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Assessing performance in the management of the urban water cycle

ANDRÉS J. PICAZO-TADEO
Universidad de Valencia. Dpto. Economía Aplicada II.
Avda dels Tarongers s/n. 46022 Valencia (Spain).

FRANCISCO J. SÁEZ-FERNÁNDEZ
Fundación Escuela de Negocios de Andalucía y
Universidad de Granada. Dpto. Economía Internacional y de España.
Campus de Cartuja. 18011 Granada (Spain).

FRANCISCO GONZÁLEZ-GÓMEZ
Universidad de Granada. Dpto. Economía Aplicada.
Campus de Cartuja. 18011 Granada (Spain).

Abstract. This paper proposes the use of directional distance functions and *Data Envelopment Analysis* techniques to assess the 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 to efficiency measurement. 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. Potential increases are also important for the volume of sewage treated, thus reporting significant environmental benefits in a territory where water scarcity has turned the efficient management of this natural resource into a pressing obligation.

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

JEL Classification: *L20; L95; C61.*

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 efficiency 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 context of neoclassical production theory and efficiency analysis. 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), 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) or, 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. 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). However, common sense suggests that utilities producing two or more water and sewage services might not be equally efficient in the management of the different services they provide.

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. As figure 1 displays, 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 or otherwise usable. 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. This unaccounted-for water may, at least partly, return to reservoirs or the subsoil and be recollected, retreated and redistributed.

Insert figure 1 about here

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, an evident interrelationship exists among them: 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).

In this framework, our paper assesses the technical efficiency of 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. Performance indicators are computed for each stage or service integrating the urban water cycle. As regards 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 do, here performance indicators are computed for the different services of the urban water cycle. 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 and the data. Section 4 is devoted to discussing the results, while Section 5 concludes.

2. METHODOLOGICAL ISSUES

As noted previously, in this paper *DEA* techniques and directional distance functions are chosen to assess how efficiently the different stages of the urban water cycle are managed. *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 (Gattoufi *et al.*, 2004 review the empirical literature).

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. Further details on *DEA* can be found in Cooper *et al.* (2004).

Let us now give a brief insight into the formalisation of the methodology by considering a production process that uses of a vector $\boldsymbol{x}$ of $n = 1, \ldots, N$ inputs to obtain a vector $\boldsymbol{y}$ of $m = 1, \ldots, M$ outputs, through a *technology* represented by:

$$T = \left[\left(\boldsymbol{x}, \boldsymbol{y} \right) : \boldsymbol{x} \text{ can produce } \boldsymbol{y} \right] \tag{1}$$

The technology can likewise be modelled through the *output possibility set* representing all the vectors of outputs attainable from a given vector of inputs. Formally:

$$P\left(\boldsymbol{x} \right) = \left[\boldsymbol{y} : \left(\boldsymbol{x}, \boldsymbol{y} \right) \in T \right] \tag{2}$$

It is assumed that 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 technology, output-oriented technical efficiency can be evaluated by using the conventional *Shephard output distance function*, defined as:

$$D_O(\boldsymbol{x},\boldsymbol{y}) = Inf\left[\theta : \left(\frac{\boldsymbol{y}}{\theta}\right) \in P(\boldsymbol{x})\right] \tag{3}$$

This distance measures the maximum equiproportional expansion of all the elements of the vector of outputs, for a given endowment of inputs and the restrictions imposed by the available technology, and it is the inverse of Farrell's output-oriented measure of technical efficiency (Färe and Lovell, 1978). The output distance takes a value smaller than one for decision-making units that are technically inefficient, the lower the score, the more technically inefficient it is. For firms attaining technical efficiency in the *Farrell-Debreu* sense, output distance equals one.

