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Water Losses and Hydrographical Regions Influence on the Cost Structure of the Portuguese Water Industry

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Abstract

There is a consensus that the emphasis on the management of water resources should be put on demand side policies. However, some questions remain to be solved on the supply side, which are frequently absent from empirical studies based on the estimation of cost functions. This paper aims to fill to some extent this gap in the literature by focusing the consequences of water losses reduction and the management of water resources based on their availability at an integrated river basin level.

Major findings indicate that it would be better in terms of costs to maintain some level of water losses than to repair the leaks and suggest advantages from more concentration in the Portuguese water industry. In addition, the costs do not seem to be systematically influenced by the hydrographical regions to which water utilities belong, what might be due to the absence of appropriate cost accounting methods.

JEL Classification: L11, L95, Q25

Keywords: water utilities; water losses; river basins; multi-product cost function

1. Introduction

Ever since water has been recognized as a scarce resource there has been considerable pressure from the general public, regulatory agencies and some governments to minimize the impacts of new water supply projects. It has, in fact, become clear that the emphasis should be shifted towards managing water demand by better utilizing the water resources already available.

The literature that debates water industry changes and restructuring conditions necessary to promote higher levels of performance is abundant. Some empirical studies focus on the analysis of the cost structure of the local utilities, a pre-requisite to define regulatory schemes intended to fulfill better efficiency targets. Examples of some of the main specific issues addressed are: the design of optimal price schemes, the evaluation of the effects of ownership and regulation and testing for economies of scale and of scope.

However, on the supply side some essential questions remain to be solved, but these are frequently absent from the empirical literature on the estimation of water cost functions. This paper aims to fill this gap in the literature to some extent by focusing on two specific issues: the consequences of reducing the volume of water losses, and the management of water resources based on their availability at an integrated river basin level.

Therefore, by analysing the Portuguese water supply cost structure, this paper has three objectives. First, it aims to assess the cost structure consequences of the joint production of water delivered to Portuguese final users and water losses, which is an issue rarely treated in the literature. Secondly, it intends to assess whether the cost structure is significantly influenced by the fact that water utilities are located in different hydrographical regions. Finally, it intends to determine whether the industry exhibits economies of scale and over what range of output it occurs.

Regarding the first purpose, one point of interest of this paper is the investigation into why water losses in Portuguese municipal systems stand at more than 30%, which is the average level estimated for OECD members. An initial possibility that does not require further explanation is that in many cases there has been insufficient investment in the water network infrastructure. Another factor, which we will look at in detail, is linked to the possible economic and financial rationality of maintaining a high level of leaks rather than repairing them.

Regardless of any economic and financial effects, there are other arguments that by themselves justify the importance of reducing water losses. One of them concerns the environmental aspects in the context of seasonal and spatial scarcity of water resources. Furthermore, the reduction of water losses can also have a significant social impact, due to the European Water Framework Directive (WFD) requirement to recover all the costs of water supply by adopting adequate pricing policies.

The rationale for including information related to river basins as potential determinants of water utilities costs comes from the requirement that all water costs, including resource costs, must be recovered in full. This is required by the WFD and also by the OECD Environmental Strategy (OECD, 2006), according to which, member countries should apply the ecosystem approach to the management of freshwater resources. The inclusion of these variables is an innovative feature of the paper.

In addition, it is particularly relevant to carry out this study in Portugal. As pointed out by the Portuguese Institute for the Regulation of Water and Solid Waste (IRAR, hereunder) it is crucial to optimize the use of water resources without ignoring the universal service obligation. In order to comply with this, special attention should be given to the reduction of leaks in the systems, to attain acceptable efficiency levels IRAR (2005:82).

Furthermore, since the Portuguese water industry is organized in multiple local monopolies, and is usually considered by national authorities – MAOT (2000), IRAR (2005) and MAOTDR (2006) – as a natural monopoly industry, it provides an interesting field of study.

To sum up, the current study is original in using the broad (and first) database collected by the Portuguese National Water Institute (INAG, hereafter), through the National Survey on Water Supply and Wastewater Systems, to estimate the cost structure of Portuguese water utilities.

The results provided by this study can, in our opinion, shed some light on how the Portuguese regulatory authority should intervene to reduce the problem of water losses while providing adequate incentives to operators of water supply systems to meet sustainable and appropriate financial targets. All in all, the findings of this study can support water allocation decision making and have important policy implications.

This paper is structured as follows. In Section 2 some economic cost analysis concepts are reviewed. Section 3 provides a brief overview of the literature on the estimation of water cost functions. Section 4 describes the model specifications. Section 5 is dedicated to the dataset description and methodology. Empirical results are presented in Section 6, and Section 7 offers some conclusions.

2. Water supply and economic cost analysis

In a context where water is accepted as a scarce resource and environmental damage caused by water consumption is recognized as an external cost for society, it is of primordial importance to understand the rationale behind the behaviour of water utilities. It is expected that water utilities try to minimize total costs while having to satisfy market demand and the regulator's impositions. Therefore, the knowledge of the cost structure of water utilities is essential to identifying the existence or the absence of incentives to efficiently satisfy demand. In fact, a supplier which needs to increase its output can choose between two options: an investment programme to repair the leaks in the system or an increase in production capacity, according to their respective costs. Obviously, the consequences in terms of the overall efficiency of the system and on the use of the resource will be different.

However, water losses are almost always treated in the current literature as a form of demand management, instead of an initiative being included, as they should be, in the supply side strategies, as pointed out by Merrett (2005:91).

There are several justifications for reducing water losses. Firstly, due to their financial and economic relevance, since they mostly represent water delivered to final costumers (water for human consumption), with very demanding quality requirements which imply high production and treatment costs. Secondly, because of the environmental consequences of water losses, related to the seasonal and spatial scarcity of water resources. Finally, the reduction of water losses can also affect consumers, because the WFD requires that by 2010 (Art. 9, no.1) the European Union's member states should recover all the costs of water supply through pricing policies.

Related to this last aspect, the study of the cost structure of water utilities is important to finding out if consumers are paying for supplier's inefficiency.

