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## ***Quality and technical efficiency in water utilities: An empirical application to Andalusian utilities***

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***Abstract.-*** *Quality is a dimension of water services that has been repeatedly omitted in the study of performance of water utilities. In this paper, we make use of Data Envelopment Analysis techniques (DEA) to compute both conventional quantity-based and quality-adjusted indicators of technical efficiency for a sample of Spanish water utilities. The key assumptions are that a lack of quality (bad quality) can be regarded as a bad output, and the existence of a trade-off between quantity and quality. Our main results indicate that quality matters in measuring technical performance, the difference between conventional and quality-adjusted evaluations representing the opportunity cost of maintaining quality. Averages and distribution functions significantly differ between both assessments of performance, although water utilities do not seem to rank differently.*

***Keywords:*** *water utilities; performance; quality; Data Envelopment Analysis.*

***JEL Classification:*** *L20; L95; C61.*

### ***1. Introduction***

Evaluating water utilities performance is a customary practice to provide both utilities' managers and regulatory authorities with meaningful information to improve the organisation of companies and also to improve the design of public policies. Furthermore, assessment of performance for water utilities located in places where water is a scarce natural resource might be

of additional interest from a social viewpoint. Several indicators have been used to evaluate relative performance (Matos *et al.*, 2003; Alegre *et al.*, 2006), ranging from very simple measures, such as the number of workers or operational costs per unit of service provided, to more sophisticated approaches that include benchmarking techniques (Parena *et al.*, 2002).

A common feature to the majority of these indicators of water utilities' performance is that they ignore the quality of the service produced. However, omitting quality might offer a biased picture of performance. Conventional quantity-based measurement of performance might lead, let us say, to *perverse* outcomes, penalising utilities that produce services of higher quality. The reasoning behind this assertion is really straightforward. Maintaining high levels of quality requires the use of resources endowed with an opportunity cost, i.e. resources that could otherwise be devoted to augment the quantity of the service produced. Accordingly, firms devoting smaller amounts of resources towards *quality* will tend to display, on equal terms, greater scores of performance.

From the eighties onwards, a number of papers have expressly focused on assessing managerial efficiency in water utilities using benchmarking techniques, through either econometric approaches or non-parametric methods based on *Data Envelopment Analysis (DEA)*. Empirical applications have been motivated by different concerns, including the study of the differences in efficiency between public and private-owned water utilities, or the effect of public regulations on utilities' performance. While it is not our intention to provide an exhaustive list, some of the most recent papers are Ashton (2000), Jones and Mygind (2000), Estache and Rossi (2002), Anwandter and Ozuna (2002), Corton (2003), Woodbury and Dollery (2004), Cubbin (2005), Kirkpatrick *et al.* (2006), García-Valiñas and Muñiz (2007), Picazo-Tadeo *et al.* (2007a, 2007b). However, these papers also share the characteristic of ignoring quality as a relevant dimension of the service produced by water utilities.

Only a few papers have introduced some variables representing the quality dimension of water services in their analyses, but for the most part in a marginal way, i.e. quality was not actually the central point being researched. For instance, quality has been introduced, jointly with other relevant variables in second-stage analyses to test for its influence on performance (Anwandter and Ozuna, 2001; Tupper and Resende, 2004); or in a regression analysis as a variable capable of explaining water utilities' costs (Bhattacharyya *et al.*, 1995a, 1995b; Garcia and Thomas, 2001; Antonioli and Filippini, 2001; Estache and Rossi, 2002). Furthermore, quality has been considered as an additional output of water utilities, besides outputs representing quantity (Fox and Hofler, 1986; and Woodbury and Dollery, 2004), as it has also been utilised to compute quality-adjusted output indices (Saal and Parker, 2001). As far as we know, only a recent paper by Lin (2005) has considered as the object of research the effect of the service quality in measuring water utilities' performance.

Lin's main concern is to examine how introducing variables representing the quality dimension of water services might affect performance comparisons across utilities. Using data from a sample of Peruvian water utilities, stochastic cost frontiers are estimated in a parametric efficiency analysis framework. Several models are estimated, the quality variables being considered either as environmental variables that might influence the behaviour of water utilities, or as additional outputs in the cost function. Although correlations between performance evaluations are, in general, important, the results achieved indicate that including quality variables changes benchmarking results. Moreover, including quality as an additional output of water utilities also alters the ranking of utilities. Accordingly, the conclusion of the paper is that variables representing the quality of water services need to be considered when measuring the performance of water utilities.