Using *DEA* techniques, the output distance function can be straightforwardly computed for a decision-making unit *k'* belonging to a sample of $k = 1,\ldots,K$ firms, from the solution to the following linear programming problem, where variable returns to scale are imposed (Banker *et al.*, 1984):

$$\begin{array}{lll}
D_O\left(\boldsymbol{x}^{k'},\boldsymbol{y}^{k'}\right)^{-1} = Max_{z^k,\phi^{k'}}\ \phi^{k'} & & \\
\textit{subject to:} & & \\
x_n^{k'} \geq \sum_{k=1}^{K} z^k x_n^k & n = 1,\ldots,N & (i) \\
\phi^{k'} y_m^{k'} \leq \sum_{k=1}^{K} z^k y_m^k & m = 1,\ldots,M & (ii) \\
z^k \geq 0 & k = 1,\ldots,K & (iii) \\
\sum_{k=1}^{K} z^k = 1 & & (iv)
\end{array} \tag{4}$$

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.

In contrast to the Shephard output distance function, which expands all outputs simultaneously, the directional output distance function allows each output to be expanded along a direction previously specified by the researcher, thus generalising the former. Färe and Grosskopf (2000) summarise the theory and main applications of directional distance functions (see also Färe and Grosskopf, 2004). The general definition of the *directional output distance function* is:

$$\vec{D}_O\left[\boldsymbol{x},\boldsymbol{y};\boldsymbol{g}_y=\left(g_{y_1},...,g_{y_M}\right)\right]=Sup\left\langle\varphi:\left[\boldsymbol{y}+\varphi\left(g_{y_1},...,g_{y_M}\right)\right]\in P\left(\boldsymbol{x}\right)\right\rangle, \tag{5}$$

$\boldsymbol{g}_y$ 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.

In what follows, 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 inputs and technology. With this particular direction vector, the directional output distance function becomes:

$$\vec{D}_O\left[\boldsymbol{x},\left(y_i,\boldsymbol{y}_{-i}\right);\boldsymbol{g}_y=\left(1,\boldsymbol{0}\right)\right]=Sup\left\langle\varphi:\left[\left(y_i,\boldsymbol{y}_{-i}\right)+\varphi\left(1,\boldsymbol{0}\right)\right]\in P\left(\boldsymbol{x}\right)\right\rangle\ , \tag{6}$$

where *i* denotes the output to be expanded, while *–i* stands for the remaining outputs.

Before computing this distance, 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). With this distinction, the directional output distance function of expression (6) for decision-making unit *k’* and output *i* comes from the following programming problem:

$$\begin{array}{lll}
\multicolumn{3}{l}{\vec{D}_O\left[\boldsymbol{x}^{k'},\left(y_i^{k'},\boldsymbol{y}_{-i}^{k'}\right);\boldsymbol{g}_y=\left(1,\boldsymbol{0}\right)\right]=Max_{z^k,\varphi_i^{k'}}\ \varphi_i^{k'}} \\
\multicolumn{3}{l}{\textit{subject to:}} \\
x_n^{k'}\geq\sum_{k=1}^{K}z^k x_n^k & n\notin A & (i) \\
x_{ni}^{k'}\geq\sum_{k=1}^{K}z^k x_{ni}^k & n\in A & (ii) \\
y_i^{k'}+\varphi_i^{k'}\leq\sum_{k=1}^{K}z^k y_i^k & i\in m \text{ and } i\notin -i & (iii) \\
y_{-i}^{k'}\leq\sum_{k=1}^{K}z^k y_{-i}^k & -i\in m & (iv) \\
z^k\geq 0 & k=1,...,K & (v) \\
\sum_{k=1}^{K}z^k=1 & & (vi)
\end{array} \tag{7}$$

where *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*.

The technical efficiency for decision-making unit *k'* and output *i* can then be assessed by merely comparing the observed level of that output with the level that would result if the firm were behaving efficiently. Formalising:

$$TE_i^{k'} = \frac{y_i^{k'}}{\left(y_i^{k'} + \varphi_i^{k'}\right)} \tag{8}$$

This measure of efficiency is upper-bounded to one and measures the maximum expansion of output *i* for decision-making unit *k'*, given the production of the remaining outputs and the use of both unallocatable inputs and inputs allocated to the production of that output. Once again this indicator is upper-bounded to one. A value equal to one means technical efficiency, while the greater the distance from one, the lower the level of technical efficiency.

