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The role of environmental factors in water utilities' technical efficiency. Empirical evidence from Spanish companies.

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Abstract.- *This paper computes input-specific scores of technical efficiency for a sample of water utilities located in the southern Spanish region of Andalusia. In addition, differences in efficiency between different operating environments are investigated. Concerning the debate about ownership and efficiency, we find that privately owned companies outperform public utilities in their management of labour. Furthermore, technical efficiency is found to be greater among firms located in highly populated areas and for utilities providing water services to tourist municipalities. Finally, no empirical evidence supporting the greater technical efficiency of consortia of water utilities, a managerial strategy strongly encouraged by regional politicians, is found.*

Keywords: *input-specific technical efficiency; Andalusian water utilities; operating environments; privatisation; consortia of water utilities.*

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1.- Introduction

Efficiency and productivity measurement is a long-standing issue of study in the field of economics. Furthermore, from the eighties onward several papers have focused on assessing efficiency in the provision of water services. Existing literature on water utilities has mostly dealt with cost efficiency, a minority of studies being aimed at examining technical efficiency (the seminal paper by Farrell, 1957 provides precise definitions of these concepts). Among the latter, some papers have used mathematical programming and non-parametric techniques (Byrnes *et al.*, 1986; Lambert *et al.*, 1993; Anwandter and Ozuna, 2002; Tupper and Resende, 2004; Woodbury and Dollery, 2004), while some others have followed econometric approaches (Bhattacharyya *et al.*, 1995b; Jones and Mygind, 2000; Ménard and Saussier, 2000).

In this paper, we assess the technical performance of a sample of water utilities located in the southern Spanish region of Andalusia. Using non-parametric techniques and activity models, a set of input-specific scores of technical efficiency is computed at the firm level. It is widely accepted that production performance in water utilities is influenced by the skills of firms' managers in organising production activities, but also by the characteristics of the environment in which production activities are carried out (Ashton, 2000; Tupper and Resende, 2004). Our hypothesis here is that environmental variables might affect the technical management of different production factors in different ways. In order to shed some light on this matter, in a second part of our study several hypotheses tests, including some non-parametric ones, are used to test for differences of input-specific scores of technical efficiency among water utilities categorised by different operating environments.

This manuscript contributes to the current strand of literature in several directions. On the one hand, it provides empirical evidence as to certain water utilities' features and environmental variables likely to affect technical management of specific production factors. Beyond their academic interest, these findings might provide firms' managers and policy-makers with meaningful information to improve the design of both management of water utilities and water policies. On the other hand, as far as we know, our paper is pioneering in its focus on efficiency of water management in the Spanish region of Andalusia.

Andalusia is located in the south of the Iberian Peninsula and occupies slightly less than 20 per cent of the territory of Spain. In recent decades, the region has faced a process of increasing desertification, most likely due to climatic change, and an alarming water shortage. Besides, in recent years there has been an increasing demand for water in which traditional uses compete with new urban and recreational uses, e.g., golf courses, motivated by growing urbanization in the region, specially along the seacoast (Andalusia has 1,101 kilometres of coast), but also by a massive influx of tourism. Even more, many European citizens are fixing their second residence on the Spanish Mediterranean coast. Both desertification and water scarcity, in addition to an increasing demand for this natural resource, have turned efficient management of water in Andalusia into a pressing need.

Furthermore, during recent decades important changes in the structure of the Andalusian water industry have been taking place. During the second half of the eighties and also in the nineties of the last century, many municipalities transferred the management of municipal water utilities to private managers. Besides, both local and regional governments gave enthusiastic support to the creation of consortia of water companies aimed at providing water services to a geographical area integrated by several municipalities. Strong support for these managerial strategies was chiefly based on the argument that they would lead to important gains in efficiency and productivity. Privatisation and formation of consortia of water companies in Andalusia continue to occur, even though no empirical studies currently exist supporting the alleged benefits of these processes. The few studies carried out on water provision in Andalusia have mostly focused on small areas of the regional geography, mainly the city of Seville, dealing with aspects like water demand (Martínez-Espiñeira, 2003; Martínez-Espiñera and Nauges, 2004) or optimal pricing policies (García-Valiñas, 2005).

The remainder of the manuscript is organised as follows. Section two deals with the methodology. Sections three and four describe the data and the results, respectively. Finally, section five concludes.

2.- Methodological issues.

Our aim in this paper is, as mentioned, to compute a set of scores of input-specific technical efficiency at the firm level. In doing so, we use the methodological approach suggested by Torgersen *et al.* (1996) and *Data Envelopment Analysis* techniques (*DEA*). *DEA* was introduced by Charnes *et al.* (1978) in a pioneering paper that used mathematical programming to pursue Farrell's approach to technical efficiency measurement (Farrell, 1957). This contribution to a then new body of literature has, to date, produced a wealth of contributions in multiple fields of research. Gattoufi *et al.* (2004) review the empirical literature on *DEA*, and Thanassoulis (2000a, 2000b) highlights its usefulness for analysing efficiency in water companies. In essence, *DEA* evaluates the performance of peer units allowing the construction of a *surface* over the data that permits the observed behaviour of a decision-making unit to be compared with best observed practices. Further details on *DEA* are in Cooper *et al.* (2004).

