implications of this characterisation of the input-output relationship.

On the one hand, as explained in Section 2, applying program (3) to the stage of water collection provides a measure of the maximum expansion in the volume of sewage collected without additional consumption of inputs, i.e. without increasing, among other

production factors, the volume of water delivered. On the other hand, as our assessment of stage-specific technical efficiency also controls for the volume of service produced in the other stages of the urban water cycle, the potential expansion of the sewage collected is also constrained by the fact that the service in the stage of water treatment and delivery, that is, the volume of water delivered, cannot be decreased.
The practical implication of this way of modelling the relationship between inputs and outputs in water and sewage utilities is really straightforward: the performance of a utility in the stage of sewage collection is evaluated by comparing its productive plan with an efficiency productive plan with exactly the same volume of water delivered. In general, the stage-specific performance of a water utility will always be evaluated by comparing its productive plan with one that produces exactly the same volume of service in the stage immediately precedent.

Finally, the stage of sewage treatment is modelled considering the volume of sewage treated (measured cubic metres) as the variable representing the output, while the only stage-specific intermediate input is the volume of sewage collected. In accordance with the specification of the input-output relationship in the other stages, unallocatable production factors here are also labour and operational costs. Let us remark again that the performance of utilities in our sample in their management of this stage is evaluated by comparing their productive plans with a plan that collects the same volume of sewage.

In our sample, 17 out of the 35 utilities provide all services of the urban water cycle, while the remaining companies either produce only the stage of water treatment and delivery (12 utilities), or water treatment and delivery together with sewage collection (6 utilities). *Table 2* displays some descriptive statistics for the data.

Table 2. Descriptive statistics of the data

Variable	Measurement unit	Mean	Standard deviation	Maximum	Minimum
Water delivered	Thousands of m^3	9,469	17,481	84,800	212
Sewage collected	Thousands of m^3	9,131	21,605	108,666	0
Sewage treated	Thousands of m^3	8,569	21,746	108,666	0
Raw water	Thousands of m^3	12,290	22,212	107,733	315
Delivery network	Kilometres	347	583	2,877	5
Sewerage network	Kilometres	203	390	1,855	0
Labour	Number of workers	73	139	732	2

Operational costs	Thousands euros	3,829	6,279	31,640	84

5. Results and discussion

This section presents and discusses the results obtained in the assessment of technical efficiency of the water and sewage utilities in our sample in performing the stages of the urban water cycle. Averages, as well as other descriptive statistics are in *Table 3*. Stage-specific technical efficiency scores have been calculated according to expression (4), after having computed efficient production in each stage of the urban water cycle from the solution to program (3).

Table 3. Estimates of stage-specific technical efficiency.

Stage	Mean	Standard deviation	Maximum	Minimum
Water treatment and delivery	0.964	0.062	1	0.785
Sewage collection	0.885	0.162	1	0.522
Sewage treatment	0.991	0.037	1	0.847

Before commenting on these results, let us highlight a couple of issues. On the one hand, in the water and sewage industry, as well as in other regulated industries in developed countries, input-oriented *DEA* models are the standard approach to efficiency measurement. The reason is that firms are supposed to face a given demand, so the main managerial decisions to achieve efficiency rely on the use of inputs. While this might also be an appropriate approach given the institutional context of the Andalusian water and sewage industry, we have chosen an output orientation because it greatly facilitates the modelling of the multi-output production structure of water and sewage firms, as well as the interpretation of the computed scores of performance. The major reason is that, while variables representing output can be clearly isolated for each stage of the urban water cycle, some inputs are common to all the stages making it difficult to use an input-based approach.

Moreover, it can also be argued that demand restrictions affect basically the service produced in the stage of water treatment and delivery, i.e. the demand of water for urban uses is mainly determined by the number of inhabitants served, but this is not so much the case with services of collecting and treating sewage, particularly in light of the fact that only part of the sewage is collected and treated in Andalusia. Furthermore, the ever-increasing demand for water in Andalusia also reinforces the usefulness of our output-oriented approach.

