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Cost Structure of the Portuguese Water Industry: a Cubic Cost Function Application

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Abstract

The main scope of this paper is to confirm, or otherwise, the idea usually presented in national reports and strategic programmes for the water sector that the Portuguese water market is a natural monopoly. Based on a multi-product approach (considering the m^3 of potable water delivered and wastewater collected as the outputs) we use a cubic functional specification to estimate water utilities cost function, and then to look for the presence of economies of scale and of scope. The estimated results show that the average production scale is below the estimated minimum efficient scale and that large utilities have moderate overall diseconomies of scale and scope. In addition, there are moderate economies of scope from the joint production of potable water and wastewater collection up to the minimum efficient scale, suggesting advantages in merging small and medium sized contiguous water utilities. Sufficient conditions for subadditivity of costs are not verified throughout the range of outputs, allowing us to conclude that the Portuguese water industry is not a natural monopoly for all output vectors.

Key words: cubic function, multi-product cost function, water utilities, regulatory policy.
JEL Classification Code: Q25, L95.

1. Introduction

Although the economic regulation of water utilities has been discussed for several decades, it is still a subject of great debate in most industrialized countries, and Portugal is no exception. One of the arguments justifying the need for economic regulation is the idea, neither empirically tested nor confirmed in Portugal, that there are natural monopoly conditions in the water sector.

The market structure for the Portuguese water sector can be described as multiple municipal monopolies, with heterogeneity of institutional arrangements in water services (water supply and wastewater collection). Portuguese local communities have been responsible for the satisfactory operation of local water supply and sanitation services since the 1970s. Nowadays municipalities can decide either to operate water utilities by themselves or to delegate responsibility to a public or private company, by a concession process. Private sector participation in the Portuguese water industry is residual (less than 0.5% of the utilities in 2002, although it is higher in 2006). In short, water services can be directly provided by local public water authorities (under municipal services - municipalities, *municipalized services*[1] – business units, hereafter designated as SMAS, or municipal public firms), or by companies acting as concessionaires of the systems. In this case there are also some public and private partnerships.

Therefore, the Portuguese water industry is considerably fragmented. If we consider entities that operate in wholesale and retail water services there are more than 300 suppliers of water and wastewater services, for 278 municipalities in mainland Portugal. In this study we only consider operators that supply water and/or provide wastewater services to final users. This option eliminates operators which only act as wholesale providers from our study. We nevertheless use information from 282 operators. Of these, 249 provide water supply and wastewater services, 16 only supply water and the remaining 17 operators only are only involved in the sewerage activity. The great majority of utilities are publicly operated. More than 72% of the operators are organized as municipal services. However, the percentage falls to approximately 33% in terms of the volume of water delivered and to 29% of the volume of wastewater collected. For these items SMAS and (public and private) firms are the most important types of utility.

Concerning economic regulation, Portugal has its own national water industry regulator (IRAR). However, its jurisdiction in terms of 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 collets data from operators and exposes 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 price regimes, based on an allowed rate of return, and only when it comes to wholesale activity. Regarding retail concessions, the price 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.

[1] These services, unlike municipal ones, have financial and management autonomy, although without a legal standard.

The overwhelming opinion in Portugal (e.g. MAOT, 2001 and MAOTDR, 2006) is that prices are underestimated and fail to cover even the operating costs. There is therefore a degree of consensus about the need to change the way tariffs are set, in order to overcome the economic and financial deficit in the sector and to meet the principles, such as the user and polluter pays principle, contained in Directive 2000/60/EC, the Water Framework Directive (WFD).

The Portuguese water market structure needs an evaluation of the cost structure of water utilities for economic regulation to be effective. This kind of analysis would make it possible to conclude, for example, if municipal monopolies are natural monopolies; if marginal cost pricing should be applied, or if greater competition brings advantages or disadvantages. Furthermore, due to the commitment to achieve the targets established on WFD, such as the recovery of costs principle by 2010, and the objectives defined by Strategic National Plan for the Water Sector, PEAASAR II – 2007-2013 (MAOTDR, 2006), such as the increase of the percentage of the population served by public systems of water supply, the need for analysing water supply cost structure is reinforced.

