# Economic and technical efficiency of water suppliers: the impact of leakages.

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## RESUMEN

La pérdida de agua en las redes de abastecimiento tiene importantes repercusiones no sólo desde el punto de vista ambiental sino también económico. En este contexto, el objetivo de este trabajo es analizar la eficiencia tanto económica como técnica de una muestra de empresas que suministran agua potable considerando las fugas de agua como output no deseado. Así mismo se investiga la posible relación entre las tarifas del agua y la ineficiencia de las empresas. Para ello se usa el análisis envolvente de daos (DEA). Los resultados muestran que existen importantes opciones para reducir las pérdidas de agua y consecuentemente significativas posibilidades de ahorro económico para las empresas. El análisis desarrollado en este trabajo muestra la utilidad que tiene la evaluación de la eficiencia como herramienta para mejorar la gestión de los servicios de suministro de agua potable.

***Palabras claves*:**

Benchmarking; eficiencia económica; Data Envelopment Analysis (DEA); pérdidas de agua: sistemas de distribución de agua urbana.

# ABSTRACT

Water leaks in supply networks have significant implications not only from an environmental point of view but also economics. In this context, the aim of this article is to assess both the economic and technical efficiency of a sample of water supply companies considering leakages as an undesirable output. Moreover, it is investigated the possible relationship between water rates and the inefficiency of the companies. For these analysis we use a Data Envelopment Analysis (DEA). The results show that there are important options to reduce water leaks and consequently significant opportunities to save costs. The assessment developed in this work shows the usefulness of the efficiency assessment as a tool to improve the management of water supply services.

***Keywords*:**

Benchmarking; economic efficiency; Data Envelopment Analysis (DEA); water leaks: urban water systems.

***Área temática*:** A1. Optimización.

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# 1. INTRODUCCIÓN

The supply and distribution of water for household use is widely regulated with regard to quality, price, the provision of services by suppliers, etc. Hence, urban water demand has been studied by many authors in the literature (Arbués et al., 2003; Bhattacharyya et al., 1995; Garcia-Valiñas, 2005; Garcia-Valiñas and Muñiz, 2007; Resentí, 2000; Reynaud, 2003, among others). The main variables in the models that analyse water demand are usually price, user purchasing power, socio-economic factors related with the composition of the family unit and its way of life, climate, and the management of the supply firms. Price is one of the most studied factors since according to the EU-water framework Directive, water pricing should aim at full-cost recovery.

Taking into account the principle that the customer should pay, the use of benchmarking offers the following main advantages: i) strongly motives operators to be efficient and innovative, thereby mitigating their operating costs and capital expenses; ii) results in a continuous pressure in water systems that improves the quality of service; iii) ensures a 'fairer' recovery of costs and capital investment and; iv) increases the sharing and transparency of information (Marques, 2010).

The works developed in this field have concentrated on a variety of issues, e.g. water distribution (Thanassoulis, 2000); sewerage services (Hernandez-Sancho and Sala-Garrido, 2009); comparison of the relative efficiency of government-owned versus privately-owned companies (Marques, 2008); or the identification of some environmental variables affecting efficiency scores (Picazo et al., 2009).

Although from the 80s onward several papers have focused on assessing efficiency of water supply utilities, none has considered the extent of water leaks in the supply network. Leakage is not just an economic issue – as it is often perceived by water companies – but is also an environmental, sustainability, and potentially a health and safety issue (Puust et al., 2010). From an environmental point of view, leakages cause inefficient energy distribution through the network (wasting energy used for pumping water) and may also affect water quality by introducing infection into water distribution networks in low pressure conditions (Colombo and Karney, 2002).

Moreover, in areas subjected to harsh conditions of water stress, water leaks are particularly important since water is a scarce and valuable resource. From an economic point of view, leaked water cannot be sold to generate revenue for the supplier. Leakage is an example of inefficiency in the supply process that negatively affects users because they must pay higher prices as a result.

The possible relationship between the existence of water leaks and the setting of higher prices would be a clear example of inefficient management with an evident detrimental effect on consumers. It must be remembered that according to the EU-water framework directive, price should be used as an incentive to achieve an efficient use of water and never as a compensation mechanism for situations of inefficiency on the supply side. In the context of efficiency analysis, water leaks can be considered as an undesirable output that is generated jointly with the supply of drinking water (desirable output) for users in urban environments.