On the other hand, it is well-known that *DEA* is a deterministic approach to efficiency measurement and that results tend to be sensitive to measurement errors and the presence of outliers, particularly if these observations are benchmarking other firms in the sample. In order to avoid this potential problem in our estimates of technical efficiency, the sample was initially submitted to a process of detection and deletion of outliers, using *scatter-plots* and some measures of *leverage*. In addition, we have tested that our estimates of efficiency do not depend on a reduced number of utilities repeatedly benchmarking other companies in the sample, but rather on a set of firms enveloping, i.e. acting as efficient referents on the frontier, two or more times the behaviour of other utilities.

As regards the assessment of performance, the average scores of stage-specific efficiency for the services of water treatment and delivery, sewage collection and sewage treatment are 0.964, 0.885 and 0.991, respectively, showing that greater inefficiencies occur in the stage of sewage collection. However, let us emphasise here again that these figures do not indicate that potential output could be simultaneously obtained in all stages of the urban water cycle. Rather, they measure the potential increase that could be achieved in the service produced in a particular stage if all utilities were making an efficient use of both unallocatable production factors and inputs allocated to the production of that output, while maintaining the volume of production in the remaining stages.

One interesting result from these scores is that by making an efficient use of available resources, the volume of water delivered could be increased by almost 6 %, while still maintaining the service produced in the remaining stages of the urban water cycle. This outcome shows how, despite how regulated the water and sewage industry is in developed countries, there is still a great deal of room for managerial inefficiencies. Moreover, it has key implications for water management in Andalusia. At present around a quarter of the water channelled into the pipe network is lost along the way, mainly due to leaks, but also to illegal connections. Some of this unaccounted-for water may return to aquifers or reservoirs and, therefore, be reincorporated into the urban water cycle, but the rest may be dumped directly into the sea, which is a waste of water in a region where this natural resource is extremely scarce. Conversely, if all the utilities in our sample managed the water treatment and distribution stage efficiently, by reducing unaccounted-for water, the volume of water delivered could be increased with the same consumption of raw water or, from a different perspective, a given demand of water could be satisfied with lesser use of raw water.

The social cost of the lack of maintenance of the distribution network on behalf of Spanish water utilities is an issue that has been repeatedly condemned. However, this behaviour has proven to be a profitable strategy from a business perspective, despite this not being the case from a social viewpoint (González-Gómez, 2005). The reason is that due to the low price of water in Spain, it is more profitable for water utilities to incur in higher costs stemming from extracting, pumping and treating unaccounted-for water than to invest in maintaining and repairing the distribution network. This is also one of the primary results found by Garcia and Thomas (2001) for French water utilities.

A second result worth highlighting is that Andalusian utilities could significantly increase the amount of sewage collected while still maintaining the service produced in the remaining stages of the urban water cycle, without incurring in additional use of productive resources. More specifically, the potential increase in the output of this stage is 11.5%. In contrast, most of the utilities in our sample are efficient in their management of the stage of sewage treatment, with the potential increase in output hardly reaching an average of 1%. The main reason for this result is that, at present, Andalusian water and sewage utilities are treating almost one hundred per cent of the sewage they collect. Moreover, although unfortunately our dataset does not provide quantitative information about this variable, the capacity of the existing sewage treatment plants is fully utilised. Considered jointly, the results obtained for the assessment of performance in the stages of sewage collection and sewage treatment might be of great interest to the managers of utilities and, more importantly, to the authorities responsible for regulating the Andalusian water and sewage industry. Regulating authorities would now be aware of the important environmental benefits that could be achieved if utilities made a more efficient use of their production factors in the stage of collecting sewage and, additionally, the capacity of sewage treatment plants was increased.

An increase in the amount of sewage collected and treated would not only avoid polluting the environment, but also save water in a region where this natural resource is certainly scarce, as recycled water might be reutilised for industrial purposes or, at least, to water gardens and golf courses. Thus, policy measures conducive to improving the efficiency of Andalusian water and sewage utilities in managing the stage of water treatment and delivery of the urban water cycle, but also the stage of sewage collection jointly with incentives to increase their capacity to treat sewage emerge as adequate strategies towards tackling the problem of water scarcity in the region.