Figure 2 provides some graphic intuition for both equiproportional and output-specific assessments of technical efficiency. For the sake of simplicity, les us assume that we observe decision-making units *A*, *B*, *C*, *D* and *E*, which are all using the same vector of inputs $\boldsymbol{x}$ to obtain two outputs, namely y_1 and y_2. Firms *A* to *D* and their convex combinations are shaping the technological frontier, i.e. the upper bound of the output possibility set, while decision-making unit E is unambiguously inefficient, as it is located at an inner point of the output set.

Insert figure 2 about here

The conventional Shephard output distance computed from the solution to program (4) would project firm *E* at point *E'* on the technological frontier, showing that both outputs could be proportionally increased by making an efficient use of available inputs. On the contrary, the directional output distance computed from program (7) for output y_1 would place firm *E* on point *E''*, showing how making an efficient use of the production factors at its disposal would drive output y_1 up to the level corresponding to point *E''*, while maintaining output y_2 at its observed level. Similar reasoning would apply when interpreting the directional distance function computed for the second output.

The next section is devoted to describing the data and discussing the results obtained for the assessment of technical efficiency in the provision of the stages of the urban water cycle of a sample of Andalusian water and sewage utilities.

3. THE ANDALUSIAN WATER AND SEWAGE INDUSTRY: SAMPLE AND DATA DESCRIPTION

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).

As regards the services provided by Andalusian water and sewage utilities, not all are responsible for all four stages of urban water cycle services. All of them treat and distribute water, whereas somewhat less than 30 per cent of them also provide sewage collection services and around 50 per cent, apart from treating and distributing water and collecting sewage, also treat the latter, that is, they provide all four services of the urban water cycle. At present, nearly 85 per cent of the sewage that is actually treated in Andalusia, receives what is known as secondary treatment, which includes the physical separation of suspended particles, mainly through decantation, before later reducing the organic material present in sewage. However, only a small amount of this water is reused, mainly for agricultural purposes.

Now that the main features of the Andalusian water and sewage industry have been outlined, let us comment on the sample and the dataset. The empirical application we carry out in this paper is based on a set of data 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 sixty-five water and sewage utilities conforming the vast majority of utilities in the region. However, a lack of responses or deficient information on some relevant variables reduced our sample to thirty-five utilities, which provide services to more than one hundred towns and cities and nearly four million inhabitants, covering nearly fifty per cent of the population in the region.

One basic step when assessing efficiency with *DEA* models is the selection of the variables to represent output and production factors, which is not always an easy decision. It has been pointed out that a modelling improvement in assessing efficiency of water utilities could be achieved if both the physical volume of water services and the number of connections are considered as outputs (Garcia and Thomas, 2001; Saal and Parker, 2006). As highlighted by Saal and Parker (2006), this specification is appropriate because both outputs have substantially different marginal costs. While this specification might be particularly suitable for assessing cost efficiency, in this paper, the choice of outputs is conditioned by the fact they should represent the volume of service provided in each of the stages of the urban water cycle.

In particular, the productive process is characterised by the production of four outputs: water treated, water delivered, sewage collected and finally, sewage treated, all of which are measured in cubic metres. These outputs are intended to account for the volume of service produced in the stages of water treatment, water delivery, sewage collection and sewage treatment, respectively. Seventeen utilities in our sample provide all four services, while the remaining companies either produce only the stages of water treatment and water delivery (12 utilities), or provide the stages of water treatment, water delivery and sewage collection (6 utilities).

Concerning inputs, the following are considered: labour (number of workers), operational costs (measured in thousands of euros), delivery network and sewerage network (both measured in kilometres). Delivery and sewerage networks are considered to be allocatable inputs only used to produce the services of water delivery and sewage collection, respectively. Conversely, our source of data does not allow the labour and operational costs allocated to producing each particular stage of the urban water cycle to be distinguished, so they are assumed to be unallocatable inputs. *Table 1* displays some descriptive statistics for the data.