The main scope of this paper is to confirm, or otherwise, the idea usually presented in national reports and strategic programmes for the water sector that natural monopoly conditions exist in the Portuguese water industry. With this purpose and to determine whether and over what range of output there are overall and product-specific economies or diseconomies of scale and scope, we estimate the cost structure of Portuguese water utilities. We intend to ascertain, first, if the idea that there are advantages in merging neighbouring local water utilities within a single water operator is correct and, second, if the joint production of water supply and wastewater services is advantageous, i.e. if the two services are more efficiently provided by a single operator than by separate entities. In other words, the goal of this paper is to analyse whether the evidence of economies of scale and scope presents a case for further horizontal integration in the industry.

One point of interest of our study is the use of a cubic cost function specification. This is very rare in empirical studies, although it is consistent on theoretically. Thus, an innovative contribution of this paper, at a methodological level, is the demonstration that the cubic cost function may be a flexible and appropriate specification for modelling multi-product cost functions, in certain contexts.

This paper is structured as follows. In Section 2 some economic cost analysis concepts are reviewed and a theoretical framework for the use of a multi-product cubic cost function is presented. Section 3 provides a brief overview of the literature on the estimation of cost functions, focusing attention where water cost structure is involved. In Section 4 model specification is given. Section 5 is dedicated to the dataset description and methodology. Empirical results are presented in Section 6, and Section 7 offers some conclusions.

2. Theoretical framework

2.1 Cost function, subadditivity and economies of scale and scope

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, relating to a sector's structural and technical characteristics and economic environment. Therefore, the cost function becomes $C(Y,W,Z)$. In the water industry these variables are related to the network length and connections, customer density, area served, capacity utilization, regulatory environment, natural resource conditions, and so on.

Later we will review some fundamental concepts of regulated market analysis, such as subadditivity, economies of scale and economies of scope, with a multi-product cost function. In order to simplify this part of the analysis, variables other than output variables are suppressed, since this procedure does not interfere with the main expressions and the results obtained throughout 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. Natural monopolies are often identified with economies of scale. However, this condition is neither necessary nor sufficient for natural monopoly under multi-product contexts. As explained by Baumol (1977), cost function's subadditivity is the sufficient and necessary condition for the existence of a natural monopoly. In its simplest formulation, 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, 1988:19-20). Therefore, under a natural monopoly it is not efficient to have several firms producing the output(s).

Following Baumol (1977) and Baumol *et al* (1988), declining "ray average costs" and "transray convexity" are sufficient conditions for subadditivity of costs, under a multi-product cost function approach. The transray convexity concept is "closely related to what Panzar and Willig have named 'economies of scope' ", Baumol (1977:811). In other words, the two sufficient conditions for subadditivity of multi-product cost functions are: economies of scope and decreasing ray average costs. The idea of ray average costs is to aggregate the entire output vector into a composite good through some fixed proportions. Thus, the output bundle varies in fixed proportions along a ray that allows one to measure the average costs as in the single-product case, as reported by Kim (1985:199).

In brief, in order to evaluate the cost structure and to check if there are natural monopoly conditions in water industry, it is important to test for the presence of economies of scope and of product-specific and overall economies of scale. These concepts and the conditions for the presence of these types of economies are reviewed below.

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:

$$SP = \frac{\sum_{i=1}^{n} C\left(Y_{n-i}\right) - C\left(Y\right)}{C\left(Y\right)} \tag{2}$$

where $C\left(Y_{n-i}\right) = C\left(y_1, ..., y_{i-1}, 0, y_{i+1}, ..., y_n\right)$.

Operators face (dis)economies of scope if *SP* takes (negative) positive values. The cost savings of joint production may arise from two sources: by lowering the fixed costs allocated to the products through an excess capacity reduction by producing a large output bundle, and by benefiting from cost complementarity (Pulley and Humphrey, 1991:4). For the two product (*i* and *j*) case, cost complementarity occurs if $\frac{\partial^2 C}{\partial y_i \partial y_j} \leq 0$, meaning that an increase in *j* production decreases, or at least keeps, the *i* product's marginal cost. Cost complementarity is, thus, important for natural monopoly. Accordingly to Baumol (1977:185), 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"[2].