A further matter to be dealt with when interpreting our measures of stage-specific technical efficiency refers to how certain features related to utility operating environments may influence efficiency assessment. For instance, one feature that could influence the assessment of technical efficiency in the stage of water treatment and delivery is the different length of the delivery network of the Andalusian water and sewage utilities in the sample. The reason is that water losses could reasonably be expected to increase as the length of the network increases, so utilities with a longer network will incur, on equal terms, in greater amounts of unaccounted-for water and will therefore record lower technical efficiency scores in the management of this stage. Nonetheless, this circumstance is indirectly accommodated in our *DEA*-based model by including delivery network length as an input in the stage of treatment and delivery of water, so that utilities in the sample will tend to be benchmarked with other utilities that use networks of a similar length. Indeed, 28 out of our 35 utilities are benchmarked with utilities that are making use of delivery networks that are exactly the same length. The deviation between observed delivery network length and the length of the efficient productive plans, i.e. the slacks in this production factor, hardly reach 4% for the sample as a whole.

In addition, some other variables of the exogenous production setting not accounted for in the model, which are beyond the control of firm managers, are also likely to influence the technical performance of Andalusian water utilities. Thus, computing a set of stage-specific estimates of technical efficiency controlling for these variables may be of certain interest in order to contribute more significant and useful empirical results for management and policymakers. In doing so, we follow the steps of the methodological approach developed by Fried *et al.* (1999) outlined in the section devoted to the methodology.

The features of the operating environment which are supposed to affect the technical performance of water utilities are the density of population (measured as the number inhabitants per kilometre squared), ownership, which is a dummy variable taking a value of 0 for publicly-owned water utilities and 1 for private firms (some utilities with property mixed between public and private stakeholders have been considered as private firms because responsibility for basic management decisions is upon private managers) and, finally, tourism, also a dummy taking a value of 0 for utilities providing water and sewage services to non-tourist municipalities and 1 for utilities serving highly-tourist areas. Furthermore, due to a problem of insufficient variation in the dependent variable in the stages of sewage collection and sewage treatment, we have estimated a joint regression for the slacks in all three outputs in our model, instead of a single regression for each service. Results from the estimation of expression (5) are in *Table 4*, which are based upon a Tobit regression in order to account for the censured nature of the dependent variable.

Table 4. Determinants of outputs slacks

Variable	Estimated parameter	Standard error
Constant	-245.1	524.0
Density of population	0.645	0.448
Ownership	-1696.6^{***}	667.0
Tourism	-1119.4^{*}	759.2
Sigma	2174.1^{***}	340.3
Log-likelihood function	-109.4	
LR test $\chi^2(3)$	8.13^{**}	

****, ** and * means significant at 2.5%, 5% and 15%, respectively*

Concerning the signs of the estimated parameters, on the one hand, we can assess at a confidence level of 2.5% that private ownership improves the technical performance of the utilities in our sample. While the relationship between property and efficiency is a long-standing matter of discussion, our results here are consistent with those in Picazo-Tadeo *et al.* (2007) that also finds a positive relationship between private property and efficiency in the management of certain inputs, mainly labour, on behalf of Andalusian water and sewage utilities. On the other hand, the variable tourism serves here as a proxy for demand seasonality, which has been mentioned as a feature capable of affecting efficiency in water utilities (Woodbury and Dollery, 2004). As regards the estimated coefficient, the location on a tourist municipality also enhances utilities' performance. Although this relationship is only significant at 15%, it is consistent with results from Picazo-Tadeo *et al.* (2007).

Estimated parameters from expression (5) have been used to compute predicted output slacks and to adjust the observed outputs, according to expressions (6) and (7), respectively. After that, adjusted data have been used to re-estimate our *DEA*-model according to its original input-output specification, generating the adjusted estimates of stage-specific technical performance displayed by *Table 5*. These estimates point to similar results to those derived from unadjusted measures of performance, showing that, although operating environments influence the performance of Andalusian water and sewage utilities, the managerial capabilities of their managers continue to play an essential role in determining their technical performance.

Table 5. Environment adjusted estimates of sage-specific technical efficiency.