Moreover, analysis of the cost structure of utilities also allows questions related to the market structure of the water industry to be addressed. Depending on whether the cost function exhibits economies of scale and of scope, arguments for or against the integration of various operators into a single one may emerge. The theoretical framework for the estimation of a proper cost function is therefore now reviewed.

Microeconomic theory generally defines cost as a function of output(s), Y, and inputs prices, W, $C(Y,W)$. However, in empirical studies, authors frequently include other explanatory variables: a Z vector, related to structural and technical characteristics as well as to the economic environment. Therefore, the cost function becomes $C(Y,W,Z)$. In the water industry variables of this type are related to the network length and connections, area served, capacity utilization, regulatory environment, and so on.

In order to simplify this part of the analysis, only output variables are included, since suppressing the others interferes neither with the main expressions nor with the results obtained in this section.

As market competition conditions are frequently absent from the water industry, it is important to determine whether the monopolies that run the industry are natural ones. Although natural monopolies are often characterized by the presence of economies of scale, this condition is neither necessary nor sufficient for natural monopoly under multi-product contexts. Cost function's strict subadditivity is the "critical concept" for the existence of a natural monopoly in multi-product industries (Baumol, 1977:809). In its simplest formulation, the cost function subadditivity condition is defined as:

$$C\left(\sum_{i=1}^{n} y_i\right) < \sum_{i=1}^{n} C(y_i) \qquad (1)$$

for all y such that $\sum_i y_i \neq 0$. Subadditivity therefore means that, over the relevant range of outputs, it is always cheaper to have a single firm producing whatever combination of output(s) since it costs less to produce the various output(s) bundles together than to produce them separately (Tirole, 1988:19). Thus, under a natural monopoly it is not efficient to have several firms producing the output(s).

Baumol (1977:185) notes that in a multi-product case, "sufficient conditions for subadditivity must include some sort of complementarity in the production of the different outputs of the industry". Declining "ray average cost" (*RAC*) and "transray convexity" (*TRC*) are two conditions that together are sufficient to guarantee the strict and global subadditivity of costs (Baumol, 1977; Baumol *et al.*, 1988), corresponding to the requirements for subadditivity with strong complementarities.

It is well known that calculating average cost implies that costs are being averaged over total output. However, in the multi-product case it raises the question of the measure of total output, since we cannot simply add different types of output. The idea behind *RAC* is to aggregate the entire output vector into a composite good (*Y*), through some fixed proportions. Thus, the output bundle varies in fixed proportions along a ray (*r)* that allows measurement of the average cost, as in the single-product case, as suggested by Kim (1985:199). For the two (*i* and *j*) output case, *RAC* becomes:

$$RAC(Y,r) = \frac{C(Y,r)}{Y}, \text{ with } r = \frac{y_j}{y_i} \qquad (2)$$

Nevertheless, because firms are not always increasing or decreasing output along rays, it is also important to know about the behaviour of the cost function between rays, or in other words, about complementarities in production by moving across rays (Berg and Tschirhart, 1988). Roughly speaking, if a cost function is transray-convex, then it means that it is cheaper to produce outputs in combinations rather than to produce them separately.

A cost function $C(Y)$ is *TRC* at *Y* if, for every two output vectors, Y^a and Y^b, lying in the same hyperplane as *Y*,

$$C(Y) = C\left[kY^a + (1-k)Y^b\right] \leq kC\left(Y^a\right) + (1-k)C\left(Y^b\right) \qquad (3),$$

for any k, $0 < k < 1$ (Baumol, 1977). The *TRC* concept is "closely related to what Panzar and Willig have named 'economies of scope'" (Baumol, 1977:811) but economies of scope are a weaker form of cost complementarity than *TRC*. Thus, Baumol *et al*. (1988) provide an alternative approach, which permits testing for subadditivity, without strong cost complementarities. In this context, sufficient conditions for subadditivity come from economies of scope together with a stronger substitute for economies of scale: specific economies of scale for each product.

A necessary condition for subadditivity is the presence of economies of scope. If it is rejected then global subadditivity is rejected. In this case, it is possible to test for ray subadditivity, a sort of partial subadditivity (Baumol *et al.*, 1988), by analysing the behaviour of *RAC*.

Economies of scope refer to the situation where the joint production costs are lower than the sum of production costs for separate specialised firms or other operators. The degree of economies of scope is, thus, given by:

$$SP = \frac{\sum_{i=1}^{n} C(Y_{n-i}) - C(Y)}{C(Y)} \tag{4}$$

where $C(Y_{n-i}) = C(y_1, ..., y_{i-1}, 0, y_{i+1}, ..., y_n)$. Operators face (dis)economies of scope if *SP* takes (negative) positive values. The cost savings of joint production may arise from two sources. One is the production of a large output bundle, and the subsequent reduction of an excess capacity, which allows for the diminution of the average fixed costs. Another source is taking advantage from cost complementarities (Pulley and Humphrey, 1991:4). For the two-product (*i* and *j*) case, cost complementarity occurs if:

$$\frac{\partial^2 C}{\partial y_i \partial y_j} \leq 0 \tag{5}$$

This inequality means that an increase in the *j* production decreases, or at least keeps constant, the *i* product's marginal cost.

Economies of scale are said to exist if an output increase is associated with a less than proportional increase in cost. Product-specific economies of scale measure how costs vary with changes in a specific output, keeping the quantities of the other outputs constant. There are product-specific (for the *i* product) and overall economies of scale if SL_i and SL, which are respectively given by:

$$SL_i = \frac{IC_i(Y)}{y_i MC_i(Y)} \quad (6.1); \qquad SL = \frac{C(Y)}{\sum_{i=1}^{n} y_i MC_i(Y)} \quad (6.2)$$

take values larger than unity, with

$$IC_i(Y) = C(Y) - C(Y_{n-i}) \tag{7}$$

being the incremental cost related to the production of a given level of product *i*, while the amounts of the other products remain constant. The utilities face decreasing returns to scale if $SL < 1$ and constant returns to scale if $SL = 1$.