In this context, our paper contributes to the current strand of literature in the field of water utilities' performance measurement by computing scores of technical efficiency adjusted by the quality of the service, in a non-parametric *DEA*-based framework. Performance is assessed on a

sample of water utilities located in the Southern Spanish region of Andalusia. Quality-adjusted scores are compared with performance indicators from a conventional quantity-based evaluation of technical efficiency in which variables representing quality are omitted. The foremost result reveals that quality matters in measuring performance of water utilities.

The remainder of the paper is organised as follows. Sections 2 and 3 are devoted to describing the methodology and the dataset, respectively. Section 4 presents and discusses the empirical results. The final section summarises and highlights some concluding remarks.

## ***2. Methodological issues***

Traditional efficiency analysis was pioneered by Farrell (1957) in a seminal paper that proposed several measures of productive efficiency, showing how they could be computed in practice. Afterwards, Charnes *et al.* (1978) introduced *Data Envelopment Analysis (DEA)* techniques in a paper that used mathematical programming to extend Farrell's approach to technical efficiency measurement to multiple input and multiple output technologies. Essentially, *DEA* evaluates the relative performance of peer units, allowing a *surface* to be built over the data, the so-called technological frontier that permits the observed behaviour of a decision-making unit to be compared with best observed practices, in terms of a performance indicator. Performance is, therefore, a *relative* concept, i.e. efficiency is only as good as the best in the sample. Thanassoulis (2000a; 2000b) highlights the usefulness of *DEA* for analysing performance in water companies. Further details on this technique can be found in Cooper *et al.* (2004).

The production theory underlying the framework of efficiency analysis posits the existence of a technology of reference that provides a complete description of all technologically feasible relationships between inputs (variable  $x$ ) and outputs (variable  $y$ ). Formally, the *reference technology* is:

$$T = [(x, y) : x \text{ can produce } y] \quad (1)$$

Technology can likewise be modelled through the *output set*, which represents all the output vectors attainable from a given vector of inputs, and is formally defined as:

$$P(x) = [y : (x, y) \in T] \quad (2)$$

Technology is assumed to satisfy the usual axioms, initially proposed by Shephard (1970) (see also Grosskopf, 1986). These properties include the possibility of inaction, no free lunch, free disposability of inputs (the same level of outputs can be always produced using higher quantities of inputs) and strong disposability of outputs (lower quantities of outputs can be produced at no cost using the same inputs). In addition, we consider that the output set is 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, Farrell's output-oriented technical efficiency can be evaluated using the *output distance function*, defined as:

$$\text{Distance}(x, y) = \text{Min} \left[ \mathbf{q} : \left( \frac{y}{\mathbf{q}} \right) \in P(x) \right] \quad (3)$$

The *output distance function* measures the maximum feasible radial expansion of the vector of outputs, given the restrictions imposed by a fixed endowment of inputs and the existing technology. This function is the inverse of Farrell's output-oriented measure of technical efficiency (Färe and Lovell, 1978).

Let us now assume that we observe a sample of  $k = 1, \dots, K$  decision-making units, using a vector  $x$  of  $n = 1, \dots, N$  inputs to produce a vector  $y$  of  $m = 1, \dots, M$  outputs. Using *DEA*, evaluation of output-oriented technical efficiency for each productive unit in the sample requires its observed data on outputs and inputs to be compared to those of units displaying the best observed practices. In the case of decision-making unit  $k'$ , this can be done by solving the

following optimisation program, where constant return to scale has been imposed (Banker *et al.*, 1984):

$$\begin{aligned}
 & [\text{Distance}_{k'}(x_{k'}, y_{k'})]^{-1} = \text{Max}_{z_k, \phi_{k'}} \phi_{k'} \\
 \text{subject to:} \quad & x_{nk'} \geq \sum_{k=1}^K z_k x_{nk} \quad n = 1, \dots, N \quad (i) \\
 & \phi_{k'} y_{mk'} \leq \sum_{k=1}^K z_k y_{mk} \quad m = 1, \dots, M \quad (ii) \\
 & z_k \geq 0 \quad k = 1, \dots, K \quad (iii)
 \end{aligned} \tag{4}$$

$z_k$  being a set of intensity variables representing the weighting of each observed decision-making unit  $k$  in the composition of the efficient frontier, i.e. they determine the combination of efficient production units firm  $k'$  is compared to.

Output-oriented technical efficiency is measured through the distance function obtained as the solution to program (4)<sup>1</sup>. The output distance function is equal to one for decision-making units technically efficient in the *Farrell-Debreu* sense<sup>2</sup>, while a computed value for this function smaller than one indicates the presence of technical inefficiency. The lesser the computed value for the output distance, the greater the technical inefficiency.