Stage	Mean	Standard deviation	Maximum	Minimum
Water treatment and delivery	0.930	0.137	1.000	0.515
Sewage collection	0.941	0.106	1.000	0.617
Sewage treatment	1.000	0.000	1.000	1.000

The last matter to deal with in this paper is related to the nature of our measures of stage-specific technical performance. As these indicators are formulated, they measure efficiency in a Farrell-Debreu sense (Farrell, 1957), so that slacks in some input dimension representing further inefficiencies might appear. While it is not our intention here to measure efficiency in a Pareto-Koopmans sense (Koopmans, 1951), *Table 6* displays the scope for variable inputs labour and operational cost savings in both unadjusted and adjusted models. In the case of labour and the unadjusted model, the average potential reduction for the whole sample ranges from 1.7 to 9.1 workers in the stages of water treatment and delivery and sewage treatment, respectively, i.e. it goes from around 2 % to 10 % of observed use of these production factors. For operational costs, slacks are particularly significant in the stage of sewage treatment, with averages of 23% and 21% for unadjusted and adjusted estimates of technical performance respectively.

Table 6. Average slacks in variable inputs labour and operational costs.

	Unadjusted estimates		Adjusted estimates	
Stage	Labour (workers)	Operational costs (thousands €)	Labour (workers)	Operational costs (thousands €)
Water treatment and delivery	1.7	224.6	1.7	83.2
Sewage collections	5.8	330.2	7.2	334.4
Sewage treatment	9.1	913.3	7.3	819.5

6. Summary and concluding remarks

Measuring performance in water and sewage utilities is a common practice that provides managers and regulating authorities with meaningful information to improve the management of utilities and, moreover, to improve the design of public policies regulating the water and sewage industry. This paper contributes to the existing literature in this field of research by assessing the technical performance in the provision of the different stages of the urban water cycle by a sample of water and sewage utilities located in the Spanish region of Andalusia. Andalusia is a territory located in the South of the Iberian Peninsula, where increasing water scarcity, most likely due to climate change, and ever-growing demand have seen the efficient management of this natural resource become a pressing need.

As regards the methodological approach, *DEA* techniques and directional distance functions are employed. Efficiency is interpreted as the capability of a water and sewage utility to increase its production in a particular stage of the urban water cycle without additional consumption of inputs, while maintaining the volume of service produced in the remaining stages. This methodological approach has the advantages of allowing stage-specific scores of efficiency to be readily computed and, furthermore, of distinguishing between unallocatable production factors and inputs that are specifically allocated to the production of a particular service. In addition, performance indicators adjusted for the effect of some features of the environments where utilities in our sample operate are computed.

In summary, the following empirical results are worth highlighting. First, the volume of water delivered could be increased without further use of resources while maintaining the service produced in the other stages of the urban water cycle. Improving technical efficiency in the management of this stage would contribute to reducing the amount of unaccounted-for water that gets lost along delivering pipelines, thus contributing to saving water in a territory where the efficient management of this natural resource has become a must.

Second, by improving efficiency Andalusian water and sewage utilities could significantly increase the volume of sewage collected while still maintaining inputs and the volume of service produced in the remaining stages of the urban water cycle. Conversely, utilities are judged to be much more efficient in the technical management of the stage of sewage treatment. If they are considered jointly, these results might be of great usefulness to utility managers but, more interestingly, to the regulating authorities in the region. An increase in the amount of sewage collected would avoid polluting the environment and, if this sewage is adequately treated and made suitable at least for some urban uses such as watering gardens or cleaning streets, also save a natural resource that is definitely scarce. Thus, incentives conducive to stimulating a more efficient management in collecting sewage on behalf of Andalusian water and sewage utilities, together with incentives to extend the capacity of their plants to treat sewage emerge as adequate strategies for public authorities to address the problem of water shortage.

Finally, we wish to highlight that the results obtained in this paper need to be interpreted in the context of the limitations imposed by the available statistical information and also by the methodology employed. Nonetheless, our belief is that approaching the issue of performance measurement in water and sewage utilities from fresher perspectives might provide utility managers and regulating authorities with relevant information that could help to improve the effectiveness of public regulation of the water and sewage industry.