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 measures how costs vary with changes in a specific output, keeping the quantities of the other outputs constant. There are product-specific (for *i* product) and overall economies of scale if SL_i and SL, which are respectively given by:

$$SL_i = \frac{IC_i(Y)}{y_i MC_i(Y)} \quad (3.1); \qquad SL = \frac{C(Y)}{\sum_{i=1}^{n} y_i MC_i(Y)} \quad (3.2)$$

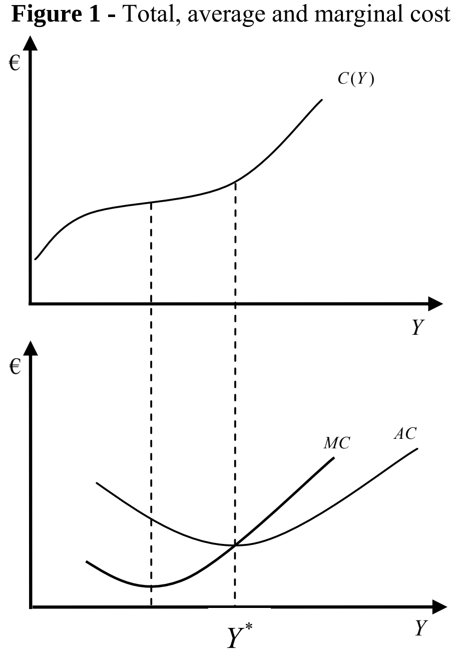
take values larger than unity, with

$$IC_i(Y) = C(Y) - C(Y_{n-i}) \quad (4)$$

being the incremental cost for *i* product, which is incurred by the utility in producing the given level of product *i*, while the quantities of the other products remain constant. The utilities face decreasing returns to scale if $SL < 1$ and constant returns to scale if $SL = 1$.

2.2. Cubic cost function

Figure 1 - Total, average and marginal cost



Estimating the cost structure of an industry requires a choice of functional form. Economic and Microeconomic handbooks contain chapters dedicated to the cost theory analysis which typically represent total costs as a cubic function, especially in the geometry of costs (see, for example Samuelson and Nordhaus (1999:119) or Frank (1999:309)). The U-shaped average and marginal cost curves, which are usually shown in economic textbooks, imply that at some level of output the average cost will start increasing because of diseconomies of scale[3].

[2] For those interested in an exhaustive analysis of the concepts of subadditivity and complementarity see Baumol *et al* (1988), who provide a detailed collection of conditions that are sufficient for subadditivity with or without strong complementarity.

[3] Theoretical references to cubic cost function are also found in water industry literature. See, for example, Dziegielewski (2003:63).

However, when turning theory into practice, the cubic form loses its popularity to quadratic and transcendental logarithmic (*translog*) forms. In this work we demonstrate that although the cubic form is seldom found in empirical literature it may have a role to play, even in the empirical area of cost analysis.

In addition to the data limitations, which sometimes requires the imposition of some restrictive form, the several properties, that a multi-product cost function should include, also limit the choice of the cost specification. About 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, which corresponds to our case, the cost function should yield a reasonable cost figure for output vectors which entail zero outputs of some goods[4]. 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. Fourth, the cost function should not require estimation of the values of an excessive number of parameters, i.e. it should be parsimonious in the number of parameters to be estimated[5]. There is a trade-off between the absence of assumptions on cost properties and the parsimony of parameters to be estimated. For instance, quadratic specification form is more parsimonious in the number o parameters than the cubic form. The latter is more flexible, however, because it permits the nonlinear behaviour of marginal cost(s), whereas the quadratic form imposes that marginal cost(s) increases at some constant rate. In short, the cost function must assume a flexible functional form, i.e. a form that imposes no restrictions on the values of the first and second partial derivatives, Baumol *et al* (1988).