Insert Table 1 about here

3. 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 for both conventional and stage-specific scores of technical efficiency are in *table 2*. Conventional scores of efficiency based on the equiproportional expansion of all outputs have been directly computed from expression (4), while stage-specific technical efficiency has been calculated according expression (8), after having computed the efficient production in each stage of the urban water cycle from the solution to program (7).

Insert table 2 about here

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 all we aim to do is to assess the efficiency in the provision of the different outputs or stages of the urban water cycle. Moreover, demand restrictions affect basically the service produced in stages of water treatment and water 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 two or more times the behaviour of other utilities. More precisely, the number of utilities acting as a reference ranges from five in the computation of the efficiency in the stage of sewage treatment, to sixteen in the case of the conventional assessment of efficiency.

As regards the computed scores of performance, evaluation of technical efficiency using conventional distance functions suggests that, on average, the water and sewage utilities in the sample are producing 87.6 per cent of their potential output, i.e. the output they could attain if all production factors were efficiently managed. In other words, the average radial score of efficiency is 0.876. However, the scores of stage-specific technical efficiency display a slightly different picture of performance, bringing to light important insights that would have gone unnoticed under the conventional approach to efficiency measurement.

The average scores of stage-specific efficiency for the services of water treatment, water delivery, sewage collection and sewage treatment are 0.741, 0.810, 0.782 and 0.744, respectively, showing that greater inefficiencies occur in the stages of water and sewage treatment. 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.

Potential increases of output in specific stages of the urban water cycle are, as noted, greater than the potential increase derived from the equiproportional measurement of technical efficiency. The reason for this is actually straightforward: when improvements in the management of inputs are devoted to increasing the production of a particular service, the increase in output associated to this service will obviously be greater than the increases that are achieved when efficiency improvements result in raising the service produced in all stages of the urban water cycle.

In order to further illustrate the usefulness of this approach to efficiency measurement in water and sewage utilities, we have chosen the results for utility number nineteen in our sample, which provides all four urban water cycle services, as an example. Conventional evaluation of technical efficiency for this utility indicates it is producing 93.3 per cent of its potential output in all stages of the urban water cycle. In contrast, stage-specific scores of technical efficiency are 0.664, 0.752, 0.852 and 0.713 for water treatment, water delivery, sewage collected and sewage treated, respectively. These figures indicate, among other relevant things, that this utility has a particularly relevant potential to increase the volume of water and sewage treated.

In general, computed stage-specific scores of technical efficiency suggest that Andalusian utilities could significantly increase the amount of sewage treated while still maintaining the service produced in the remaining stages of the urban water cycle, without incurring in additional use of productive resources. While this result needs to be interpreted in the context of the restrictions imposed by the available statistical information (for instance, attaining the efficient volume of sewage treated might be limited in practice by variables not accounted for in our model, such as the capacity of the water purification plants, as a fixed production factor) and the limitations of the methodology, it might be of great interest to the managers of these utilities and, more importantly, to the authorities responsible for regulating the Andalusian water and sewage industry. Regulating authorities would be now aware of the important environmental benefits that could be achieved if utilities made a more efficient use of their inputs in treating sewage.

An increase in the amount of sewage 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 sewage treatment stage of the urban water cycle emerge as adequate strategies towards tackling the problem of water scarcity in the region.

Moreover, a second interesting result is that, by making an efficient use of available resources, the volume of water delivered could also be substantially increased, while still maintaining the service produced in the remaining stages of the urban water cycle, i.e. average efficiency in the management of the water delivery stage is 0.810. This outcome has, in our view, important 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. If all the utilities in our sample managed the water distribution stage efficiently, the amount of unaccounted-for water would be considerably reduced. 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.

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.