References

Alegre, H., J.M. Baptista, E. Cabrera, F. Cubillo, P. Duarte, W. Hirner, W. Merkel, and R. Parena (2006), *Performance Indicators for water supply services*, Second edition. International Water Association Publishing, London

Ashton, J.K. (2003), Capital utilisation and scale in the English and Welsh water industry, *The Service Industries Journal 23*, 137-149.

Aubert, C., and A. Reynaud (2005), The impact of regulation on cost efficiency: An empirical analysis of Wisconsin water utilities, *Journal of Productivity Analysis 23*, 383-409.

Banker, R.D., A. Charnes and, W.W. Cooper (1984), Some models for estimating technical and scale inefficiencies in data envelopment analysis, *Management Science 30*, 1078-1092.

Burns, P., Jenkins, C. and C. Riechmann (2005), The role of benchmarking for yardstick competition, *Utilities Policy 13*, pp. 302-309.

Charnes, A., WW. Cooper, and E. Rhodes (1978), Measuring the efficiency of decision making units, *European Journal of Operational Research 2*, 429-44.

Coelli, T. and, D. Lawrence (Eds.) (2006), *Performance Measurement and Regulation Network Utilities*, Edward Elgar. Cheltenham.

Cooper, W., L. Seiford, and J. Zhu (2004), *Handbook on Data Envelopment Analysis*, Kluwer Academic Publishers, Boston.

Emrouznejad, A., B.R. Parkerb and G. Tavaresc (2008), Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. *Socio-Economic Planning Sciences 42*, 151-157.

doi:10.1016/j.seps.2007.07.002, in press.

Estache, A., and L. Trujillo (2003), Efficiency effects of ‘privatization’ in Argentina’s water and sanitation services, *Water Policy 5*, 369-80.

Fabbri, P. and G. Fraquelli (2000), Costs and structure of technology in the Italian water industry, *Empirica 27*, 65-82.

Färe, R. and, C.A.K. Lovell (1978), Measuring the technical efficiency of production, *Journal of Economic Theory 19*, 150-162.

Färe, R. and, S. Grosskopf (2000), Theory and application of directional distance functions, *Journal of Productivity Analysis 13*, 93-103.

Färe, R. and, S. Grosskopf (2004), *New directions: efficiency and productivity*. Kluwer Academic Publishers, Boston/London/Dordrecht.

Faria, R.C., G. Souza, and T.B. Moreira (2005), Public *versus* private water utilities: Empirical evidence for Brazilian companies, *Economics Bulletin 8*, 1-7.

Farrell, M.J. (1957), The measurement of productive efficiency, *Journal of the Royal Statistical Society*, *Series A 120*, 235-90.

Garcia, S. and, A. Thomas (2001), The structure of municipal water supply costs: application to a panel of French local communities, *Journal of Productivity Analysis 16*, 5-29.

Garcia, S. and, A. Thomas (2003), Regulation of public utilities under asymmetric information. The case of municipal water supply in France, *Environmental and Resource Economics 26*, 145-162.

Garcia, S., M. Moreaux, and A. Reynaud (2007), Measuring economies of vertical integration in network industries: An application to the water sector, *International Journal of Industrial Organization 25*, 791-820.

Gattoufi, S., M. Oral, and A. Reisman (2004), Data Envelopment Analysis literature: a bibliography update (1951-2001), *Socio-Economic Planning Sciences 38*, 159-229.

González-Gómez, F. (2005), El precio del agua en las ciudades. Reflexiones y recomendaciones a partir de la Directiva 2000/60/CE, *Ciudad y Territorio. Estudios Territoriales 144*, 305-320.

González-Gómez, F. and García-Rubio, M.A. (2008), Efficiency in the management of urban water services. What have we learned after four decades of research?, *Hacienda Pública Española. Revista de Economía Pública 185* (in press).

Jones, D.C. and N. Mygind (2000), The effects of privatization on productive efficiency: evidence from the Baltic Republics, *Annals of Public and Cooperative Economics 71*, 415-39.

Kirkpatrick, C., D. Parker, and Y.F. Zhang (2006), An empirical analysis of state and private sector provision of water services in Africa, *The World Bank Economic Review 20*, 143-163.

Koopmans, T. C. (1951), An analysis of production as an efficient combination of activities. In T. C. Koopmans (Ed.) Activity Analysis of Production and Allocation, John Wiley & Sons, New York, 33–97.