Estimating the cost structure of an industry requires choosing a functional form. According to both theoretical considerations and the type of data available, different cost function specifications, such as transcendental logarithmic (*translog*), hybrid, parabolic, or quadratic, are found in the literature. The *translog* specification seems to be currently the most popular one for the estimation of multi-product cost functions. However, the quadratic specification is particularly helpful in certain contexts, including the analysis of economies of scope, while the *translog* function is not capable of robustly representing the cost function unless modified for zero output values (Baumol, 1977; Fuss *et al*., 1978; and Baumol and Willig, 1986).

In addition to data restrictions, which sometimes require the imposition of a restrictive form, the several properties that a multi-product cost function should exhibit also limit the choice of the cost specification. In relation to those properties, first, the cost function must be nondecreasing, concave and linearly homogeneous in the input prices, and nonnegative and nondecreasing in its outputs (Diewert, 1982; Baumol *et al.*, 1988). Second, for the purposes of a multi-product industry analysis, the cost function should yield a reasonable cost figure for output vectors which entail zero outputs of some goods[1]. Third, the functional form should not presuppose the presence or absence of any of the cost properties that play an important role in the analysis of the specific industry, such as complementarity of costs or scope (dis)economies, when considering firms whose production of some output is zero. Fourth, the cost function should be parsimonious in the number of parameters to be estimated.

[1] According to Baumol *et al.* (1988:449), "this is a desideratum violated by several of the functional forms often used in statistical studies". Examples of those specifications are the Cobb-Douglas and the *translog* cost function. In that case, that violation occurs if input prices are considered to be included in the fixed components and in the coefficients to be estimated as unspecified functions of the vector *W,* instead of being explicitly incorporated.

3. Overview of the empirical literature on water cost functions

Empirical literature on water cost functions belongs to the major field of water utilities performance analysis, usually in the context of regulating and reorganizing the water industry. Most of the studies relate to the United States (US), England and Wales (E&W) and France (Renzetti and Dupont: 2003). Despite some differences between the studies with respect to specific objectives and approaches, empirical studies have almost always tended to focus on the efficiency (a particular measure of the performance) of municipal water utilities.

In order to pursue the stated general objective, one of the possible approaches, followed by Byrnes *et al*. (1986), Cubin and Tzanidakis (1998), Bhattacharyya *et al*. (1995) and others, consists of using data envelopment analysis (DEA).

The DEA model uses linear programming to define a frontier of the most efficient firms in order to compare all the other firms' performance with this frontier. This methodology thus underpins the use of benchmarking tools to better regulate water and sewerage services. De Witte and Marques (2007), for example, address the specific policy issue of benchmarking to provide incentives for cost containment in the context of several EU member states. For Portugal, Marques (2006) proposes a yardstick competition model for Portuguese water and sewerage services regulation, also derived from DEA methodology.

The same objective of studying efficiency issues can be studied by the econometric approach, which is based on the estimation of water utilities cost functions. Three main specific purposes can be found in the relevant empirical literature. One is to evaluate price schemes and to design optimal prices (Garcia-Valiñas, 2005; Garcia and Reynaud, 2004; Kim, 1995; Renzetti, 1992). Another is to analyse the effects of ownership and regulation on utility performance (Saal and Parker, 2000; Bhattacharyya *et al*., 1995; Feigenbaum and Teeples, 1983). Finally, the third purpose is to check for the presence of economies of scale and of scope in the water industry (Stone & Webster Consultants, 2004; Fraquelli *et al*., 2002; Garcia and Thomas, 2001; Fabbri and Fraquelli, 2000; Hayes, 1987; Kim, 1985).

Our research focuses on the third objective, for two reasons. Firstly because the ownership issue is a secondary question, since the great majority of utilities operating in the Portuguese water sector are publicly owned and operated. Second, because evidence of scope and scale economies is central to the debate on the existence of a natural monopoly structure. As noted by Kim (1985:185), if there are economies of scale, large firms could produce at lower average costs than smaller ones, “then a valid policy argument can be made for the establishment of a large firm in order to gain the benefits of these economies.”

Regardless of the main purpose of the studies, the empirical literature which has dealt with the estimation of water cost functions offers several methods of calculating marginal costs. These include econometric techniques (see Garcia-Valiñas, 2005; Garcia and Reynaud, 2004; Timmins, 2002; Feigenbaum and Teeples, 1983; Renzetti, 1992; Bhattacharyya *et al*., 1995) and direct formulas (see Turvey, 1976; Ford and Warford, 1969). The dependent variable commonly used is production (operational) costs, because there is more uncertainty about the calculation of the remaining elements of costs, such as economic and environmental externalities and opportunity costs (Rogers *et al.*, 2002), as pointed out by Garcia-Valiñas (2005:192).

Table 1 provides information related to some of the main studies published on the estimation of water cost function literature.