The cubic function thus seems to be a very flexible specification for modelling total cost, because it allows different behaviour of total, marginal and average costs (see Figure 1). Marginal and average costs first decrease and then increase, and so there is an optimal production scale, Y^*. Moreover, the cubic specification seems to be well suited to measuring economies of scope when considering firms whose production of some output is zero.

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[4] According to Baumol *et al* (1988:449), "this is a desideratum violated by several of the functional forms often used in statistical studies", such as the Cobb-Douglas and even the *translog* cost function. In this latter case, 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.

[5] If we have data on input prices the number of parameters to be estimated through the use of a cubic cost function specification is much greater.

For a multi-product firm, maintaining the suppression of variables other than output variables (i.e. in the magnitude of the outputs), the cubic cost function has the following specification:

$$C(Y) = a + \sum_{i=1}^{n} b_i y_i + \frac{1}{2}\left(\sum_{i=1}^{n} c_i y_i\right)^2 + \frac{1}{3}\left(\sum_{i=1}^{n} d_i y_i\right)^3 \qquad (5)$$ [6]

Since we have no data for input prices, we assume that: a, b_i, c_i and d_i are unspecified functions of the vector *W*. To simplify the analysis and because it corresponds to our empirical case, as we will see later on, we continue this brief study of the cubic cost function for the case of two products (i = 1,2). The cost function then becomes:

$$\begin{aligned} C(y_1, y_2) = a + b_1 y_1 + b_2 y_2 + \frac{1}{2}\left(c_1^2 y_1^2 + c_2^2 y_2^2\right) + c_1 y_1 c_2 y_2 \\ + \frac{1}{3}\left(d_1^3 y_1^3 + d_2^3 y_2^3\right) + d_1^2 y_1^2 d_2 y_2 + d_1 y_1 d_2^2 y_2^2 \end{aligned} \qquad (6)$$

Estimates of marginal cost (*MC*) for each output can be derived by differentiating the cost equation (6) with respect to each output, whose expressions are given by equations (7.1) and (7.2) below:

$$MC_1(y_1, y_2) = b_1 + c_1^2 y_1 + c_1 c_2 y_2 + d_1^3 y_1^2 + 2 d_1^2 y_1 d_2 y_2 + d_1 d_2^2 y_2^2 \qquad (7.1);$$

$$MC_2(y_1, y_2) = b_2 + c_2^2 y_2 + c_1 y_1 c_2 + d_2^3 y_2^2 + 2 d_1 y_1 d_2^2 y_2 + d_2 d_1^2 y_1^2 \qquad (7.2)$$

These marginal costs must represent nonnegative values throughout the relevant domain for equation (6) be a *proper* cost function.

The condition for cost complementarity becomes:

$$\frac{\partial^2 C(\cdot)}{\partial y_1 \partial y_2} \leq 0 \Leftrightarrow c_1 c_2 + 2 d_1^2 y_1 d_2 + 2 d_1 d_2^2 y_2 \leq 0 \Leftrightarrow y_1 \leq -\frac{c_1 c_2}{2 d_1^2 d_2} - \frac{d_2}{d_1} y_2 \qquad (8)$$

And it may be verified or not, depending on the data values, as the third set of properties that the cost function should possess, mentioned above.

Finally, incremental costs become:

$$IC_1(y_1, y_2) = b_1 y_1 + \frac{1}{2} c_1^2 y_1^2 + c_1 y_1 c_2 y_2 + \frac{1}{3} d_1^3 y_1^3 + d_1^2 y_1^2 d_2 y_2 + d_1 y_1 d_2^2 y_2^2 \qquad (9.1);$$

$$IC_2(y_1, y_2) = b_2 y_2 + \frac{1}{2} c_2^2 y_2^2 + c_1 y_1 c_2 y_2 + \frac{1}{3} d_2^3 y_2^3 + d_1^2 y_1^2 d_2 y_2 + d_1 y_1 d_2^2 y_2^2 \qquad (9.2).$$

[6] The coefficients 1/2 and 1/3 are simplifications.