Many studies dealing with the assessment of technical performance of decision-making units have computed single radial Farrell-type measures of efficiency, using the standard formulation of *DEA*. Nevertheless, at times, and particularly in the case of samples with small size relative to the number of input and output dimensions, the extent of inefficiency cannot be fully assessed by computing radial measures only, but also *slacks* need to be considered in order to provide a complete picture of firms' performance. Torgersen *et al.* (1996) suggested a two-step procedure to distinguish decision-making units that are *radially* efficient, i.e., efficient in a Farrell-Debreu sense, but inefficient in some input or output dimension, from efficient decision-making units in a Pareto-Koopmans sense (Koopmans, 1951). For an input-orientation, this paper develops measures of efficiency that extend the traditional radial efficiency measures to account for potential input shrinkages due to both proportional reductions and slack adjustments[1].

In order to develop the main insights of this methodology, let us consider that we observe a set of $k = 1,\ldots, K$ decision-making units that use a vector x of $n = 1,\ldots,N$ inputs to produce a vector y of $m = 1,\ldots,M$ outputs. The first step is to identify the efficient subset of decision-making units by solving the following set of linear programming problems, one for each decision-making unit k' in the sample (Charnes *et al.* 1985):

$$
\begin{array}{llll}
Max_{s^x_{nk'},\, s^y_{mk'},\, z_k} & s_{k'} = \sum_{n=1}^{N} s^x_{nk'} + \sum_{m=1}^{M} s^y_{mk'} & & \\
\text{subject to:} & x_{nk'} - \sum_{k=1}^{K} z_k x_{nk} = s^x_{nk'} & n = 1,\ldots,N & (i) \\
 & \sum_{k=1}^{K} z_k y_{mk} - y_{mk'} = s^y_{mk'} & m = 1,\ldots,M & (ii) \\
 & \sum_{k=1}^{K} z_k = 1 & k = 1,\ldots,K & (iii) \qquad (1) \\
 & z_k \geq 0 & k = 1,\ldots,K & (iv) \\
 & s^x_{nk'} \geq 0 & n = 1,\ldots,N & (v) \\
 & s^y_{mk'} \geq 0 & m = 1,\ldots,M & (vi)
\end{array}
$$

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. In addition, y_{mk} and x_{nk} stand for the observed output m and input n of decision-making unit k, respectively.

The set of constraints in program (1) characterises an output set with variable returns to scale satisfying the properties of strong disposability of inputs and outputs, convexity,

[1] Several other methodological approaches have also been proposed to compute input-specific reductions required to attain full (radial and non-radial) technical efficiency (Färe and Lovell, 1978, Färe *et al.*, 1983, Zieschang, 1984, Bogetoft and Hougaard, 1998 and Asmild *et al.*, 2003). The difference between approaches is, primarily, the choice of the reference point on the frontier.

and the condition that all observations are in the set (see Grosskopf, 1986 for further details on the characterisation of the technology). Based on the solutions to program (1), the efficient subset of observations *H* is defined as the set of decision-making units having no slacks, neither in inputs (s^x_{nk}) nor in outputs (s^y_{mk}):

$$H = \left(k \in K \,\middle|\, s_k = 0\right) \qquad (2)$$

In a second-step, the input-efficiency measure for each decision-making unit $k = 1,\dots,K$ in the sample is computed from a linear programming problem analogous to the conventional *BCC* model (Banker *et al.* 1984), where the full set of observations is replaced by the reference subset of efficient decision-making units *H*. Formalising for firm *k'*:

$$\begin{aligned}
&Min_{\theta_{k'},z_k}\ \theta_{k'} \\
&\text{subject to:}\quad \theta_{k'} x_{nk'} - S^x_{nk'} = \sum_{k=1}^{H} z_k x_{nk} && n = 1,\dots,N && (i) \\
&\qquad y_{mk'} + S^y_{mk'} = \sum_{k=1}^{H} z_k y_{mk} && m = 1,\dots,M && (ii) \\
&\qquad \sum_{k=1}^{H} z_k = 1 && k = 1,\dots,H && (iii) \qquad (3) \\
&\qquad z_k \ge 0 && k = 1,\dots,H && (iv) \\
&\qquad S^x_{nk'} \ge 0 && n = 1,\dots,N && (v) \\
&\qquad S^y_{mk'} \ge 0 && m = 1,\dots,M && (vi)
\end{aligned}$$

The parameter θ obtained as the solution to program (3) measures the maximal feasible proportional reduction of all inputs that could be achieved by each decision-making unit in the sample without decreasing its level of outputs, i.e., it assesses conventional *Farrell*-type input-oriented technical efficiency at the firm level. Nevertheless, once the maximum proportional shrinkage of all inputs has been attained, additional input-specific reductions may still be feasible in some input directions, while maintaining the vector of outputs. These additional shrinkages are measured through the *slacks in inputs* (S^x_{nk}), which can be computed directly at the input level from the optimal solution to program (3) and the set of restrictions in (3i).