Table 1 - Summary of selected studies on water utilities cost functions

Author(s) (ano)	Studied area	Functional form	Outputs	Other explanatory variables)	Main results
Martins (2007)	Portugal	*Quadratic, cubic*	$Y_S;Y_I$; $Y_S;Y_{WW}$;	Network length; Customer density; Dummies for privatization and regulation; …	*SP*>0; SL>1 for small and medium production scales; *SP*<0 between Y_S and Y_{WW} for high production scale
Martins *et al*. (2006)	Portugal	*Quadratic*	$Y_R;Y_N$; $Y_S;Y_L$	Network length; Customer density; dummies for management type and regulation;…	*SP*>0 for small production scales; SL>1 for small and medium production scales; Industry average production scale< MES
Coelho (2006)	Portugal	*Quadratic*	$Y_R;Y_N$	---------	*SP*>0; SL>1 for small and medium production scales; Industry average production scale< MES
(*) Garcia-Valiñas (2005)	Seville, Spain	*Cobb-Douglas*	$Y_{S;}$	Input prices; Network length;	Feldstein's formula for pricing achieves distributional objectives without substantially reducing social welfare
Aubert and Reynaud (2005)	Wisconsin US	*Translog*	$Y_{S;}$ Customer s	Input prices; Value of assets; Technical variables	Short run *SL*>1; Long run *SL* ≃ 1 Efficiency partly explained by the regulatory environment
Stone & Webster Consultants (2004)	E & Ws	*Translog*, quadratic	Proxies for Y_S and Y_{WW}	Input prices; Capital stock; …	*SP* < 0 between Y_S and Y_{WW}; Vertical *SP* > 0; *SL* ≃ 1 for WoCs; *SL* < 1 for WaSCs
(*) Garcia and Reynaud (2004)	Bordeaux France	*Translog*	Y Y_S	Input prices; Network length Customers	Prices ≠ Marginal costs → Small welfare losses; Distributional effects of the fixed charge > effects of moving toward efficient pricing
Fraquelli *et al.* (2002)	Italy	*Translog*	Y_i	Input prices	*SP*>0; Moderate *SL* for small production scales
Garcia and Thomas (2001)	Bordeaux France	*Translog*	Y_S; Y_L	Input prices; Number of costumers; Network length; Production, stocking and pumping capacity.	*SP*>0; Moderate *SL*
Saal and Parker (2000)	E & W	*Translog*	Y_S; Y_{WW}	Input prices; Dummies for privatization	*SL*<1 for WaSCs, *SP* < 0 Privatisation increased profits but not productivity; Efficiency improvements with new price-caps.
Fabbri and Fraquelli (2000)	Italy	*Translog, Cobb-Douglas*	Y_S	Input prices; Customers; Network length, water input cost, treatment costs	High *SL* for the average size of Italian firms, *SL*<1 for the biggest operators.
Ashton (2000)	E & W	*Translog*	Proxy for Y_S	Input prices;	*SL*>1
Bhattacharyya *et al.* (1995)	US	*Translog*	*Y*	Input prices	Privately owned water utilities: more efficient for small operation, Public utilities: more efficient for large operation.
Kim (1995)	US	*Translog*	$Y_R;Y_N$;	Input prices; Capacity utilization; Service distance	Existing price structure ≠ Marginal costs but close to second-best optimum.
(*) Renzetti (1992)	Vancouve r Canada	*Translog*	Y_S	Input prices; Customers, Capital stock	Prices ≠ Marginal costs→ Small welfare losses; Ramsey prices→Large reduction in welfare
Hayes (1987)	US	Quadratic	Y_{WH}; Y_R	---------	*SP*>0; SL>1 for small and medium production scales
Kim (1985)	US	*Translog*	$Y_R;Y_N$	Input prices Capacity utilization; Service distance	SL_i >1 for Y_N; SL_{ii} < 1 for Y_R; Generally *SL* = 1; Average production scale> MES
Ford and Warford (1969)	E & W	Linear, quadratic, logarithmic.	Y_S	---------	Uncertainty about *SL*.

Notes: 1 (*) In this Table only aspects related to the cost function are presented, although demand for water function is are also derived.
2. For easier comparison of the studies, the original notation has sometimes been changed.
Y - Water produced, Y_S - Total water supplied; Y_R - Residential water supplied; Y_N - non-residential water supplied; Y_{WH} - wholesale water; Y_{RT} -retail water; Y_L - water losses; Y_{WW} - wastewater collected; Y_i, *i* = gas, water, electricity supply.
WaSCs: Water and Sewerage Companies; WoCs: Water only Companies.
MES: Minimum efficient scale
Source: authors.

As mentioned before, concerning the independent variables, empirical studies test for the influence of two types of variable: output, and other kinds of explanatory variables. In relation to output, some studies follow a single output approach and others a multiple output one. In this latter case, it is usual to find the purpose of analysing whether there is scope for horizontal integration between the supply of water to residential and non-residential consumers, between water supply and sewage collection. Less often involved is the analysis of the water supply and water losses, which is our scope of analysis, and the rationale for vertical integration, i.e., the consequences of the joint production of wholesale and retail water.

When available, authors frequently consider data on the prices of inputs, such as labour, capital, energy, materials and other consumable inputs. In addition, the use of qualitative and technical variables has become common in the literature.

However, when it comes to the availability of water, and even though the importance of an efficient management of these resources is recognized, no cost estimation studies which incorporate that type of information are known. Since the WFD imposes the complete recovery of all components of costs, including scarcity ones, it is extremely relevant to include data related to the availability of water resources in empirical studies, which we have tried to do with our hydrographical region variables.

Different types of data, such as time-series, cross-section and panel data, have been used and several functional forms for the cost equation (Cobb-Douglas, transcendental logarithmic form - *translog*, or quadratic) have been tested.

Regarding the main findings, and in relation to the evaluation of pricing schemes, empirical studies reveal that second best prices do not imply relevant welfare losses. The empirical literature does not indicate a clear relationship between ownership or regulation and performance. With respect to returns to scale and economies of scope, estimations are not conclusive either. However, most studies found that there are economies of scale in the water industry, but only for some levels of output production. In several cases authors even found that diseconomies of scale can occur for high production levels. These last results contradict the belief that the water industry is a natural monopoly for all output levels.

4. Model specification

As seen in earlier, the empirical literature provides several cost function forms. Although the popularity of the *translog* specification is evident, the quadratic functional form has some advantages for our purposes over the *translog* one. As noted by Kwoka (2002:659), the strict cost minimization proposition imposed for Shepherd's Lemma, which is usually applied in *translog* estimation, is suspect in the case of regulated utilities. Indeed, the *translog* form presupposes a firm's rational behaviour[2], which is difficult to find in the water industry, where there is no competition and public management and ownership is very strong, particularly in Portugal. On the other hand, the quadratic form requires fewer behavioural assumptions, it is parsimonious in relation to the number of parameters to be estimated and it is very well-suited to capture the fixed cost effects, which are important in an industry supposed to be a natural monopoly. In addition, the quadratic specification easily gives a measure for economies of scope without requiring modifications concerning zero outputs.