Introducing the output quality dimension in this framework requires two key assumptions to be made. It is assumed, on the one hand, that a lack of quality (bad quality) can be interpreted as an undesirable or bad output (Olesen and Petersen, 1995; Prior, 2006). On the other hand, we also assume a trade-off between quantity and quality. More specifically, let us consider that output has a set of  $h = 1, \dots, H$  quality attributes measured by the variable  $q$ , which can be equivalently expressed in terms of bad quality (variable  $b$ ). In fact, hereafter we will refer to the quality dimension mostly as bad quality attributes. After introducing quality as a relevant variable, the

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<sup>1</sup> Technical performance might be likewise evaluated using the inverse of the distance function, i.e. the Farrell's output-oriented technical efficiency score (parameter  $\phi$ ).

<sup>2</sup> There exists another more restrictive concept of efficiency, the *Pareto-Koopmans* efficiency (see Färe *et al.*, 1994).

output set describing all combinations of quantity of outputs and bad quality ( $y, b$ ) attainable from a given endowment of inputs  $x$  is:

$$P^q(x) = \left[ (y, b) : (x, y, b) \in T^q \right], \quad (5)$$

$T^q$  being the technology of reference when quality is considered, which represents all technologically feasible relationships among inputs, quantity of outputs and bad quality.

In technologies producing undesirable outputs together with desirable outputs, Färe *et al.* (1989) proposed to modify the characterisation of the output set by assuming that desirable outputs are strongly disposable, while bad outputs are under the axiom of weak disposability. Weak disposability is a sensible way to model the idea that reducing bad outputs is not a costless activity, but it involves a cost that can be measured either as an increase in the use of productive resources or as a decrease in the production of desirable outputs<sup>3</sup>. Since then, this asymmetric treatment has been a customary practice in performing efficiency analyses in the presence of bad outputs (see, for instance, Tyteca, 1997; Hcazo-Tadeo *et al.*, 2005). In our particular case, reducing bad quality (or, in other words, increasing quality) requires firms to divert resources that could otherwise be devoted to *producing quantity*. In other words, there is an evident trade-off between quality and quantity.

In this new scenario that incorporates quality as a relevant dimension of production processes, the output distance required to assess technical performance is:

$$\text{Distance}(x, y, q(b)) = \text{Min} \left[ \mathbf{J} : \left( \frac{y}{\mathbf{J}}, b \right) \in P^q(x) \right], \quad (6)$$

and it can be obtained by solving the following modified program (Prior, 2006):

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<sup>3</sup> Formally, the axiom of *weak disposability of outputs* can be expressed as:

$$\begin{aligned}
& \left[ \text{Distance}_k(x_k, y_k, q_k(b_k)) \right]^{-1} = \text{Max}_{z_k, \phi_k} \phi_k \\
\text{subject to: } & x_{nk'} \geq \sum_{k=1}^K z_k x_{nk} \quad n = 1, \dots, N & (i) \\
& \phi_k y_{mk'} \leq \sum_{k=1}^K z_k y_{mk} \quad m = 1, \dots, M & (ii) \\
& b_{hk'} = \sum_{k=1}^K z_k b_{hk} \quad h = 1, \dots, H & (iii) \\
& z_k \geq 0 \quad k = 1, \dots, K & (iv)
\end{aligned} \tag{7}$$

This program searches, given a fixed endowment of resources and the restrictions imposed by the available technology, the maximum feasible expansion of outputs while at the same time maintaining the level of quality, defined in terms of the bad attributes (restriction *iii*)<sup>4</sup>. In other words, it looks for the greatest attainable increase in outputs without diverting resources from *producing quality*. Obviously, the output distance function computed as the solution to program (7) is necessarily equal to or greater than the distance function obtained from the optimal solution to program (4), the difference representing the opportunity cost of maintaining the attributes of quality.

*Figure 1* provides some graphic intuition of conventional quantity-based and quality-adjusted evaluations of technical performance. For the sake of simplicity, let us assume that we observe decision-making units *A*, *B*, *C*, *D* and *E*, which are making use of a single input *x*, to produce a single output. The variable *y* measures the quantity of output produced, while quality is measured by the attribute *q* (or *b*, in terms of bad quality). Observations on efficient productive units *A*, *B* and *C*, as well as their convex combinations, give shape to the upper bound of the *output set*, i.e. the technological frontier. The down-sloping segment of the frontier represents the trade-off between quantity and quality. Furthermore, decision-making units *D* and *E* are unmistakably inefficient, because they are located at an inner point of the output set.

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$(y, b) \in P^q(x); 0 \leq \mathbf{b} \leq 1 \Rightarrow (\mathbf{b} y, \mathbf{b} b) \in P^q(x)$

<sup>4</sup> The strict equality in this restriction incorporates weak disposability (see Färe *et al.*, 1989).