The purpose of this paper is twofold. The first aim is to analyse the efficiency of a sample of urban water systems (UWS) by considering not only the inputs and desirable outputs but also the water leaks in the network. More specifically, technical and economic efficiency are assessed for each UWS. In doing so, and based on benchmarking techniques, two models are solved that differ only in the variable used as desirable output. To assess technical efficiency, the production volume of water (m3/year) is used as desirable output; and the measurement of revenue (€/year) is used to evaluate economic efficiency. The second objective is to evaluate the possible relationship between efficiency indexes and tariffs charged to users as a mechanism to compensate for technical inefficiency. An empirical application is carried out for a sample of various UWS located in the Valencia region of Spain.

## 2. METHODOLOGY

The term efficiency is used in a wide variety of contexts with different interpretations. However, in the economic field, it refers to the rational use of available resources. In this sense, Data Envelopment Analysis (DEA) is one of the most commonly used methods to assess the efficiency of a set of units by benchmarking procedures. Since DEA was developed by Charnes et al. (1978) it has been used to assess efficiency in multiple fields of research, including water utilities.

It is widely known that DEA has many variations and extended forms. 'Classical' DEA models rely on the assumption that inputs have to be minimised and outputs have to be maximised. However, a production process may also generate undesirable or bad outputs that have to be minimised (Scheel, 2001). In this context, Färe et al. (1989) can be considered as a pioneer in the incorporation of environmental aspects into efficiency analysis since these authors introduced a non-linear programming problem for efficiency evaluation in the presence of undesirable outputs. Subsequently, several models have been developed to assess environmental efficiency under various conditions (such as Seiford and Zhu, 2002; Hadi Vencheh et al., 2005; Gomes and Lins, 2008; Sueyoshi and Goto, 2011).

To carry out our methodological approach, let's assume a production process in which from an input vector $x \in \Re_+^N$ we can obtain a vector of desirable outputs $y \in \Re_+^M$ and another vector of undesirable outputs $z \in \Re_+^H$ using the technology T in such a way that,

$$T = \{(x, y, z); x \; can \; produce \; y, z\}$$

This technology T can be also expressed in an equivalent way from the point of view of inputs, i.e.

$$(x, y, z) \in T \Leftrightarrow x \in L(y, z)$$

where, $L(y, z)$ represents the set of input vectors x that enables us to reach a vector of desirable outputs y together with another vector of undesirable outputs z.

Let's start with $k = 1,2,...,K$ producers with each using a vector of $n$ input $x^k = (x_1^k, x_2^k, ..., x_N^k)$ to carry out the joint production of a vector of $m$ $y^k = (y_1^k, y_2^k, ..., y_M^k)$ desirable output and another vector of $h$ undesirable outputs

$z^k = (z_1^k, z_2^k, ..., z_H^k)$, being $\lambda = (\lambda_1, \lambda_2, ..., \lambda_K)$ a vector of the intensity of variables. Following Färe et al. (1994), for each unit $k'$ we can obtain an efficiency index solving the next optimisation problem with linear programming:

$$\begin{aligned}
&\text{Min } E = \theta^{k'} \\
&\text{s.t.:} \\
&\sum_{k=1}^{K} \lambda^k x^k \le x_n^{k'} && n = 1,.....,N \\
&\sum_{k=1}^{K} \lambda^k y^k \ge y_m^{k'} && m = 1,.....,M \\
&\sum_{k=1}^{K} \lambda^k z^k = \theta_h^{k'} z_h^{k'} && h = 1,.....,H \\
&\sum_{k=1}^{K} \lambda^k = 1 && k = 1,....,K \\
&\lambda^k \ge 0 && k = 1,....,K
\end{aligned} \tag{1}$$

In the model used, we minimise the undesirable output by considering a specific level of inputs and desirable outputs. Moreover, we assume variable returns to scale and, as a basic requirement, the joint production of both types of outputs (Färe and Grosskopf, 2004). The measure of efficiency is bounded between 0 and 1. In our specific case study, efficiency (index value equals one) would mean that further reducing the water leaks is impossible, while inefficiency (index value far from one and closer to zero) would imply that leakage could be further minimised.

## 3. SAMPLE AND VARIABLES

The statistical information used for this research comes from a sample of 91 UWS in the Valencia region (on the Mediterranean coast of Spain). Each UWS corresponds to a municipality and the total population was 2,513,202, representing 52% of the regional population (IVE, 2012). Urban water prices are proposed by the water supply firms but they require approval from local and regional authorities. These water prices are always established on the full cost recovery principle.