Given the contribution of studies conducted in the field of multi-product water cost function and the type of data available, we use the following quadratic multi-product cost function:

$$C(Y,Z) = a + \sum_{i=1}^{n} b_i y_i + \frac{1}{2}\left(\sum_{i=1}^{n} c_i y_i\right)^2 + \sum_{k=1}^{l} x_k z_k \qquad (8)$$

where C is the (short run) total cost of water supply, a is the regression constant, Y is the outputs vector and Z is the vector of the other variables (technical, structural and industry ambience). Since we have no data for input prices, we assume that: a, b_i and c_i are unspecified functions of the vector W (see Section 2).

The Portuguese water industry's cost structure is evaluated through a multi-product cost function estimation approach, considering two outputs: water supplied (y_S) and water losses (y_L). The model to be estimated is:

[2] The consistency with the production theory requires that if the utilities operate efficiently the cost function must be homogeneous of degree one in input prices and the cost function's Hessian matrix must be symmetric with respect to input prices.

$$
\begin{aligned}
C\left(y_{S_m}, y_{L_m}, Z_m\right) = a + b_1 y_{S_m} + b_2 y_{L_m} + \frac{1}{2}\left(c_1^2 y_{S_m}^2 + c_2^2 y_{L_m}^2\right) + c_1 y_{S_m} c_2 y_{L_m} \\
+ x_1 Leng_m + x_2 Dens_m + x_3 Acq_m + x_4 CM_m + x_5 Reg_m \\
+ x_6 HR_{1m} + x_7 HR_{2m} + x_8 HR_{3m} + x_9 HR_{4m} + x_{10} HR_{5m} + x_{11} HR_{6m} \\
+ x_{12} HR_{7m} + x_{13} HR_{8m} + \mu_m
\end{aligned} \quad (9)
$$

The variables of the Z vector, described in more detail in the next section, are the network length of the system (*Leng*), the customer density (*Dens*), the proportion of raw water acquired from other utilities (*Acq*), the type of utility management (*CM*), a variable related to regulation (*Reg*) and a set of dummy variables related to the Portuguese hydrographical regions. m is the index which identifies each operator (municipality) and μ denotes the usual error term.

The inclusion of water losses as an explanatory variable in the estimation of water utilities' cost functions is very seldom found in the literature. The exceptions known are Garcia and Thomas (2001), Martins *et al*. (2006) and Martins (2007). According to these, water losses can be considered part of the overall inefficiency of the systems and an important concern for water utilities' managers in terms of opportunity costs. From an efficient resource management point of view, water losses are undesirable but, when a final demand has to be satisfied and network leaks exist, utilities' managers face a trade-off between repairing leaks and increasing water production. So we consider water losses as an output jointly "produced" with water delivered to customers. The presence of y_L in our model reports if utilities find it profitable or not to have water losses in water production, and consequently whether they have incentives to repair network leaks, or, alternatively, if a regulatory policy is needed for water losses, to enforce more efficient water supply system.

Marginal cost (*MC*) equations for each output can be easily obtained by differentiating equation (9) with respect to each output. Those marginal costs must represent nonnegative values throughout the relevant domain for equation (9) to be a *proper* cost function.

As mentioned in Section 2, in order to calculate *RAC* it is necessary to aggregate the various outputs into a composite product. Then, considering the ratio (r) between y_L and y_S, we compute the following composite product: $Y = y_S + r y_s$, with $y_S = \frac{1}{1+r}Y$ and $y_L = \frac{r}{1+r}Y$. It is therefore possible to transform equation (9) into a single product cost function, as follows:

$$C(Y,r) = A + \frac{1}{1+r}\left(b_1 + rb_2\right)Y + \frac{1}{2}\frac{1}{(1+r)^2}\left(c_1^2 + r^2c_2^2 + rc_1c_2\right)Y^2 \quad (10),$$

where $A = a + \sum_{k=1}^{l} x_k z_k$.

From (10) we obtain the marginal and ray average cost for the composite product:

$$MC(Y,r) = \frac{1}{1+r}\left(b_1 + rb_2\right) + \frac{1}{(1+r)^2}\left(c_1^2 + r^2c_2^2 + rc_1c_2\right)Y \quad (11);$$

$$RAC(Y,r) = \frac{A}{Y} + \frac{1}{1+r}\left(b_1 + rb_2\right) + \frac{1}{2}\frac{1}{(1+r)^2}\left(c_1^2 + r^2c_2^2 + rc_1c_2\right)Y \quad (12)$$

These measures are very helpful in the cost structure analysis, allowing the interpretation of economies of scale, the existence of a minimum efficient scale on the relevant range of production, and to evaluate the production mix in terms of industry efficiency.

5. Data and estimation procedures

Local communities in Portugal have been responsible for the provision of local water supply and sanitation services since the 1970s. Nowadays these services can be directly provided by municipalities (through municipal services), by *municipalized services*[3] (hereafter designated as SMAS) or by firms. In this last case, there are both municipal public firms and also concessionaries, which can be private, public or public-private partnerships.

The rule is one operator for each municipality. Therefore, the Portuguese water industry is considerably fragmented. Indeed, if we consider entities operating in both wholesale and retail water services then there are more than 280 water supply service providers for the 278 municipalities in mainland Portugal.

Economic regulation is restricted to concessions, and it is limited to a light form of benchmarking regulation, known as "sunshine regulation". This means that the regulator only collects data from operators and discloses information about their relative performance in an annual report. IRAR's power in the field of setting prices is limited to issuing non-binding opinions about pricing regimes, based on an allowed rate of return, and only when it comes to

[3] These services are business units which, unlike municipal ones, have financial and management autonomy, although without a legal standard.

wholesale activity. Regarding retail concessions, the pricing system is one criterion for the selection of the bidders, so it is regulated by the concession contract. But where regulation of quality of water for human consumption is concerned, all water utilities face the same regulatory environment, regardless of the type of arrangement.

Our dataset is composed of data relating to 2002 from INSAAR (National Survey on Water Supply and Wastewater Systems), made available by the Portuguese National Water Institute (INAG); from APDA (Portuguese Association of Water Suppliers); and from the Portuguese National Statistics Office (INE). It is a cross-section data base containing information from 265 utilities.