*Insert Figure 1 about here*

Let us now focus our attention on productive unit  $D$ . Conventional quantity-based assessment of output-oriented technical efficiency for this decision-making unit, i.e. the solution to program (1), allows us to assert that production of output could be increased up to a potential level of  $y_D^{eff}$ . This potential or efficient production coincides with the level of output of reference unit  $C$ , which is the *efficient* firm in the sample that obtains the maximum quantity of output  $y$  from its endowment of input  $x$ , regardless of its level of quality. From the picture it immediately follows that the achievement of technical efficiency implies a loss of quality, i.e. for firm  $D$ , attaining potential output requires diverting resources that are currently channelled towards producing quality.

Conversely, quality-adjusted evaluation of output-oriented technical efficiency for decision-making unit  $D$ , i.e. the solution to program (4), reveals quite a different picture of performance. Now, given that maximising output is constrained by the need of maintaining the level of quality (or, in other words, the attributes of bad quality), the technological reference of unit  $D$  is point  $D'$ , on the upper bound of the output set, i.e. a convex combination of productive plans of efficient firms  $B$  and  $C$ . Thus, potential output for firm  $D$  is now  $y_D^{eff(q)}$ . Obviously, potential output under both conventional and quality-corrected measures of technical efficiency is fairly different, the divergence representing the opportunity cost of maintaining quality.

Introducing the quality dimension in measuring technical efficiency also enhances accuracy when comparing firms' managerial performance. In order to illustrate this assertion, let us have a look at decision-making units  $D$  and  $E$ , which use the same amount of input  $x$  to produce an identical quantity of output  $y$ . Conventional evaluation of efficiency would award both firms the same score of output-oriented technical efficiency (in both cases the *efficient* unit of reference is  $C$ ), even though they are producing rather distinct levels of quality. In contrast, quality-adjusted efficiency measurement would assign these decision-making units different scores of technical

performance, the divergence capturing differences of quality. As can be readily observed in *Figure 1*, the output distance of decision-making unit *E* from the technological frontier is rather different to that for unit *D*, as a consequence of the difference in quality between both firms.

Now that the main insights into the methodology have been explained, next section is devoted to describing the sample and the dataset used. Following this, the empirical results are presented and discussed.

### ***3. The water industry in Andalusia: sample and data description.***

The assessment of performance we carry out in this paper is based on a set of thirty-eight water utilities located in the Spanish region of Andalusia. The data come from a comprehensive survey performed by the authors with the support and funding of the *Agencia Andaluza del Agua*, and refer to 2001. The utilities in our sample provide water services to one hundred and thirty-six municipalities and more than four million inhabitants, covering over fifty per cent of the region's population.

Andalusia is located in the South of Spain and occupies about 15 per cent of the Iberian Peninsula. Nowadays, the region faces a worrying process of desertification and increasing water shortage, most likely due to climatic change, and desert conditions are advancing gradually in the Southeast. Furthermore, the last two decades have seen an increasing demand for water sparked by extraordinary urban development, most of which has taken place on the coast (Andalusia has 1,101 kilometres of coastline). Growing urbanization is being boosted, to a large extent, by an increasing influx of tourism and the arrival of many citizens from the Centre and North of Europe that, attracted by the mild climatic conditions of the Spanish Mediterranean coast, are establishing their second residence in Andalusia. Both water scarcity and increasing demand have turned efficient management of this natural resource into a pressing need.

As regards the characterisation of the productive process of water utilities, three outputs have been considered: water delivered, collected sewage and treated sewage, all measured in cubic meters. Inputs are: delivery network, sewer network (both measured in kilometres), labour (number of workers) and finally, operational costs (measured in thousands of euros) as an intermediate production factor. Some descriptive statistics for the data are included in *Table 1*.

*Insert Table 1 about here*

Unlike most of the previous empirical work on the technical efficiency of water utilities, a noteworthy feature of our dataset is that utilities are considered as multi-output firms producing the three services that integrate the urban water cycle<sup>5</sup>. The first service is the distribution of water, previously treated to make it suitable for urban consumption. The second service is sewage collection and the third consists of treating sewage to be either returned to the environment minimising its environmental impact or re-entered in the water cycle, e.g. to irrigate golf courses. In our sample, 20 water utilities provide the three services that integrate the urban water cycle, 6 utilities provide the services of water delivery and sewage collection, while the remaining 12 firms only deliver water. Additionally, one feature that makes our estimates of technical performance much easier to interpret is that outputs and most inputs are measured in physical units.