Prior to computation of input-specific scores of technical efficiency, both aggregate input savings and the *efficient* use of inputs need to be calculated. The aggregate saving of input *n* needed to bring decision-making unit *k'* into a *Pareto-Koopmans* efficient status is computed by adding up radial contractions and input-specific slacks:

$$x_{nk'}^{saving} = \left(1 - \theta_{k'}\right) x_{nk'} + S_{nk'}^{x} \quad (4)$$

The first term on the right hand side of expression (4) measures maximum attainable reduction of input *n* due to the radial contraction of the productive plan of firm *k'* towards the frontier, while the second term quantifies the input excess in the direction of this production factor. Likewise, the efficient use of input *n* is computed by subtracting the aggregate saving of input *n* from its observed use, yielding:

$$x_{nk'}^{efficient} = x_{nk'} - \left[\left(1 - \theta_{k'}\right) x_{nk'} + S_{nk'}^{x}\right] = \theta_{k'} x_{nk'} - S_{nk'}^{x} \quad (5)$$

Finally, the slack-adjusted input-oriented technical efficiency (*SAITE*) for decision-making unit *k'* and input *n* is computed as the quotient between the efficient use of that input and its actually observed use:

$$SAITE_{nk'} = \frac{x_{nk'}^{efficient}}{x_{nk'}} = \theta_{k} - \frac{S_{nk'}^{x}}{x_{nk'}} \quad (6)$$

By construction, this measure of input-oriented technical efficiency is upper-bounded to one. Decision-making unit *k'* will make an efficient use of input *n* when its computed score of technical efficiency for that input equals one, i.e., no reduction of that input is feasible without decreasing any output. Conversely, input-specific technical inefficiency results in computed efficiency scores of less than one: the smaller this score, the lower the level of technical efficiency.

Including slacks in the measurement of technical efficiency reveals the full potential for improving firms' performance. As noted, when the number of dimensions is large relative to the number of observations, slacks might be picking up an important part of total potential input savings, and input-specific measures of efficiency provide a substantially enhanced picture of performance. The importance of slacks in explaining input-specific technical efficiency can be assessed by computing the weighting of non-radial input savings, i.e., those due to slacks, on total input savings. Formalising:

$$\sigma_n = \frac{\sum_{k=1}^{K}\left(x_{nk}^{radial} - x_{nk}^{efficient}\right)}{\sum_{k=1}^{K}\left(x_{nk} - x_{nk}^{efficient}\right)} = \frac{\sum_{k=1}^{K}\left(S_{nk}^{x}\right)}{\sum_{k=1}^{K}\left[\left(1-\theta_k\right)x_{nk} + S_{nk}^{x}\right]} \tag{7}$$

$x_{nk}^{radial} = \theta_k x_{nk}$ being the use of input *n* by decision-making unit *k* that would result from the radial contraction of its vector of inputs toward the frontier.

3.- Data description.

The dataset we use in this paper corresponds to a sample of water utilities located in the southern Spanish region of Andalusia. The data were collected from a comprehensive survey made by the authors with support and funding from the *Agencia Andaluza del Agua* of the regional government of Andalusia, and they correspond to the year 2001. The survey was initially conducted on sixty-five water utilities, forming the vast majority of utilities in the region. Unfortunately, some companies did not answer the survey, while some others provided incomplete information about some relevant variables for our study. Lack of response or deficient information reduced our sample to thirty-four utilities, providing water services to more than one hundred municipalities and nearly four million inhabitants, covering almost fifty per cent of the population in the region.

Concerning the characterisation of the productive process of water utilities, three outputs were 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, an intermediate input consisting of ground, surface and purchased water (in cubic meters). *Table 1* provides some descriptive statistics of the data.

Insert Table 1 about here

An interesting feature of this dataset that lends a certain added value to our research is that, unlike most of the previous empirical work, water utilities are considered as multi-output firms producing the three main services or phases that integrate the urban water cycle. The first of these services is the distribution of water, which has been previously acquired and chemically treated to make it suitable for urban consumption. The second service is sewage collection, while the third service consists of treating sewage either to be delivered to the environment minimising its environmental impact or to be re-entered into the water cycle. Multi-output approaches are more usual in assessing cost efficiency, whereas previous literature dealing with technical efficiency has mostly considered water utilities as single-output firms providing the service of water delivery[2]. Fifty per cent of the water utilities in our sample provide the three services considered, while of the remaining companies 11 provide only the service of water delivery and 6 the services of water delivery and sewage collection.

Finally, our dataset presents a couple of additional characteristics that enhance its usefulness in performing the analysis we carry out in this paper. On the one hand, outputs and inputs are all measured in physical units, greatly facilitating the economic interpretation of our estimates of technical efficiency. On the other hand, the source of data provides a wide-ranging set of information on firms' features and other environmental variables, which are used to investigate the factors that could be related to differences among water utilities in respect of their technical efficiency.

[2] Only recent studies have included collected sewage or the amount of water treated, in addition to water delivered, as outputs of water companies (Estache and Trujillo, 2003, Tupper and Resende, 2004).

4.- Empirical results and discussion.

4.1.- Measurement of technical efficiency.

The purpose of this section is to present and discuss our estimates of input-oriented technical performance for the thirty-four water utilities in the sample. Radial scores of input-oriented technical efficiency and slacks in inputs have been worked out by solving program (3), using the reference subset of efficient decision-making units of expression (2). Furthermore, slack-adjusted input-oriented scores of technical efficiency have been calculated according to expression (6). *Table 2* presents some descriptive statistics for both radial and input-specific measures of technical efficiency, in addition to a measure of the importance of slacks computed using expression (7).