According to the objectives of the paper, the following variables have been selected:

*Inputs:* (i) staff cost; (ii) maintenance cost; (iii) water purchased and energy cost for producing drinking water; (iv) amortisation and taxes; and (v) other costs.

*Desirable outputs:* to evaluate the technical efficiency, the total production of drinking water produced is considered as the desirable output production volume. As regards the assessment of the economic efficiency, the desirable output is the revenue expressed as cubic meters of water sold multiplied by the average tariff.

*Undesirable outputs:* leakage volume is defined as the difference between production volume and sales volume.

The sum value of these variables for the year 2006 is shown in Table 1.

Table 1. Sample description for the 91 UWS

| | | | **Sum for the 91 UWS** |
|---|---|---|---|
| **Inputs (€/year)** | Staff costs | | 39,603,088 |
| | Maintenance costs | | 14,210,988 |
| | Water purchased and energy costs | | 46,342,754 |
| | Amortization and taxes | | 17,875,740 |
| | Other costs* | | 36,759,455 |
| **Desirable Output** | Technical | Production volume ($m^3$/year) | 210,332,527 |
| | Revenue | Revenue (€/year) | 154,792,024 |
| **Undesirable Output** | Leakage ($m^3$/year) | | 49,801,709 |

Table 1 shows that for the 91 UWS the total cost amounts to around €155 million per year and taking into account the volume of water supplied, the cost is 0.73 €/$m^3$. The most important inputs are water purchased and energy costs, representing almost one third of the total costs. Staff and other costs have a similar percentage weight, contributing 26% and 24% respectively to the total cost. As regards water leaks, these are quantified as 24%, meaning that each year nearly 50 million cubic meters of water is 'produced' but are not sold.

The 91 UWS are managed by ten firms whose main characteristics are described in Table 2. The number of municipalities supplied by each firm varies, as some (firms 2 and 6) supply just two municipalities – while other firms, such as firm 3, supply some 20 municipalities. As shown in Table 2, the percentage of water leaks by firm is very variable, since the minimum value is 10% (firm 2), while the maximum is 38% (firm 7). The weighted average for the 10 firms is 24%. The differences between firms with respect to water supply costs are also noteworthy since the minimum cost is 0.37 €/m$^3$ while the maximum is 1.11 €/m$^3$ (three times greater).

Table 2. Sample description for the 10 firms

| FIRM | Number of UWS | Production volume (m$^3$/year) | Leakage (m$^3$/year) | Leaks (%) | Total cost (€/year) | Total cost (€/m$^3$) |
|---|---|---|---|---|---|---|
| 1 | 9 | 10,096,889 | 3,251,928 | 30 | 4,717,347 | 0.47 |
| 2 | 2 | 32,492,714 | 3,510,513 | 10 | 36,193,303 | 1.11 |
| 3 | 20 | 22,951,800 | 5,679,796 | 25 | 13,264,868 | 0.58 |
| 4 | 6 | 11,759,583 | 3,797,971 | 32 | 6,317,183 | 0.54 |
| 5 | 15 | 9,159,362 | 1,875,946 | 18 | 4,133,476 | 0.45 |
| 6 | 2 | 52,726,845 | 9,507,610 | 16 | 53,371,800 | 1.01 |
| 7 | 11 | 16,130,197 | 6,855,882 | 38 | 6,011,316 | 0.37 |
| 8 | 7 | 5,576,347 | 1,350,737 | 24 | 2,582,447 | 0.46 |
| 9 | 7 | 4,073,542 | 1,399,058 | 34 | 1,676,719 | 0.41 |
| 10 | 12 | 45,365,248 | 12,572,268 | 26 | 26,523,565 | 0.58 |
| **TOTAL** | **91** | **210,332,527** | **49,801,709** | **24** | **154,792,024** | **0.73** |

## 4. RESULTS

To obtain the efficiency scores of the 91 UWS we have twice solved Eq (1) using the variables previously described depending on whether we are assessing the technical or economic efficiency (total production of drinking water or revenue from the sale of water). Table 3 presents a summary of the technical and economic efficiency scores for the 91 UWS assessed.

Table 3. Efficiency indexes according to the desirable output used.