Moreover, two variables that are representative of the quality of the service provided by water utilities have been included: *tests for water quality* that measure the frequency of sanitary controls to verify the suitability of water for human consumption, and *unaccounted-for water* that measures water losses along delivery pipelines. On the one hand, information about the number of sanitary controls comes from the *Encuesta de Infraestructuras y Equipamientos Locales*

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<sup>5</sup> Existing literature dealing with the technical efficiency of water utilities has mostly considered utilities as single-output firms, providing the service of water supply. Only recent studies have included collected sewage and/or the amount of water treated as additional water company outputs (Estache and Trujillo, 2003; Tupper and Resende, 2004; Picazo-Tadeo *et al.*, 2007b).

(*Local Infrastructure and Equipment Survey*) elaborated by the *Spanish Ministerio de Administraciones Públicas*. This source of information provides data on the frequency of sanitary controls on a municipal scale, indicating whether controls are performed daily, every two days, weekly, fortnightly, and so forth. Using this information, we have constructed the variable *tests for water quality* for each water utility in the sample as the gap, in hours, between sanitary controls<sup>6</sup>. For utilities supplying water services to several municipalities, a population-weighted average has been computed. No municipality is supplied by more than one water utility. On the other hand, figures on unaccounted-for water share the same source as the data on inputs and outputs, and have been computed as the quantity of water lost along delivery pipelines expressed as a fraction of the total amount of water supplied. Averages and other descriptive statistics for quality variables are included in *Table 1*.

Let us now comment on how suitably these variables represent the quality dimension of water utility services in the Spanish region of Andalusia. In the water industry, the variables representing service quality might differ considerably from one country to another. In some developing countries, where low coverage rates and near-to-the-ground service quality characterise the water industry, service coverage, service continuity or the percentage of water receiving chemical treatment are adequate variables to measure water quality. However, in industrialised countries where water services cover nearly all the population and water quality reaches higher standards, alternative measures of quality are required<sup>7</sup>.

As in other developed countries, almost one hundred per cent of the water supplied by water utilities in Spain has been previously analysed and chemically treated to ensure its suitability for human consumption. Consequently, there is not point analysing the percentage of water under

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<sup>6</sup> This variable will take a value of twenty-four for water utilities that test quality daily, forty-eight for utilities performing a control every two days and so forth.

chemical treatment to assess quality<sup>8</sup>. Alternatively, the frequency of sanitary controls provides a more adequate variable to proxy water quality. Reducing the gap between controls to test for the quality of water unambiguously diminishes the risk of water contamination and, therefore, the probability of catching diseases from drinking contaminated or bad quality water. Water utilities in our sample perform, on average, a sanitary control every 28 hours and many firms test the quality of water on a daily basis. Other papers have used very similar variables to account for the quality of water services (Fox and Hofler, 1986). Concerning the opportunity cost for water utilities of controlling for water quality, it is evident that performing quality tests consumes resources, such as expenditure on chemical products, workers required to perform sanitary controls, among others, that could otherwise be used to increase the quantity of service produced. In other words, there is a clear trade-off between quantity and quality.

The suitability of our second variable, *unaccounted-for water*, to measure water quality requires more detailed comments. Unaccounted-for water is defined, as previously noted, as the fraction of the total amount of water supplied which is lost from pipelines due to inadequate maintenance and, also, illegal connections. The average unaccounted-for water ratio for the water utilities in our sample is 25.9 per cent. This variable has been employed in several papers to proxy the quality of water services (Antoinioli and Filippini, 2001; Garcia and Thomas, 2001; Tupper and Resende, 2004; Lin, 2005; Kirkpatrick *et al.*, 2006). Furthermore, Coelli *et al.* (2003) regards water loss as an indicator of the technical quality of the service. In the particular case of the Andalusian water industry, unaccounted-for water might also represent, in our opinion, service quality from a social perspective.

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<sup>7</sup> Batteries of indicators of the service provided by water utilities, including variables representing service quality, can be found in Parena *et al.* (2002), Matos *et al.* (2003), and Alegre *et al.* (2006).

<sup>8</sup> The characteristics and intensity of the chemical treatment undertaken differs across municipalities, which would allow us to construct a variable representing the quality of water services. However, we do not have this information.