Insert Table 2 about here

Concerning the computed radial scores of efficiency, our results suggest that, on average, the water utilities in the sample could reduce equiproportionally their consumption of inputs by nearly 5 per cent, while maintaining their levels of outputs, i.e., the radial index of technical efficiency is 0.952. The means of slack-adjusted scores of input-oriented technical efficiency are, as they should be by construction, smaller than the average of radial efficiency. Sample averages for delivery network, sewer network, labour, and the intermediate input consisting of ground, surface and purchased water, are 0.885, 0.781, 0.894 and 0.951, respectively[3]. In addition, the standard deviations are noticeably larger than that computed for the radial measure. These outcomes show that

[3] In order to facilitate the economic interpretation of these indices, let us take water utility number two in our sample and input labour as an example. This decision-making unit employs 130 workers. According to its computed score of radial input-oriented technical efficiency, which is equal to 0.855, it could reduce its use of labour by 14.5 per cent, which implies a reduction of 19 workers. In addition, computed input excess in labour for this utility would allow for a further shrinkage of 14 employees. In consequence, adding up radial reduction and input-specific excess, the aggregate reduction in labour necessary to achieve technical efficiency amounts to 33 workers, so that the efficient use of this input is 97 workers. Finally, the slack-adjusted score of technical efficiency for this water utility arises from the comparison of its efficient use of labour with actually observed use of this production factor, yielding a score of 0.747.

greatest inefficiencies arise in the use of the sewer network, i.e., the average maximum attainable reduction of this production factor reaches 21.9 per cent, while the most efficient management corresponds to ground, surface and purchased water, where potential saving reaches an average close to 5 per cent.

As to the importance of slacks in explaining the aggregate potential saving of inputs, our results show that, excluding the input consisting of ground, surface and purchased water, non-proportional potential reductions explain more than fifty per cent of total feasible input savings, a percentage that reaches 70 per cent for the sewer network. Furthermore, all inefficient decision-making units have at least one slack in some input direction. In other words, computing input-specific measures of technical efficiency, instead of a single radial score of input-oriented technical efficiency, manifestly improves the assessment of technical performance in our sample of Spanish water utilities. In addition, computation for each utility in the sample of a set of scores of technical efficiency at the input level allows us to test whether environmental variables affect the management of different production factors in different ways.

4.2.- Technical efficiency and environmental variables.

Empirical literature in the field of efficiency measurement has habitually performed two-stage analyses to investigate, in the second stage, the factors related to firms' efficiency scores obtained in the first stage. In performing the second stage, two primary methodological approaches have been followed. The most common approach involves using regression analysis, e.g., censored Tobit regression or ordinary least squares after transforming estimates of efficiency, to find out any factors capable of explaining efficiency differences among decision-making units. Nonetheless, this procedure presents important shortcomings. From a conceptual view, Grosskopf (1996) noted that if the variables in the second-stage regression were (obviously) expected to have an effect on performance, they should have been included in the original first-stage model. Furthermore, from a technical standpoint, Simar and Wilson (2006) show that second-stage analyses based on regressing first-stage *DEA* efficiency estimates against a set of explanatory variables may lead to wrong results, mainly because of the serial correlation of the first-stage *DEA* estimates and the correlation between the error term and the set of covariates in the second stage.

The second approach entails grouping firms according to some specific features or environmental variables that seem likely to be related to efficiency, and then checking for the existence of statistically significant differences among groups as to their computed scores of efficiency, e.g., using non-parametric tests of hypotheses. Our choice here is to follow this second approach, and test for significant differences among technical efficiency scores between water utilities categorised according to several operating environments. In order to do this, a simple *t-test* for equality of means, in addition to two non-parametric tests, the *Kolmogorov-Smirnov* distribution test (*KS*) and the *Mann-Whitney* ranksum test (*MW*), are used (Conover, 1999 provides details on these non-parametric tests).

There is no formal theory as to what the determinants of differences in firms' performance should be. From a practical viewpoint, there are some features and environmental variables that could help to explain such differences, including managerial skills, the degree of competition faced, agency objectives or the regime of ownership. The variables included in our second stage are drawn from previous literature, and also from our own beliefs regarding these factors in the case of water utilities. Furthermore, some of our environmental variables have been included in order to investigate any efficiency gains derived from certain managerial strategies strongly supported by local and regional authorities in Andalusia, among them the privatisation of water companies and the creation of consortia of utilities. Obviously, our set of environmental variables is also conditioned by the availability of statistical information.

The environmental variables are as follows. *Ownership*, which is a variable that distinguishes private water utilities from publicly owned companies. *Services supplied*, which separates utilities providing all three services of the urban water cycle, i.e., water delivery, sewage collection and sewage treatment, from the rest of the utilities in the sample. *Density of population*, making a distinction between utilities providing water services to areas of high density of population from those supplying low density areas[4]. *Number of municipalities supplied*, differentiating firms supplying a geographical area integrated by several municipalities from utilities that provide water services to only one municipality. Finally, *tourism index* is a variable aimed at differentiating firms located in tourist areas from utilities providing services to non-tourist municipalities[5].

Averages of radial scores of firms' technical efficiency according to operating environments, and results from the *t-tests* for equality of means and the *KS* and *MW* tests, are reported in *Table 3*. Furthermore, *Table 4* reports the averages of slack-adjusted technical efficiency scores by operating environments, in addition to the results of the *t-tests* for equality of means. Finally, results for the *KS* and *MW* tests for input-specific scores of technical efficiency and operating environments are displayed in *Table 5*.