Lambert, D.K., D. Dichev, and K. Raffiee (1993), Ownership and sources of inefficiency in the provision of water services, *Water Resources Research 29*, 1573-1578.

Lin, Ch. (2005), Service quality and prospects for benchmarking: evidence form the Peru water sector, *Utilities Policy 13*, 230-239.

Matos, R., A. Cardoso, R. Ashley, P. Duarte, A. Molinari, and A. Schulz (2003), *Performance indicators for wastewater services*. International Water Association Publishing. London.

Ménard, C. and S. Saussier (2000), Contractual choice and performance: the case of water supply in France, *Revue D'Èconomie Industrielle 92*, 385-404.

Mugisha, S. (2007), Effects of incentive applications on technical efficiencies: Empirical evidence from Ugandan water utilities, *Utilities Policy 15*, 225-233.

Nin, A., Ch. Arndt, T.W. Hertel, and P.V. Preckel (2003), Bridging the gap between partial and total factor productivity measures using directional distance functions, *American Journal of Agricultural Economics 85*, 928-942.

Picazo-Tadeo, A.J., F. González-Gómez, and F.J. Sáez-Fernández (2009), Accounting for operating environments in measuring water utilities' managerial efficiency. *The Service Industries Journal* (doi: 10.1080/ 02642060802190300).

Picazo-Tadeo, A.J., F.J. Sáez-*Fernández*, and F. González-Gómez (2007), The role of environmental factors in water utilities' technical efficiency. Empirical evidence from Spanish companies, *Applied Economics*, doi: 10.1080/00036840601007310, in press.

Picazo-Tadeo, A.J., F.J. Sáez-Fernández, and F. González-Gómez (2008), Does service quality matter in measuring performance of water utilities? *Utilities Policy 16*, 30-38.

Saal, D., and D. Parker (2000), The impact of privatization and regulation on the water and sewerage industry in England and Wales: a translog cost function model, *Managerial and Decision Economics 21*, 253-268.

Saal, D., and D. Parker (2006), Assessing the performance of water operations in the English and Welsh water industry: A lesson in the implications of inappropriately assuming a common frontier in *Performance measurement and regulation of network industries*, by Coelli, T., and D. Lawrence (editors). Edward Elgar.

Saal, D., D. Parker, and T. Weyman-Jones (2007), Determining the contribution of technical change, efficiency change and scale change to productivity growth in the privatized English and Welsh water and sewerage industry: 1985–2000, *Journal of Productivity Analysis 28*, 127-139.

Sabbioni, G. (2008), Efficiency in the Brazilian sanitation sector, *Utilities Policy 16*, 11-20.

Sauer, J. (2005), Economies of scale and firm size optimum in rural water supply, *Water Resources Research 41*, 1-13.

Sauer, J., and K. Frohberg (2007), Allocative efficiency of rural water supply –a globally flexible SGM cost frontier, *Journal of Productivity Analysis 27*, 31–40.

Souza, G.S., Faria, R.C., and T.B. Moreira (2007), Estimating the relative efficiency of Brazilian publicly and privately owned water utilities: a stochastic cost frontier approach, *Journal of the American Water Resources Association 43*, 1-8.

Shephard, R.W. (1970), *Theory of cost and production functions*. Princeton University Press, Princeton.

Thanassoulis, E. (2000a), The use of data envelopment analysis in the regulation of the UK water utilities: water distribution, *European Journal of Operational Research 126*, 439-453.

Thanassoulis, E. (2000b), DEA and its use in the regulation of water companies, *European Journal of Operational Research 127*, 1-13.

Torres, M., and C.J. Morrison-Paul (2006), Driving forces for consolidation or fragmentation of the US water utility industry: A cost function approach with endogenous output, *Journal of Urban Economics 59*, 104-120.

Tupper, H.C., and M. Resende (2004), Efficiency and regulatory issues in the Brazilian water and sewage sector: an empirical study, *Utilities Policy 12*, 29-40.

Woodbury, K., and B. Dollery (2004), Efficiency measurement in Australian Local Government: The case of New South Wales municipal water services, *Review of Policy Research 21*, 615-36.