In Spain, the lack of expenditure on pipeline maintenance on behalf of water utilities has been repeatedly denounced. This behaviour has proved to be a profitable strategy from a managerial perspective (González-Gómez, 2005). The reason is that, given the low price of water, it becomes more profitable for utilities' managers to incur higher expenses derived from the acquisition, treatment and pumping of water that will actually be lost along the pipelines, than to invest the funds necessary to maintain and repair delivery pipelines. Recent results by Picazo-Tadeo *et al.* (2007a) provide this assertion with empirical support. Making use of our source of data on Andalusian water utilities, this paper finds that the magnitude of unaccounted-for water exercises a negative and statistically significant effect on the operational costs of water utilities, so that costs are lower in the case of utilities that suffer the largest water losses along pipelines. Obviously, although profitable from a managerial or *private* perspective, this behaviour has the non-negligible *social cost* of wasting water in a territory where both desertification and water scarcity, in addition to an increasing demand for this natural resource, have turned efficient management of water into a pressing need.

Furthermore, from previous arguments it immediately follows that, for Andalusian water utilities, avoiding expenditure necessary to maintain pipelines, thus increasing water losses and lowering the quality of the service (or, in other words, increasing bad quality), liberates productive resources endowed with an opportunity cost, i.e. resources that can be used to increment the quantity of water services produced. Again, the trade-off between quantity and quality appears.

#### ***4. Empirical results and discussion***

Estimates of conventional quantity-based and quality-adjusted technical performance have been computed by solving programs (4) and (7), respectively. Results are summarised in *Table 2*. Quality-adjusted performance has been assessed under two different scenarios concerning the variables representing quality. In the first scenario the quality dimension is introduced considering

only the variable tests for water quality, while the second one includes both tests for water quality and unaccounted-for water. Both scenarios are labelled as quality-adjusted model 1 and 2, in that order. As they have been defined, both variables representing the quality dimension of water services account for bad quality attributes, i.e. the greater the gap between sanitary controls or the higher the amount of unaccounted-for water, the worse the quality of the service.

*Insert Table 2 about here*

Before commenting on these results, let us mention that *DEA* is a deterministic approach to efficiency measurement that produces results which tend to be sensitive to measurement errors and outliers, particularly if these observations are shaping a portion of the frontier. In order to test the influence of this potential problem in our estimates of technical efficiency, we have verified that they do not depend on a reduced number of utilities repeatedly shaping the frontier, but rather on a set of water utilities enveloping two or more times the behaviour of other utilities in the sample<sup>9</sup>. The number of utilities acting as a reference ranges from eight in the computation of conventional quantity-based scores of efficiency to eighteen for the second quality-adjusted model.

Let us now comment on our quantity-based estimates of technical performance. The mean of the individual scores of conventional output-oriented technical efficiency is 0.713, with eight firms behaving efficiently. In other words, the water utilities in our sample are producing, on average, 71.3 per cent of their potential output, i.e. the output they could attain from their endowment of inputs by behaving efficiently. Technical efficiency of Andalusian water utilities could be further analysed by performing additional calculations, e.g. analysing the magnitude of slacks in outputs and their contribution to potential non-radial output increases. However, as this issue is not the main concern of our paper, we leave it for future research.

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<sup>9</sup> Considering water utilities acting two or more times as a reference for other utilities in the sample, allows us to exclude *self evaluators*, i.e. efficient firms that do not act as a benchmark for any unit except for themselves.

As regards the quality-adjusted scores of technical efficiency, the averages for models 1 and 2 are 0.846 and 0.889, respectively. In both cases, the increment in average technical efficiency with respect to conventional performance assessment when variables of quality are omitted, represents the opportunity cost of maintaining the quality of the water service, in terms of potential output losses<sup>10</sup>. In other words, maintaining observed levels of quality consumes productive resources, thus lowering the quantity of output that utilities could achieve from their endowment of inputs in the case of being technically efficient.

In order to reinforce the economic interpretation of these results, we have randomly chosen water utility number two in our sample as an example. Conventional quantity-based evaluation of technical performance for this utility yields a score of 0.906, indicating that, given its consumption of inputs, it is producing 90.6 per cent of its potential output, regardless of the level of quality achieved at the projection on the efficient frontier that determines this potential output. Conversely, forcing this utility to maintain the observed frequency of tests for water quality, it currently performs sanitary controls every twenty-four hours, increases its score of technical efficiency to 0.91 (potential output is reduced, as some productive resources must be unavoidably devoted to *producing quality*). Finally, the score of output-oriented technical efficiency when this water utility is forced to maintain both the frequency of sanitary controls and water losses at their observed levels is 0.934, indicating that, conditioned by its observed quality, the utility is producing 93.4 per cent of its potential output.