The dependent variable, total cost (*C*), was computed as the sum of direct operation and management costs, financial costs (interest charges), raw water acquisition expenses (when applicable) and other general costs, such as assets depreciation (INSAAR, 2005). Thus, it is similar to what Rogers *et al.* (2002) have termed "water supply costs"[4]. In relation to this it is important to note that, as it is usual in the empirical literature, because we are using accounting data, we are not able to include some relevant cost components of the true economic cost, such as opportunity costs[5] and environmental and economic externalities.

Concerning the output variables, y_L was directly available from INSAAR, while y_S[6] was computed as the sum of water delivered by public networks to agriculture, households, industry, commerce and services, to other water utilities and to other kinds of customers.

In this analysis, two subsets of other variables (included in the *Z* vector) are considered. The first set includes the network length (*Leng*); the customer density (*Dens*); the proportion of raw water acquired from other utilities (*Acq*), which we calculated by dividing the amount of water acquired from other utilities by the computed value of total amount of water produced (from several sources); the type of utility management (*CM*), a dummy which is equal to 1 if

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[4] Stephenson (2003:209) gives an extensive list of factors affecting water supply costs.

[5] Green (2003:253) considers it more appropriate to use the expression "opportunity value" because it refers to the value of water in an alternative use.

[6] A correction was made to an exceptional case concerning Empresa Portuguesa de Águas Livres, SA (EPAL). EPAL is the unique case of a municipal system, providing retail water supply services to final customers in the city area of Lisbon, and simultaneously a *multimunicipal* system. In this last activity, EPAL acts as wholesale provider to other municipalities. The water delivered to other utilities represents a great part of total water produced compared with the residual role of this part of the business to the whole group of water utilities. Thus, the quantity of water delivered to other utilities by EPAL was ignored, along with the corresponding part in terms of costs.

the utility has a corporate management and 0 otherwise[7] and a dummy variable related to regulation (*Reg*), equal to 1 if the utility faces an economic regulation environment and 0 otherwise.

The second subset corresponds to the group of dummy variables related to the eight[8] hydrographical regions (*HR*)[9]. With these variables, we intend to find out whether the water utilities cost structure varies systematically with the location in a specific *HR*, as long as there is different spatial availability and utilization of water resources. The series for each of these variables is computed admitting the value 1 if the utility belongs to one of the specific *HR* and 0 otherwise.

Empirical literature on the estimation of water industry cost functions reveals that the input prices most commonly used are capital, raw water, labour and energy input prices. Unfortunately, as mentioned earlier, there are no available data for input prices faced by Portuguese water utilities[10].

Constrained by the availability of data, we considered capital a quasi-fixed input (in the sense that its modification in the short-run is either not feasible or extremely costly), letting its effect be captured by variables such as *Leng* and *Dens*. *Dens* was computed by dividing the number of customers of the water supply service (number of connections to the water network system) by the area of the municipality (in square kilometres) in order to obtain a measure of customer density. Similar significance is given to these variables by Garcia and Reynaud (2004) and Aubert and Reynaud (2005).

Concerning raw water, its effect on total cost is captured by the *Acq* variable. Regarding labour and energy inputs, and due to the data constraints mentioned, we have assumed that

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[7] In order to compute *CM* we considered that municipalized water services, municipal water firms and concessionaries (public or private) have a corporate management style, and that municipalities (municipal services), have a non-corporate management style.

[8] HR_1 – Minho and Lima; HR_2 – Cávado, Ave and Leça; HR_3 – Douro; HR_4 – Vouga, Mondego, Lis and Ribeiras do Oeste; HR_5 – Tejo; HR_6 – Sado and Mira; HR_7 – Guadiana; HR_8 – Ribeiras do Algarve.

[9] A hydrographical region (HR) is defined in the Portuguese Water Law (Law no. 58/ 2008, which transposes the WFD for Portugal) as the "land area and sea consisting of one or more contiguous river basins and the associated underground and coastal water resources, being the main unit of management of the river basins".

[10] Even when considering the data collected by INSAAR, the small number of operators which provide information concerning, for example, their labour costs or energy costs, do not provide data on the number of hours worked, nor on the amount of energy used. Thus, it was not possible to compute the respective input prices. This situation can be explained by the fact that of the overwhelming majority of operators do not implement appropriate cost accounting procedures.

utilities face similar inputs prices[11]. This assumption means that, as input prices cannot be explicitly incorporated, they are considered to be included in the fixed components and in the coefficients to be estimated, as unspecified functions of the vector *W*.

Table 2 summarizes some descriptive statistics of the variables used.

Table 2 – Sample descriptive statistics

Series	Obs	Mean	Std Error	Minimum	Maximum
C	218	1,771,827.592	3,718,236.988	1,575	27,760,143.5
y_S	218	1.850	4.076	0.097	41.538
y_L	218	0.614	1.732	0.003	18.771
Leng	218	251.140	384.619	0.06	3,957
Dens	218	137.852	440.138	1.184	3,944.992
Acq	218	0.274	0.379	0	1
CM	218	0.252	0.435	0	1
Reg	218	0.073	0.261	0	1
*HR*1	218	0.055	0.229	0	1
*HR*2	218	0.082	0.276	0	1
*HR*3	218	0.261	0.440	0	1
*HR*4	218	0.280	0.450	0	1
*HR*5	218	0.289	0.454	0	1
*HR*6	218	0.069	0.254	0	1
*HR*7	218	0.096	0.296	0	1
*HR*8	218	0.060	0.237	0	1

The variability of the data is quite high, as revealed, for example, by the amount of potable water delivered, ranging from 90,000 to 41,500,000 cubic meters. Indeed, because cross-section data is used, White's variance-covariance matrix procedure for heteroscedasticity correction was applied in the econometric estimation.

Provided that the model represented by equation (9) was not linear[12], it was estimated using a nonlinear method: the maximum likelihood[13], with the Broyden, Fletcher, Goldfarb, Shanno (BFGS)[14] algorithm.