Another matter to be dealt with when interpreting our measures of stage-specific technical efficiency refers to how certain features related to utility operating environments that are not controlled for in this model may influence efficiency assessment. For instance, one feature that could influence the assessment of technical efficiency in the stage of water delivery is the different customer dispersion faced by the Andalusian water and sewage utilities in the sample. The reason is that water losses could be reasonably expected to increase as the length of the network increases, so utilities with a longer delivery network due to greater customer dispersion 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, so that water and sewage utilities in the sample will tend to be benchmarked with utilities that use networks of a similar length. Indeed, twenty-nine out of our thirty-five utilities, i.e. more than 80 per cent, 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 unit utilities are compared to hardly reaches 5 per cent for the sample as a whole.

One further consequence of computing stage-specific scores of technical efficiency is that, as it changes benchmarking results with respect to conventional assessment based on equiproportional increases in output, the ranking of utilities ordered in accordance to their managerial performance is also altered. Going back to the results for utility number thirteen in our sample, it occupies the twenty-first place in a ranking of utilities ordered according to the scores obtained from conventional technical efficiency assessment. Conversely, when utilities are ranked by their efficiency scores for the stage of water treatment, it drops to thirty-first position, and goes up again to twentieth when ranked according to its efficiency in the management of the stage of water delivery.

Although changes are also significant for some other utilities, utility rankings cannot be judged statistically different when ordered according to either conventional scores of efficiency or specific scores for the stages of water treatment and water delivery. This assertion is based on the results of performing a *Spearman* correlation test (*table 3*), which rejects the hypothesis that different assessments of efficiency lead to different rankings of utilities in all cases at a confidence level of 1 per cent (*p-values* are negligible). In performing this test, efficient utilities, i.e. utilities with efficiency scores equal to one, have been ranked according to their importance as benchmarks, measured as the number of times they are benchmarking other inefficient utilities (Charnes *et al.*, 1985).

Insert table 3 about here

5. 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. In this paper, we evaluate the technical performance of a sample of utilities located in the Spanish region of Andalusia in the provision of the different stages that integrate the urban water cycle. 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.

Data Envelopment Analysis techniques and directional distance functions are employed as analytical tools. 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, 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 computed and, furthermore, of distinguishing between unallocatable production factors and inputs that are allocated to the production of a particular service.

In summary, the following empirical results are worth highlighting. Conventional assessment of technical efficiency reveals that, on average, water and sewage utilities in the sample are producing around 87 per cent of their potential output in all the stages of the urban water cycle. Conversely, the assessment of the technical efficiency in the management of each stage displays a rather different picture of performance, bringing to light relevant information that could have remained hidden in the usual approaches to efficiency measurement in the water and sewage industry.

Among other interesting results, our analysis shows that Andalusian water and sewage utilities are producing about 74 per cent of their potential output in the stage of sewage treatment. In other words, by improving efficiency, treated sewage could be significantly increased while still maintaining the volume of service produced in the remaining stages of the urban water cycle. This result 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 treated would avoid polluting the environment, but also save a natural resource that is definitely scarce. Thus, incentives conducive to stimulating a more efficient use of inputs on behalf of Andalusian water and sewage utilities in performing their treatment of sewage emerge as adequate strategies for public authorities to address the problem of water shortage.

Furthermore, another remarkable result is that the volume of water delivered could also be significantly increased without reducing the service produced in the other stages of the urban water cycle, thus reducing the amount of unaccounted-for water that gets lost along delivering pipelines. This improvement would also contribute to saving water in a territory where the efficient management of this natural resource has become a pressing need.

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.

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Table 1. Sample description.

Variable	Measurement unit	Mean	Standard deviation	Maximum	Minimum
Outputs					
Water treated	Thousands of m^3	12,290	22,212	107,733	315
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
Unallocatable inputs					
Labour	Number of workers	73	139	732	2
Operational costs	Thousands euros	4,162	6,722	33,648	99
Allocatable inputs					
Delivery network	Kilometres	347	583	2,877	5
Sewerage network	Kilometres	203	390	1,855	0

Table 2. Estimates of technical efficiency.