Insert Tables 3, 4 and 5 about here

The most efficient form of utilities ownership is a long-standing issue of debate in economics. Concerning water utilities, a number of papers have focused on analysing whether differences exist between public and private companies regarding their managerial efficiency (see Renzeti and Dupont, 2004 for a comprehensive review of the literature). Nonetheless, existing research does not provide conclusive support either to assert

[4] Low and high density are defined in relation to the sample average, so that areas of low density of population are those with a density below the average density in the sample. Conversely, high density areas are characterised by a density of population above the sample average. Figures on density of population come from the official statistics of the regional *Instituto Andaluz de Estadística*.

[5] This variable is also defined by taking the sample average as reference. The intensity of tourism has been measured according to the tourism index provided by La Caixa (2004).

unequivocally the superiority of one regime of ownership over the other, or to affirm that privatisation leads to efficiency improvements. Without aiming to be exhaustive, some papers have found empirical evidence supporting better performance on the part of public utilities (Bruggink, 1982; Lambert *et al.*, 1993; Bhattacharyya *et al.*, 1994, 1995a), while other authors consider that privately owned water utilities outperform public utilities (Morgan, 1977; Crain and Zardkoohi, 1978; Bhattacharyya *et al.*, 1995b). Inconclusive evidence is also found (Feigembaum and Teeples, 1983; Byrnes *et al.*, 1986; Fox and Hofler, 1986; Jones and Mygind, 2000; Ménard and Saussier, 2000; Estache and Rossi, 2002).

During the last two decades, many Spanish municipalities decided to transfer the management of water utilities from public to private managers, arguing that this would lead to efficiency gains. Privatisation continues to take place in Andalusia, but no empirical studies exist supporting the hypothetical gains of efficiency associated with this managerial strategy. In our sample, 26 out of 34 Andalusian water utilities are under private ownership, while the remaining firms are public utilities. Within the former group, i.e., private firms, some companies whose ownership is shared between private and public stakeholders have been included. They have been treated as private firms because responsibility for basic management decisions is always delegated to private managers.

According to our results, the average technical efficiency scores for privately and publicly owned water utilities are 0.956 and 0.937, respectively, the difference being statistically insignificant. In addition, the hypothesis that both samples, i.e., private and public utilities, are drawn from the same distribution cannot be rejected. In other words, we find no empirical evidence that one regime of ownership outperforms the other. Nonetheless, in this paper we aim to go further in the assessment of the relationship between efficiency and ownership. Our relevant question here is: might differences in technical efficiency exist between public and private water utilities as to their management of specific production factors?

The answer to this question is that private water utilities outperform publicly owned utilities in technical management of both labour and delivery pipelines. On the one hand, labour-specific scores of efficiency are 0.928 for private firms and 0.783 for public utilities, the difference being statistically significant (the computed *p-value* is 0.063). In addition, both samples, i.e., labour-efficiency of private and public utilities, can be said to come from different underlying populations. A reasonable hypothesis that could explain, at least partly, this finding is that publicly owned utilities face greater restrictions in adjusting wages and levels of labour force than private utilities. Affiliation to unions is greater among workers of publicly-owned utilities, and public utilities have less incentive than private companies to resist pressures of workers that could lead to political conflicts. Thus, the attitude of publicly-owned companies' managers when they face worker's demands is usually weaker than that adopted by managers of private water utilities.

On the other hand, scores of technical efficiency in the management of delivery pipelines are 0.916 and 0.784 for private and public water utilities, respectively, with a *p-value* for the difference of means of 0.086. Although we have no clear arguments to explain this outcome, a reasoning that could be of some help is that publicly-owned companies usually face stronger budgetary restrictions than private firms, making it difficult to fund the works necessary to maintain pipelines and adapt them to changes in spatial distribution of population and demand. This actually happened in Spain, especially in the late 1980s and early 1990s, when public indebtedness prevented utilities belonging to local governments from undertaking the works necessary to maintain delivery pipelines in many Spanish municipalities (Soler, 2003). In addition, it might be the case that private companies were tending to take over the management of areas with more favourable conditions in their pipe network for efficient operation.

Given that in our sample the number of water services provided differs from one utility to another, it might make sense to test for differences in efficiency among utilities providing the entire urban water cycle, i.e., the services of water delivery, sewage collection and sewage treatment, and utilities that only supply one or two of these services. The variable *services supplied* is intended here for this purpose. Other studies have tested for the existence of scope economies in water utilities derived from cost reductions as the number of water services provided increases (Hayes, 1987, Lynk, 1993, Hunt and Lynk, 1995, Saal and Parker, 2000, Fraquelli *et al.*, 2005). However, most of these papers only consider two of the services representative of the urban water cycle, water distribution and sewage collection. Although we do not measure cost reductions as the number of water services increases, but gains in technical efficiency, a noteworthy feature of our paper is that we also include the service of sewage treatment. However, our results indicate that the average of radial technical efficiency is not statistically different for utilities providing the entire urban water cycle and utilities that only supply one or two services[6]. Neither it is possible to affirm that both samples come from different distributions.