[11] This assumption could not be very restrictive because Portugal is a small country and thus labour (particularly in municipalities and other public organisations) and energy prices are similar across its regions.

[12] Although the model represented by equation (9) in is not linear, with a redefinition of independent variables (previously modifying the series related to outputs, in order to obtain the squares and the products) it should be possible to use the Ordinary Least Squares (OLS) estimation method. However, this redefinition might not ensure (as confirmed by the attempts done) that the coefficients of y^2_S and y^2_L would be nonnegative and that the coefficient of $y_S.y_L$ would be equal to the square root of the product of the coefficients of y^2_S and y^2_L.

[13] As explained by Greene (2003: 468-492) or by Johnston and DiNardo (2000: 164).

[14] Described in Estima (2004: 253 and after) and in Greene (2003: 170).

6. Empirical results

The estimation results[15] obtained for the quadratic cost function that was set out in equation (9), and applying the methodology described above, are reported in Table 3[16].

Table 3 – Regression results

Parameters	Variable	Coefficients		t-statistic
a	*Const.*	-635,332.6	*	*-2.284*
b_1	y_S	444,401.6	**	*5.318*
b_2	y_L	601,694.4	**	*3.547*
c_1	y_S	-0.000135		*0.000*
c_2	y_L	-0.000245		*0.000*
x_1	*Leng*	440.986		*0.989*
x_2	*Dens*	1,144.94		*1.298*
x_3	*Acq*	1,124,869.9	**	*5.456*
x_4	*CM*	937,294.1	**	*3.409*
x_5	*Reg*	388,279.44		*0.762*
x_6	HR_1	689,466.44	*	*2.344*
x_7	HR_2	-185,152.2		*-0.869*
x_8	HR_3	264,882		*1.385*
x_9	HR_4	496,864.17		*1.601*
x_{10}	HR_5	354,609.94		*1.174*
x_{11}	HR_6	21,939.948		*0.120*
x_{12}	HR_7	27,351.247		*0.120*
x_{13}	HR_8	601,018.31	**	*2.579*
Observations				218
R^2				0.89787

* Significant at 5%
** Significant at 1%

The model considered seems to fit the data well, as indicated by the adjusted R^2 value of approximately 0.90. Even though the estimated regression constant, *a*, is negative, it is more relevant to analyse the value of the overall constant, which corresponds to the fixed costs. As suggested by Kwoka (2002), this overall constant can be obtained by adding to the regression constant the product of the mean value of the other variables (that have no interactions with the outputs) by their corresponding estimated coefficient. Indeed, a joint significance test for

[15] Using *Win*RATS 6.02 software.
[16] The parameters were obtained through an iterative process, which converged after 490 iterations.

these variables confirms their statistical significance[17] and the overall constant becomes positive.

In relation to the output variables, the estimation results indicate that the coefficients for y_S and y_L have the expected positive signal and are both statistically significant. On the contrary and unfortunately, the estimated coefficients for the c_1 and c_2 parameters are not.

Regarding the subset of variables included in the *Z* vector, apart from the *HR* ones, only the coefficients for the *Acq* and *CM* variables are significant at 1% level. The fact that the *Acq* variable is positively correlated with total costs may indicate that it is more expensive to buy wholesale water than to produce it. The *CM* variable is positively correlated with total costs, suggesting that when water is supplied by a corporate management entity, which corresponds to the biggest utilities in terms of volume of water delivered and population served, its total costs are higher than those faced by smaller utilities.

Concerning the *Leng* and *Dens* variables, their coefficients are not statistically significant. However, the *Leng* coefficient exhibits the expected positive sign, suggesting that an increase in the size of the network increases total costs.

The fact that the *Reg* variable does not reveal statistical significance is not surprising since economic regulation in the Portuguese water industry does not seem to be effective in relation to cost efficiency.

With respect to the subset of *HR* variables, even though most of them are not individually statistically significant, a joint significance test[18] for these variables confirms their importance to the model. Although the relevance of environmental and resource costs (remember the legal imposition of its recovery by water utilities pricing policies, mentioned earlier), these results are not entirely surprising since those cost elements were not taken into account when computing total costs. In fact, when composing the database it was observed that only two water utilities had provided[19] information related to these types of costs for the year 2002.

Among the *HR* variables used, only HR_8 is significant at 1% level. Its positive and significant influence on costs may come from its specificities. HR_8 is the Algarve tourism

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[17] χ^2 (14) = 134.698809, significant at 1% level.

[18] χ^2 (8) = 24.178901, significant at 1% level.

[19] Which seems to derive from difficulties of measuring and accounting those costs and not that they do not exist.

region which has the highest water capitation index (INAG, 2007), due to the great percentage of usage of water for various purposes such as golf and other tourism activities, highly intensive in terms of water consumption.

As mentioned in Sections 2 and 4, in order to calculate *RAC* it is necessary to aggregate the various outputs into a composite product (see equation 10). With the estimated coefficients obtained and considering the overall constant, the estimated cost function comes out as:

$$\hat{C} = 580{,}135 + \frac{1}{1+r}\left(444{,}402.61 + 601694.37r\right)Y + \frac{1}{(1+r)^2}\left(0.0000000091 + 0.0000000301r^2 + 0.0000000165r\right)Y^2$$

Ceteris paribus, a lower water losses ratio *r* drives *RAC* and marginal cost downwards. For instance, considering the industry average in terms of the composite output, roughly speaking, the reduction of *r* to 10%[20] would reduce the *RAC* by 3.5% and the marginal cost by 5%.

In order to analyse the behaviour of costs we simulated three levels of production: small, industry average and large scale, considering the proportion $r = y_L / y_S$ fixed at the industry average level. The “small” scale corresponds to a production level of 0.5 million m^3 of the composite output and the “large”[21] scale of 20 million m^3. Then, we computed both marginal and ray average costs, and the degree of economies of scope and of scale for the composite product, as defined in Sections 2 and 4, for the production scales specified above. These results are presented in Table 4.