Returning to the main objective of this paper, the relevant question was: does service quality matter in measuring the performance of water utilities? In accordance with our results, the answer is that quality matters, as shown by the difference between conventional quantity-based and

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<sup>10</sup> In *DEA*, it is well known that when the set of restrictions relative to the number of observations and variables increases, the number of efficient units also tends to augment, as a consequence of the

quality-adjusted assessments of technical performance. Nonetheless, we have evaluated the statistical significance of this difference by performing a simple *t-test* for equality of means, in addition to the non-parametric *Wilcoxon signed-rank* test for equality of distributions. Besides, the *Spearman correlation* test has been used to test whether water utilities in the sample rank differently according to their conventional and quality-adjusted evaluations of performance. Efficiency estimates involve a certain number of ones, i.e. scores of efficient water utilities showing best observed behaviour, creating ties in the calculation of ranks. In order to overcome this difficulty, we have established a ranking of the efficient utilities in accordance with their importance as benchmarks measured as the number of times they act as a referent for other inefficient utilities (Charnes *et al.*, 1985). The results are presented in *Table 3*, where the conventional estimates of efficiency are always the reference of comparison.

*Insert Table 3 about here*

According to the results for the t-tests of equality of means, the difference between conventional and quality-adjusted scores is statistically significant for both models (model 1 and 2), with a confidence level of 99 per cent (*p-values* are negligible). The results from the Wilcoxon test indicate that the distributions of conventional and quality-adjusted scores of technical efficiency are, also at the 99 per cent confidence level, statistically different. However, from the results of the Spearman test we reject, at standard confidence levels, the hypothesis that conventional and quality-adjusted evaluations of performance lead to statistically different rankings of water utilities (*p-values* are 0.000 and 0.074 for quality-adjusted models 1 and 2, respectively). In other words, our water utilities do not seem to rank differently when ordered according to either their conventional evaluation of technical performance or their quality-adjusted

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enlargement of the number of *self evaluators*. This circumstance might also be contributing to elevate averages of quality-adjusted scores of technical efficiency.

scores of technical efficiency. From this latter result, it follows that managerial abilities still continue to play an important role in determining the technical efficiency of Andalusian water utilities.

In essence, our results here about the effect of introducing the quality dimension in non-parametric *DEA*-based analyses of water utilities performance, basically coincide with those of Lin (2005) in a parametric efficiency analysis framework. In both scenarios, omitting quality might be offering a biased picture of performance, as quality-adjusted assessment of performance provides a better valuation of water utilities performance. Furthermore, measures of performance adjusting for quality could be of certain usefulness for utilities' managers and policy-makers. In the case of the Andalusian water industry, we also believe that our outcomes might have some interest from a social perspective.

From a managerial perspective, achieving a better understanding of the cost of maintaining quality and the nature of the existing trade-off between quality and quantity should help to improve the management of utilities. Evaluation of performance accounting for the quality dimension of water services might also be of some use to politicians. According to Spanish legislation, municipalities have the ultimate responsibility of water service provision, although the management of most water utilities has been delegated to private managers. Therefore, a quality-adjusted valuation of performance would provide local governments with meaningful information to reach a better design of public policies concerning the regulation of the water industry. Finally, in light of the fact that our measures of quality account for an essential social concern in Andalusia: the efficient management of water in a territory where water is a scarce natural resource subject to increasing demand, identifying utilities that employ better water management practices also has a certain interest for the society as a whole.

## ***5. Summary and concluding remarks***

Empirical literature on the measurement of water utilities' performance runs into tens of papers, although most of them have omitted quality as a relevant dimension of water services. Omitting quality can affect the results of efficiency comparison, and water utilities termed as inefficient on the basis of a conventional *quantity* criterion, might well be efficient under a *quality* criterion. This manuscript contributes to the existing literature in this field of research by using *Data Envelopment Analysis* to compute both conventional quantity-based and quality-adjusted scores of technical efficiency for a sample of Spanish water utilities located on the Southern region of Andalusia. The key assumptions made are that a lack of quality (bad quality) can be regarded as an undesirable output, and that a trade-off between quantity and quality exists, in that *producing quality* requires the use of resources that can be made available by reducing the quantity of output produced.

The quality dimension of the service of water utilities has been incorporated through a couple of variables that represent the frequency of sanitary controls to verify the suitability of water for human consumption and the amount of unaccounted-for water, respectively. The latter, i.e. water lost along pipelines, allows us to incorporate in our analysis an assessment of the quality of water services from a social perspective, a crucial dimension in a territory where increasing water scarcity is turning efficient management of this natural resource into a pressing need.