Our primary hypothesis as to the relationship between the number of services offered and efficiency in the management of specific inputs, is that utilities providing the entire urban water cycle could have the chance of being more efficient in the management of the intermediate input consisting of ground, surface and purchased water. The reason is that some of the sewage collected might be treated and then re-entered into the water cycle, at least for specific uses, e.g., to irrigate golf courses. However, we do not also obtain empirical evidence supporting this hypothesis. Probably, the reason is that, for

[6] In addition, we have run the *Kruskal-Wallis* test (see Conover, 1999 for details), which generalizes the *MW* test for more than two samples, considering three groups of utilities, i.e., firms that only provide the service of water delivery, utilities supplying water delivery and sewage collection and, finally, utilities supplying the entire urban water cycle. Nevertheless, differences among groups were found to be statistically insignificant.

the moment, most of the Andalusian water utilities providing the three services of the urban water cycle only carry out what we might call a *soft treatment* of sewage, not allowing water to be reutilized, but rather dumping it onto the local environment in such a way that its environmental impact is minimised. In fact, regional and also European authorities are currently encouraging Andalusian water utilities to treat sewage in order to avoid environmental damage. Nevertheless, still very few companies recycle sewage allowing its re-utilization, since the use of recycled water is restricted to certain uses, which exclude human consumption and, in some areas, agricultural use.

The next operating scenario we consider is determined by the density of population of the geographical area supplied. A number of papers have already introduced this variable to test for its impact on the efficiency of water companies. Although most of them have focused on cost efficiency, their results seem to confirm the existence of economies of density, i.e., the higher the density of population the greater the level of efficiency (Mann and Mikesell, 1976, Teeples and Glyer, 1987, Fabbri and Fraquelli 2000, Antonioli and Filippini, 2001 and Estache and Rossi, 2002, among others). Inconclusive evidence is also found by García and Thomas (2001), while Tupper and Resende (2004) find empirical evidence supporting the existence of density economies in the provision of the service of water delivery, but not in the service of sewage collection. In our research, we find that technical efficiency is statistically greater for utilities supplying areas of high density of population than for companies serving sparsely populated areas. Average scores of efficiency are 0.985 and 0.938, respectively. In addition, results from *KS* and *MW* tests allow us to assert that both samples, i.e., utilities supplying high and low density areas, are drawn from different populations.

Concerning the relationship between density of population and input-specific technical efficiency, our empirical evidence is inconclusive. Although the mean of technical efficiency in managing delivery network is, as expected, greater for firms located in areas of higher density of population than for utilities providing water services to less populated areas, high standard errors prevent us from obtaining conclusive empirical evidence as to the statistical significance of this difference.

Let us now address the study of the relationship between efficiency and the number of municipalities supplied. About two thirds of the companies in the sample (23 out of 34 firms) supply water services to only one municipality, while the remaining 11 utilities provide services to two or more municipalities. The foremost reason for including this variable is, as noted, that regional politicians gave strong support to the creation of consortia of water utilities in Andalusia, arguing that this managerial strategy would improve efficiency.

Consortia of water utilities arise normally from agreements among small municipalities that decide to create a common entity to supply water services to them. However, our results provide weak empirical support for technical efficiency gains, other than possible scale economies associated with an increase in size. Only technical efficiency in managing the sewer network statistically differs between water utilities that provide services to one municipality and utilities supplying several municipalities. Nonetheless, the hypothesis that both samples are drawn from the same population cannot be rejected. Hence, further research is needed to investigate in depth where any efficiency gains derived from consortia of water companies are hidden. Perhaps the main savings associated with this managerial strategy may have to do with variables not considered in this study. For instance, one of the reasons why consortia may be a profitable strategy could be the ability to avoid duplication of billing and customer services.

The last hypothesis we consider in our second-stage analysis is motivated by the fact that a number of water companies in the sample provide water services to highly tourist municipalities. These municipalities are principally located along the Mediterranean seacoast, and their population increases seasonally more than twofold, mainly during summer holidays. Some studies have already pointed to seasonal variation in water demand as a factor likely related to efficiency in water utilities (Woodbury and Dollery, 2004). Our empirical results give support to this relationship. Computed scores of technical efficiency are 0.994 and 0.936 for firms located in tourist and non-tourist areas, respectively, the difference being statistically significant (*p-value* is 0.025). Moreover, we also accept the hypothesis that the two samples come from different populations. Additionally, utilities located in tourist areas are more efficient at managing labour and the intermediate input consisting of ground, surface and purchased water.

Regarding labour, greater technical efficiency could be sensibly explained if water utilities made their decisions about contracting labour considering the permanent population, without bearing in mind the population who come temporarily in holiday time or other peak seasons. In this way, water utilities located in tourist areas would require workers to contribute a greater labour effort at times of greater influx of tourists or other foreign population. Probably this will also imply a lower quality of the service (Lin, 2005). Unfortunately, lack of information about variables relating to the quality of the service (time taken to repair breakdowns, water pressure, among others) precludes further considerations on this question. Finally, the reasons for the greater efficiency of utilities located in tourist municipalities in the management of ground, surface and purchased water are really straightforward. On the one hand, during some months of the year, these utilities under-use a part of their delivery network, precisely that intended to deliver water to the temporary population, avoiding losses of water along pipelines. On the other hand, since mass tourism in Andalusia is relatively recent and also a growing phenomenon, many tourist areas have younger and modern delivery networks that also avoid losses of water.