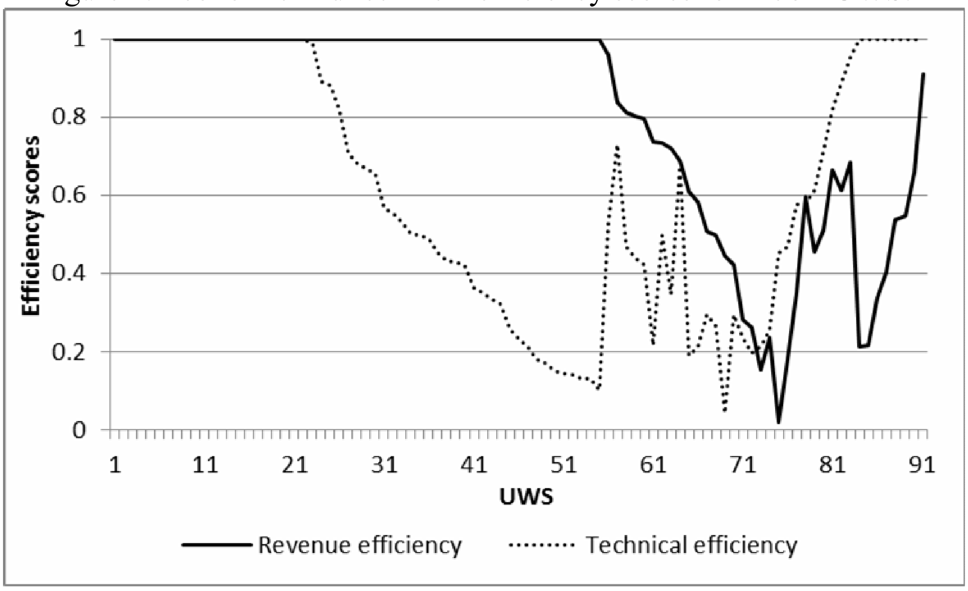
| | Mean | Std. Dev. | Minimum | Maximum | Number of UWS efficient |
|---|---|---|---|---|---|
| **Technical efficiency** | 0.63 | 0.33 | 0.25 | 1.00 | 30 |
| **Economic efficiency** | 0.81 | 0.27 | 0.35 | 1.00 | 55 |

The efficiency indexes obtained are low – especially when the volume of water supplied is used as the desirable output. We can say that the possibilities for improving the network and, therefore, reducing the level of leaks are high. Knowing that the production volume of water of the 91 UWS is 210,332,527 m$^3$/year, we estimate that if all UWS were efficient, the quantity of water saved would be approximately 79 hm$^3$/year, yielding significant economic and environmental savings. If this quantity of water could be sold, considering that the average price of water is 0.73 €/m$^3$, the suppliers would gain an additional revenue of €57.5 million per year. In terms of economic efficiency, i.e. when the volume of revenues is used as desirable output, the mean efficiency index increases to 0.81, meaning that the chances of improvement are 19%.

Likewise, it is worth noting that if revenue volume is considered as desirable output, the percentage of efficient UWS is approximately twice as high as when the volume production is used. This fact shows the importance of the variable selection in the assessment of efficiency.

Since one of the main advantages of the DEA methodology is that it enables the calculation of an efficiency index at unit level, Figure 1 represents the economic and technical efficiency scores for the 91 UWS analyzed. The graph illustrates that 22 UWS, or 24% of the total, are efficient both from the economic and technical point of view. A second group, comprising 50 UWS, have economic efficiency greater than the technical efficiency. This fact verifies that 55% of the UWS in our sample use the water supply price as a mechanism to compensate for their technical inefficiency. Finally, 19 UWS (i.e. 21% of the total) are more efficient from the technical point of view than economic one. Moreover the determination coefficient ($R^2$) between technical and economic efficiency scores shows that there is no relation between both indicators.

Figure 1. Economic and technical efficiency scores for the 91 UWS.



Taking into account that the 91 UWS assessed are managed by ten firms, the next step in our analysis is to identify the existence of links between efficiency performance and prices charged to users by the ten firms. In doing so, the average scores of technical and economic efficiency at firm level are firstly evaluated. By using the UWS efficiency indexes obtained, and linking this information to the operating firm in each case, Table 4 shows the efficiency indexes for each firm as weighted average of the UWS indexes and the number of efficient firms from a technical and economic point of view.