	Mean	Standard deviation	Maximum	Minimum
Radial efficiency	0.876	0.188	1	0.394
Stage-specific efficiency				
Water treatment	0.741	0.259	1	0.270
Water delivery	0.810	0.245	1	0.241
Sewage collection	0.782	0.227	1	0.297
Sewage treatment	0.744	0.231	1	0.339

Table 3. Results for the *Spearman* correlation test (ρ-*Spearman*)*(1)*

	Radial efficiency	Efficiency in water treatment	Efficiency in water delivery
Radial efficiency	1	-	-
Efficiency in water treatment	0.813 (0.000)	1	-
Efficiency in water delivery	0.900 (0.000)	0.893 (0.000)	1

(1) p-values are in parenthesis.

Figure 1. The urban water cycle

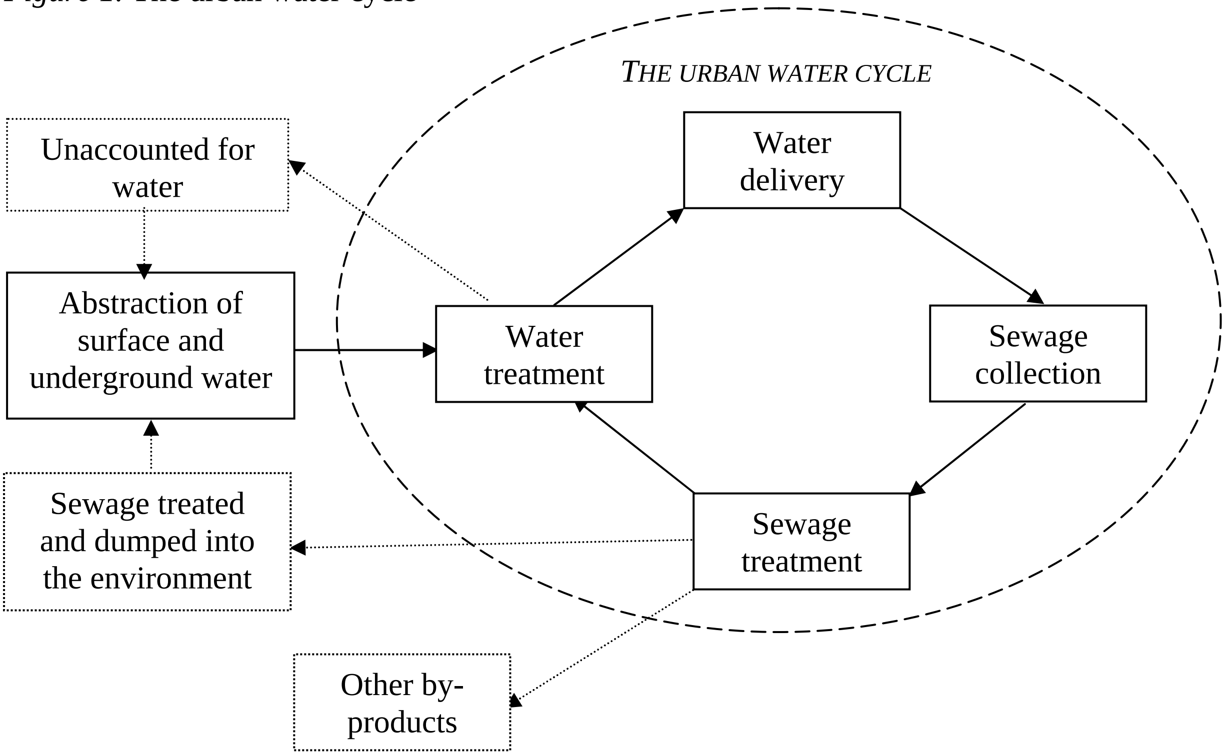

Figure 2. The production possibilities set.