Our foremost findings are as follows. First, conventional assessment of managerial performance ignoring quality reveals, let us say, a *moderate* degree of technical inefficiency. Second, introducing the quality dimension into the analysis significantly increases the average scores of technical performance, the difference with regard conventional assessment representing the opportunity cost of maintaining quality. Third, the distributions of conventional quantity-based and quality-adjusted scores of technical efficiency are statistically different, although water utilities in our sample do not rank differently when they are ordered in accordance with both evaluations of performance. All these results can be summarised in an overall conclusion: quality matters when

measuring the technical performance of water utilities. Accordingly, future research on performance evaluation of the water industry should take into account the quality dimension of the service provided by water utilities.

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Figure 1. The production possibilities set.

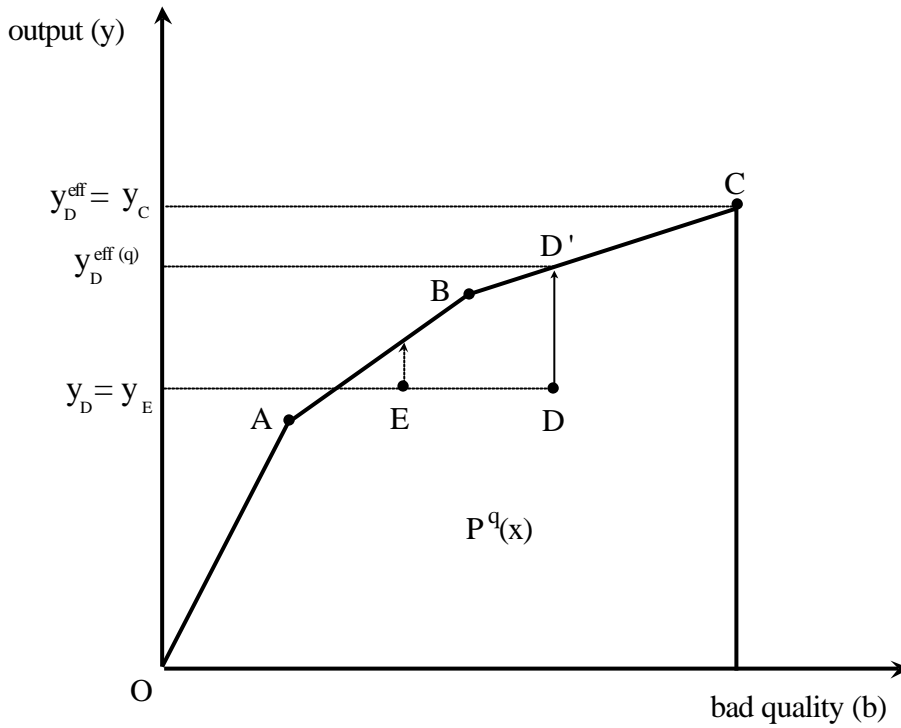


Table 1. Sample description

Variable	Measurement	Mean	Standard		
			deviation	Maximum	Minimum
<i>Outputs</i>					
Water delivered	Thousands of m <sup>3</sup>	9,435	16,803	84,800	212
Collected sewage	Thousands of m <sup>3</sup>	8,722	20,778	108,666	0
Treated sewage	Thousands of m <sup>3</sup>	7,979	20,948	108,666	0
<i>Inputs</i>					
Delivery network	Kilometres	362	564	2,877	5
Sewer network	Kilometres	213	377	1,855	0
Labour	Number of workers	81	135	732	2
Operational costs	Thousands €	4,258	6,476	33,648	99
<i>Quality variables</i>					
Tests for water quality	Gap in hours	28	7	82	24
Unaccounted-for water	Percentage	25.9	7.1	42.0	9.6

Table 2. Conventional and quality-corrected estimates of output-oriented technical efficiency

	<i>Mean</i>	<i>Standard deviation</i>	<i>Maximum</i>	<i>Minimum</i>
Conventional	0.713	0.246	1	0.243
Quality-adjusted (model 1)	0.846	0.211	1	0.316
Quality-adjusted (model 2)	0.889	0.189	1	0.321

Table 3. Some tests of hypothesis of the difference between conventional quantity-based and quality-adjusted scores of technical efficiency<sup>(1)</sup> (*p-values* in parenthesis)

	t-test <sup>(2)</sup> <i>t-statistic</i>	Wilcoxon test <sup>(3)</sup> <i>Z-statistic</i>	Spearman test <sup>(4)</sup> <i>r-Spearman</i>
Quality-adjusted model 1	-4.161 (0.0002)	-4.797 (0.0000)	0.6130 (0.0000)
Quality-adjusted model 2	-4.577 (0.0001)	-4.858 (0.0000)	0.2932 (0.0740)

(1) The reference is always the conventional assessment of technical efficiency.

(2) The null hypothesis is the equality of means.

(3) In this case, the null hypothesis is that both distributions are the same.

(4) The null hypothesis is that both variables are independent.