The ultimate purpose of our research is to try to bring economic analysis closer to the concerns of both firms' managers and policy-makers. Beyond the interest that our findings could have for the managers of water utilities, we would like to highlight a couple of results that, in our view, touch on interesting issues of economic policy, chiefly for the regional government of Andalusia and, also, for local councils of Andalusian municipalities. First, we obtain empirical evidence showing that the privatisation of public water utilities carried out in the region of Andalusia from the eighties onward, and firmly supported by public authorities, led to improvements of efficiency but only regarding certain production factors, mainly labour. Second, we obtain really poor empirical evidence of technical efficiency gains associated with consortia of water utilities, a managerial strategy that also had strong support from Andalusian politicians.

Finally, our research also identifies several directions for further investigation. On the one hand, a number of environmental factors influencing technical efficiency in water companies are identified, so further empirical research should include computation of efficiency scores accounting explicitly for different operating environments. On the other hand, availability of data on water utilities' costs and input prices could allow our research to be extended to the study of allocative and cost efficiencies and their relationship with the quality of the service.

5.- Summary and concluding remarks

The literature dealing with efficiency and productivity measurement has a deep-rooted tradition in the field of economics. This manuscript provides further empirical evidence concerning the managerial efficiency of water utilities. Our aim is twofold. On the one hand, a set of input-specific scores of technical efficiency is computed for a sample of water companies located in the southern Spanish region of Andalusia. On the other hand, a second-stage analysis is performed to learn about environmental factors related to differences in efficiency among water utilities. In doing so, both *DEA* techniques and some tests of hypotheses are utilised. Compared with previous literature, a contribution of this manuscript worth mentioning is that we make available measures of technical efficiency that vary across production factors, also providing empirical evidence as to the relationship between water utilities' input-specific efficiency and some operating environments. In addition, this paper leads empirical research dealing with the assessment of managerial efficiency of water utilities in the Spanish region of Andalusia, where increasing desertification and water shortage have turned efficient management of this natural resource into a dire necessity.

Concerning efficiency measurement, our main results are as follows. First, average radial efficiency is found to be fairly high, with relatively small differences among water utilities. Second, as to technical efficiency in the management of specific inputs, greater inefficiency appears in the use of the sewer network, while the most efficient management corresponds to the intermediate input consisting of ground, surface and purchased water. Third, non-proportional potential reductions of inputs due to slacks explain a large part of aggregate technical inefficiency, and consequently the computation of input-specific measures of efficiency, rather than a single radial score, noticeably improves the assessment of technical performance in Spanish water utilities.

Regarding efficiency and operating environments, an overriding conclusion is that computation of input-specific scores of technical efficiency helps to discover important features that would have remained out of sight with the mere study of the relationship between the environmental variables and a radial measure of technical efficiency. Some of these findings are as follows. In relation to the long-lasting debate about ownership and efficiency in water utilities, we contribute empirical evidence showing that privately owned water utilities outperform public companies but only in the management of specific production factors, principally labour. Furthermore, we find evidence supporting the existence of economies of density in the provision of water services, i.e., technical efficiency of water utilities is greater for firms serving densely populated areas. Our results also reveal that Andalusian utilities providing water services to tourist municipalities display greater efficiency scores in their management of labour and of the intermediate input consisting of ground, surface and purchased water. Conversely, no empirical evidence is found supporting either an increase of technical efficiency as the number of water services offered increases, or efficiency gains associated with consortia of utilities providing water services to several municipalities.

Our belief is that apart from their academic interest, these findings lead to two economic policy implications. First, privatisation of water utilities in Andalusia leads to improvements in efficiency but only in respect of certain production factors, mainly labour. Second, the argument of efficiency gains used by local and regional authorities to encourage the formation of consortia of water utilities finds weak empirical support in our research.

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Tables and Figures

Table 1
Sample description.

Variable	*Measurement unit*	*Mean*	*Standard deviation*	*Maximum*	*Minimum*
Outputs					
Water delivered	Thousands of m^3	9,695	17,635	84,800	212
Collected sewage	Thousands of m^3	8,901	21,828	108,666	0
Treated sewage	Thousands of m^3	8,220	21,994	108,666	0
Inputs					
Delivery network	Kilometres	356	583	2,877	5
Sewer network	Kilometres	203	387	1,855	0
Labour	Number of workers	81	141	732	2
Ground, surface and purchased water	Thousands of m^3	12,627	22,370	107,733	315

Table 2
Computed scores of input-oriented technical efficiency.

	Mean	*Standard deviation*	*Maximum*	*Minimum*	*Importance of slacks (σ_n)*
Radial technical efficiency	0.952	0.068	1	0.798	-
Slack-adjusted input-specific technical efficiency					
Delivery network	0.885	0.191	1	0.244	0.63
Sewer network (1)	0.781	0.258	1	0.130	0.70
Labour	0.894	0.194	1	0.175	0.56
Ground, surface and purchased water	0.951	0.068	1	0.798	0.01

(1) Computed only for water utilities making use of this production factor.

Table 3.-
Radial scores of technical efficiency categorised by operating environments.