As suggested by Kim (1985), in a multi-product cost analysis context, sometimes it is convenient to analyse the structure of costs through a single product cost function methodology. By aggregating the various products into a composite good it is possible to determine the ray average cost of production and to draw curves of ray average and marginal costs in a bi-dimensional Cartesian graphic. For the two product case, considering the ratio (r) between y_1 and y_2, we could compute a composite product, $Y = y_1 + ry_1$, with $y_1 = \frac{1}{1+r}Y$ and $y_2 = \frac{r}{1+r}Y$. It is therefore possible to transform equation (6) into a single product cost function, as follows:

$$\begin{aligned} C(Y,r) = a + \frac{1}{1+r}\left(b_1 + rb_2\right)Y + \frac{1}{2}\frac{1}{(1+r)^2}\left(c_1^2 + r^2c_2^2 + rc_1c_2\right)Y^2 \\ + \frac{1}{3}\frac{1}{(1+r)^3}\left(d_1^3 + r^3d_2^3 + 3rd_1^2d_2 + 3r^2d_1d_2^2\right)Y^3 \end{aligned} \tag{10}$$

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

$$\begin{aligned} MC(Y,r) = \frac{1}{1+r}\left(b_1 + rb_2\right) + \frac{1}{(1+r)^2}\left(c_1^2 + r^2c_2^2 + rc_1c_2\right)Y \\ + \frac{1}{(1+r)^3}\left(d_1^3 + r^3d_2^3 + 3rd_1^2d_2 + 3r^2d_1d_2^2\right)Y^2 \end{aligned} \qquad (11);$$

$$\begin{aligned} RAC(Y,r) = \frac{a}{Y} + \frac{1}{1+r}\left(b_1 + rb_2\right) + \frac{1}{2}\frac{1}{(1+r)^2}\left(c_1^2 + r^2c_2^2 + rc_1c_2\right)Y \\ + \frac{1}{3}\frac{1}{(1+r)^3}\left(d_1^3 + r^3d_2^3 + 3rd_1^2d_2 + 3r^2d_1d_2^2\right)Y^2 \end{aligned} \tag{12}$$

Taking different values for r we can draw different marginal and ray average level cost curves. For example, if we consider the mean value of r, obtained from our data basis, we can graphically represent the curves of marginal and ray average costs for the data sample used. These geometrical representations are very helpful in cost structure analysis, allowing for the interpretation of economies of scale, the existence of a minimum efficient scale on the relevant range of production, and to determine the optimal production mix relative to firm profitability or industry efficiency.

3. Overview of the empirical literature on water cost functions

Various studies have dealt with the estimation of water cost functions in the context of regulating or reorganizing the water industry. Generally, the literature on this subject has two main purposes: one of them is to analyse the importance of ownership to utility performance (see Saal and Parker, 2000; Bhattacharyya *et al*, 1995; Hausman *et al*, 1986; Feigenbaum and Teeples, 1983; among others) and the other one is to check for the presence of economies of scale in the water industry (see, for example, 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 latter type of objective for two reasons. Firstly because the great majority of utilities operating in the Portuguese water sector are publicly owned and operated. Second, because evidence of scale economies is central to the debate on the existence of a natural monopoly structure, the marginal cost pricing practice and the advantages or disadvantages of increasing competition in regulated industries.