Table 4. Efficiency indexes by firm

| **Firm** | **Number of UWS** | **Technical efficiency (1)** | **Economic efficiency (2)** | **Difference between (2) and (1)** |
|---|---|---|---|---|
| 1 | 9 | 0.57 | 0.89 | 0.33 |
| 2 | 2 | 1.00 | 0.55 | -0.45 |
| 3 | 20 | 0.65 | 0.78 | 0.12 |
| 4 | 6 | 0.67 | 0.94 | 0.28 |
| 5 | 15 | 0.71 | 0.94 | 0.23 |
| 6 | 2 | 0.47 | 0.81 | 0.35 |
| 7 | 11 | 0.67 | 0.93 | 0.26 |
| 8 | 7 | 0.69 | 0.71 | 0.02 |
| 9 | 7 | 0.36 | 0.76 | 0.41 |
| 10 | 12 | 0.55 | 0.79 | 0.24 |
| Mean | - | 0.63 | 0.81 | 0.19 |

Table 4 shows that the score for economic efficiency is greater than technical efficiency for all the analyzed firms, except for firm 2. The fact that, in general terms, firms show an improvement in the efficiency indexes when variable revenue is considered as desirable output reveals the leading role of price when assessing the efficiency of a firm. The difference between revenue and technical efficiency could be associated to the degree to which firms use tariffs to compensate for water leakages. Firm 9 shows the highest difference (0.41) between the two efficiency indicators. Other significant differences are presented by firms 6 and 1. Moreover, only firm 2 is technically efficient (score equal to one) showing a negative difference in relation to economic efficiency.

To verify the hypothesis that firms 'compensate' their technical inefficiency through pricing, we assess the degree of correlation between the average technical efficiency score of each firm and its average price (see Table 5).

Table 5. Average prices by firm and efficiency indexes.

| Firm | Average price (€/m$^3$) | Technical Efficiency |
|---|---|---|
| 1 | 0.66 | 0.57 |
| 2 | 1.30 | 1.00 |
| 3 | 0.84 | 0.65 |
| 4 | 0.86 | 0.67 |
| 5 | 0.65 | 0.71 |
| 6 | 1.12 | 0.47 |
| 7 | 0.59 | 0.67 |
| 8 | 0.65 | 0.69 |
| 9 | 0.67 | 0.36 |
| 10 | 0.83 | 0.55 |
| Mean | 0.82 | 0.63 |

Theoretically, it could be expected that the firms with highest average price of domestic water should be the most efficient since they have more resources for the maintenance and restoration of the supply network that minimises water leaks. However, results shown in Table 5 indicate that this is not so given that the determination coefficient ($R^2$) between average price of domestic water and scores for efficiency is only 0.17.

This result is consistent with the work of Cabrera et al. (2010) who suggest that part of the tariffs go to finance other projects and is not used to make the necessary improvements in the networks.

Likewise, it is worthwhile highlighting some specific situations. Firstly, firm 2 has the highest level of technical efficiency and the highest tariffs. It would appear that this company is clearly committed to quality service through proper network maintenance and minimisation of water leaks. This implies a comparatively high tariff for users. The case of firm 6 deserves further study because it has the second highest tariff in the sample and is also the second most inefficient company in the sample. This supplier suffers a high level of water leaks and has considerable room for improvement in comparison with the other companies studied. While a high tariff could be justified by the existence of problems in extraction, water scarcity, or pumping needs, these circumstances are contradicted by a high level of water leaks. Although it is hoped that such situations are uncommon, the solution would be the establishment of agreements regarding service quality, investments in improving the network, and tariff levels between the municipalities that have powers to oversee the suppliers.

## 5. CONCLUSIONS

In a context of scarce water resources and rising demand, one of the main problems in urban water management is leakage in water distribution systems. Such leaks affect both water companies and their customers. Efficient management by water firms implies a good maintenance of the network and a minimisation of water leaks, and these practices will have a positive effect on the quality of the service provided – as well as having the effect of reducing tariffs. Efficient management contributes to rationalising water consumption and so saves water and energy resources – as required by various regulations.

The analytical benchmarking methodology *Data Envelopment Analysis (DEA)* is used to calculate efficiency measurements for a Spanish sample of urban water systems. In this context, water leaks are considered as an undesirable output that is jointly produced with the supply of drinking water (desirable output). Moreover, the relationship between efficiency scores and tariffs charged to the users is analysed.

The efficiency indexes obtained show that the possibilities of reducing water leaks are high – and this demonstrates that there is room for savings from an economic and environmental point of view. In general, the technical efficiency scores are lower than economic efficiency indexes, suggesting that firms could be using tariffs as a mechanism to compensate for their technical inefficiency. However, the fact that the degree of correlation between the average price of domestic water and technical efficiency is low may indicate that tariffs are used not only for the maintenance and improvement of the existing networks but also to finance new infrastructure.

Finally, we can remark the need to set up a regulatory organism that establishes the conditions of the water supply service and monitors technical and economic efficiency in order to improve, from an economic and environmental point of view, the quality of the water distribution services.

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