	Two sample t-test for equality of means [1]			Kolmogorov-Smirnov test [2]	Mann-Whitney test [3]
	Mean	*Difference of means* [4]	*t-statistic (p-value)*	*KS-statistic (p-value)*	*Z-statistic (p-value)*
Ownership					
Private firms	0.956	0.019	0.679	1.195	1.474
Public firms	0.937		*(0.502)*	*(0.206)*	*(0.140)*
Services supplied					
Entire urban water cycle	0.939	-0.025	-1.071	0.857	-1.383
Only part of the urban water cycle	0.964		*(0.292)*	*(0.245)*	*(0.167)*
Density of population					
Firms supplying high density areas	0.985	0.047	1.914*	1.284*	2.246**
Firms supplying low density areas	0.938		*(0.065)*	*(0.051)*	*(0.025)*
Number of municipalities supplied					
Several municipalities	0.963	0.018	0.690	0.927	1.033
Only one municipality	0.945		*(0.494)*	*(0.273)*	*(0.301)*
Tourism index					
Firms located on tourist areas	0.994	0.058	2.354**	1.235*	1.954*
Firms located on non-tourist areas	0.936		*(0.025)*	*(0.064)*	*(0.051)*

** significant at 10 per cent; ** significant at 5 per cent.*

(1) The null hypothesis is that the difference of means is equal to zero.

(2) The null hypothesis is that the distribution of the two samples is the same.

(3) In this case, the null hypothesis is that the two samples are drawn from the same population.

(4) Mean of the first group minus mean of the second group.

Table 4.-
Input-specific scores of technical efficiency categorised by operating environments. Two sample t-test for equality of means.

	Delivery network		*Sewer network* [(1)]		*Labour*		*Ground, surface and purchased water*	
	Mean	*t-statistic (p-value)*	*Mean*	*t-statistic (p-value)*	*Mean*	*t-statistic (p-value)*	*Mean*	*t-statistic (p-value)*
Ownership								
Private firms	0.916	1.770*	0.801	0.549	0.928	1.927*	0.956	0.668
Public firms	0.784	*(0.086)*	0.736	*(0.589)*	0.783	*(0.063)*	0.937	*(0.509)*
Services supplied								
Entire urban water cycle	0.819	-2.132**	0.791	0.296	0.864	-0.899	0.939	-1.087
Only part of the urban water cycle	0.952	*(0.041)*	0.754	*(0.770)*	0.924	*(0.376)*	0.964	*(0.285)*
Density of population								
Firms supplying high density areas	0.924	0.761	0.804	0.301	0.882	-0.227	0.945	-0.372
Firms supplying low density areas	0.869	*(0.452)*	0.769	*(0.766)*	0.899	*(0.822)*	0.954	*(0.713)*
Number of municipalities supplied								
Several municipalities	0.906	0.439	0.896	1.801*	0.896	0.041	0.963	0.702
Only one municipality	0.875	*(0.664)*	0.707	*(0.086)*	0.893	*(0.968)*	0.946	*(0.488)*
Tourism index								
Firms located on tourist areas	0.950	1.204	0.905	1.574	0.991	1.799*	0.994	2.362**
Firms located on non-tourist areas	0.862	*(0.238)*	0.727	*(0.130)*	0.859	*(0.082)*	0.936	*(0.024)*

** significant at 10 per cent; ** significant at 5 per cent.*
(1) Means have been computed excluding water utilities that do not make use of this production factor.

Table 5.-
Input-specific scores of technical efficiency categorised by operating environments. Kolmogorov-Smirnov (KS-statistic) and Mann-Whitney (Z-statistic) tests for equality of populations and distribution functions.

	Delivery network		*Sewer network* [1]		*Labour*		*Ground, surface and purchased water*	
	KS-statistic (p-value)	*Z-statistic (p-value)*	*KS-statistic (p-value)*	*Z-statistic (p-value)*	*KS-statistic (p-value)*	*Z-statistic (p-value)*	*KS-statistic (p-value)*	*Z-statistic (p-value)*
Ownership	1.047	2.011**	0.749	0.837	1.094	1.810*	0.999	1.479
	(0.148)	*(0.044)*	*(0.473)*	*(0.403)*	*(0.134)*	*(0.070)*	*(0.206)*	*(0.140)*
Services supplied	0.857	1.763*	0.578	0.138	0.857	-1.497	0.857	-1.383
	(0.245)	*(0.078)*	*(0.754)*	*(0.855)*	*(0.245)*	*(0.134)*	*(0.245)*	*(0.167)*
Density of population	0.553	0.042	0.514	0.337	0.664	-0.437	0.664	-0.374
	(0.858)	*(0.967)*	*(0.864)*	*(0.736)*	*(0.687)*	*(0.662)*	*(0.687)*	*(0.708)*
Number of municipalities supplied	0.927	1.114	1.077	1.840*	0.809	1.074	0.972	1.033
	(0.273)	*(0.265)*	*(0.114)*	*(0.066)*	*(0.425)*	*(0.283)*	*(0.273)*	*(0.302)*
Tourism index	1.052	1.590	0.926	1.708*	1.235*	1.912*	1.235*	1.954*
	(0.162)	*(0.112)*	*(0.249)*	*(0.088)*	*(0.064)*	*(0.056)*	*(0.064)*	*(0.051)*

** significant at 10 per cent; ** significant at 5 per cent.*

(1) Means of efficiency have been computed excluding water utilities that do not make use of this production factor.