Table 4 – Costs and economies of scale and scope

Scale of production	Output (10^6 m^3)			Marginal Cost (EUR/m^3)			*RAC* (EUR/m3)	SP	SL
	y_S	y_L	Y	y_S	y_L	Y			
Small	0,375416	0,124584	0,500000	0,44	0,60	0,48	1,64	0,706	3,399
Industry average	1,850229	0,614012	2,464241	0,44	0,60	0,48	0,72	0,327	1,487
Large	15,016624	4,983376	20,000000	0,44	0,60	0,48	0,51	0,057	1,060

[20] The economically optimum level of water losses, reported by OECD (2006:23), is, on average, between 10 and 20% depending on the nature of individual systems.
[21] This scale falls into the group of the biggest water utilities, according to the criteria of APDA (2006), which covers utilities with more than 100,000 customers.

Table 4 reveals that the marginal costs for each of the two specific outputs are almost[22] constant for the three production scales considered. The marginal cost for y_L is greater than the marginal cost of y_S. Therefore, it seems that it is cheaper to produce one additional m^3 of y_S than of y_L, which may be an incentive for reducing water losses.

However, as revealed by the values for the degree of economies of scope (greater than 0), it appears that the joint production of water delivered to final users and water losses is advantageous (in terms of costs), especially for small producers. Thus, it may be a counter-argument to cutting water losses. For the smallest utilities (and even for medium ones, although less evident), water losses can be viewed as a way to compensate the small scale of production. For these operators, it can be inferred from the level of economies of scale that it may preferable to invest in expanding production and storage capacity (even if it implies a greater level of water losses), than in the prevention, detection and repairing of leaks in the system networks, especially if the first option is publicly subsidized.

Regarding the composite output, for the relevant output range, the *RAC* and economies of scale decrease as more *Y* is produced. The smaller utilities seem to benefit from strong economies of scale, while for the largest production scale suggested economies of scale are almost extinguished.

In terms of subadditivity, it seems possible to confirm that there is ray subadditivity because *RAC* is decreasing with the composite output, for the ratio *r*, computed according to the industry average. Therefore, the industry is a natural monopoly for that mix of production.

The industry average production scale does not exhaust the returns to scale allowed. Therefore, more concentration in the water industry should be advantageous in terms of economic efficiency, since it would enable advantage to be taken from economies of scale. This agglomeration benefit is particularly clear for small and medium sized water utilities. Obviously, this efficiency advantage only seems feasible for contiguous operators. Besides, due to the WFD's imposition of complete recovery of total costs through pricing policies, such a strategy would also benefit consumers of water services by the decrease in prices it would permit.

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[22] In Table 5 only two decimal places were considered when reporting marginal costs.

7. Conclusions

The current study of the cost structure of Portugal's water utilities is original in using the broad (and first) database collected on water supply. Moreover, it is innovative in terms of the inclusion of variables related to the hydrographical regions to which water utilities belong.

The results of this study generally agree with the empirical literature and allow us to highlight some general conclusions. Our findings suggest that there are economies of scope from the production of water supply and water losses taken together, meaning that it could be advantageous in terms of technical efficiency for those utilities to maintain some level of water losses than to repair the leaks.

Another major conclusion of this study is that the industry seems to exhibit economies of scale. Therefore, there are pro-aggregation arguments, especially for small and medium sized local water supply systems. Considering the recovery of costs principle, imposed by the WFD, the advantages of such agglomeration would be transferred to users through the likely reduction in the tariff levels.

Even though, in general, the variables related to the hydrographical variables used did not present significant effects on water costs, this does not mean that they are not important to the industry costs. In fact, the resource costs are expected to be directly related to water scarcity, which varies among river basins and hydrographical regions. In our view, the point is that the water operators are not yet appropriately accounting those costs.

Some important policy implications can be derived from the study. One of them is the exhibition of economies of scope between water supply and water losses, which confirms the relevance of an intervention by the regulatory authority on this subject. A key policy recommendation is therefore that the suggestion or definition of an adequate smaller level of water losses by the regulatory authorities may take into account differences among utilities. Although these economies of scope are moderate, their relevance stems from the fact that they could be viewed as way to compensate for the small scale of some municipal utilities, since the water industry seems to have high economies of scale for the smaller scales of production considered.

However, it should be noted that IRAR's limited power to impose or to eliminate barriers to entry into the water industry restricts its role in the promotion of an appropriate market structure. This means that the regulatory authority should be given more effective powers in the Portuguese water industry, especially by extending regulatory control to all the operators.

Another policy implication of the study is that there is a trade-off between the economic and environmental consequences of water losses, which should be appropriately managed by decision makers. This seems to be of particular relevance in the context of scarce water resources. Despite the European and national legal impositions of the complete recovery of water costs, including environmental and resource costs, Portuguese water utilities do not properly account these categories of costs. In our opinion, this situation should be changed, given that it occurs not because these costs do not exist at all, but because few utilities apply proper cost accounting methods. As long as environmental and resource costs are not incorporated, they are not recovered by prices either.

Furthermore, it should be remembered that the most accessible and best quality sources of water are the first ones to be used. As long as it is necessary to use other sources, less accessible and of worse quality, the environment and scarcity costs tend to increase. Therefore, it means that if all those components of costs could have been included in the analysis the results of the study could be modified. Hence, regulatory authorities and other policy makers need to be aware that when the operators are, in fact, compelled to recover those costs, consumers will suffer the consequences in higher water tariffs. Thus, it is crucial to counter-balance this direct influence on tariffs with a higher level of technical efficiency in water supply systems.

The results obtained have to be interpreted with caution, due to the context and limitations of the study. Although we have used the most recently collected data for the Portuguese water sector, no data are available for some relevant variables, such as the input prices and the opportunity, resource and environmental costs, and there is a lack of more detailed information related to availability versus utilization of water resources at integrated river basin level. Further research is also needed on testing for some cost functions properties, and this is only possible if the types of variables mentioned above are included in the estimation process. The limitations are nonetheless simultaneously pointers for further research.

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