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 offers several methods of calculating marginal costs, such as 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 the production (operational) costs (variable, total or average), 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 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	Explanatory variables used (than output)	Main results
(*) Garcia-Valiñas (2005)	Seville, Spain	*Cobb-Douglas*	$Y_{S;}$	Input prices (*K*, *L*, *E*); Network length	Feldstein's formula for pricing achieves distributional objectives without substantially reducing social welfare.
Aubert & Reynaud (2005)	Wisconsin, US	*Translog*	$Y_{S;}$ Costumers	Input prices (*L*,*E*); Value of all assets; Technical variables	Short run $SL > 1$; Long run $SL \simeq 1$
Stone & Webster Consultants (2004)	England & Wales	*Translog* and quadratic	Proxies for Y_S and Y_{WW}	Input prices (*K*, *L*, *E*, *O*) Capital stock (Regulatory capital value, replacement cost value of assets)	$SP < 0$ between Y_S and Y_{WW}; Vertical $SP > 0$; $SL \simeq 1$ for WoCs; $SL < 1$ for WaSCs
(*) Garcia & Reynaud (2004)	Bordeaux, France	*Translog*	Y Y_S	Input prices (*L*, *E*, *M*); Network length (proxy for *K*); % of losses; costumers	Prices ≠ Marginal costs→ Small welfare losses; Distributional effects of the fixed charge > effects of moving toward efficient pricing
Fraquelli *et al* (2002)	Italie	*Translog*	Y_i	Input prices	$SP > 0$; Moderate *SL*; $SL_i > 1$
Saal & Parker (2000)	England & Wales	*Translog*	Y_S; Y_{WW}	Input prices (*L*, *K*, *O*) Dummies for privatization	$SL < 1$ for WaSCs, $SP < 0$ Privatisation increased profits but not productivity
Garcia & Thomas (2001)	Bordeaux, France	*Translog*	Y_S; Y_L	Input prices (*L*, *E*, *M*); Number of costumers; Network length; Production, stocking and pumping capacity.	$SP > 0$; Moderate *SL*
Fabbri and Fraquelli (2000)	Italie	*Translog, Cobb-Douglas*	Y_S	Input prices (*L*, *E*, *M*); Costumers; Network length, water input cost, treatment costs	High *SL* for the average size of Italian firms, $SL<1$ for the biggest operators.
Ashton (2000)	England & Wales		Proxy for Y_S	Input prices (*L*, *M*, *O*);	$SL >1$
Bhattacharyya *et al* (1995)		*Translog*	*Y*	Input prices (*L*, *E*, *M*)	Privately owned water utilities are comparatively more efficient when the operation is small, while public utilities are more efficient when operation is large.
Kim (1995)	US	*Translog*	Y_S; Y_R	Input prices (*L*, *K*, *E*); Capacity utilization; Service distance	$SP > 0$; Moderate *SL*
(*) Renzetti (1992)	Vancouver Canada	*Translog*	Y_S	Input prices (L_o, L_s, *K*); Costumers, Capital stock	Prices ≠ Marginal costs→ Small welfare losses
Hayes (1987)	US	Quadratic	Y_W; Y_R	--	$SP > 0$
Kim (1985)	US	*Translog*	Y_S; Y_R	Input prices (*K*, *L*, *E*) Capacity utilization; Service distance	$SL_{ii} > 1$ for Y_N; $SL_{ii} < 1$ for Y_R; generally $SL = 1$
Ford & Warford (1969)	England & Wales	Linear, quadratic,, logarithmic.	Y_S	--	Uncertainty about *SL*.

Notes: (*) Estimation of the cost function together with the demand for water function. In this Table only aspects related to the cost function are presented.
Translog – Transcendental logarithmic
Y – Water produced, Y_S – Total water supplied; Y_R - Residential water supplied; Y_N non-residential water supplied; Y_W - wholesale water; Y_{RT} -retail water; Y_L – water losses; Y_{WW} – wastewater collected
Y_i, *i* = gas, water, electricity supply
K, L, E, M, O - Capital, Labour, Energy, Materials (consumables), Other inputs, respectively.
SL – Economies of scale; SL_i – product specific scale economies; *SP* - Economies of scope
WaSCs: Water and Sewerage Companies; WoCs: Water only Companies
Source: authors.

Regarding the independent variables, empirical studies test for the influence of two types of variables: output, and other explanatory variables. Concerning output, some studies follow a single output approach and others a multiple output one. In this case, it is usual to find the purpose of analysing whether there is scope for horizontal integration between residential and non-residential water supplied, or less commonly between water and sewerage, which is our scope of analysis, and for vertical integration, between 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 variables has become common in the literature.

Different types of data - 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.

Although theoretical models (based on property rights, public choice and principal agent models) tend to favour the idea that privately owned water utilities will outperform public ones, there are some theoretical counter arguments (based on the degree of competition and the presence of regulation). Furthermore, the empirical literature does not indicate a clear relationship between ownership and performance, Renzetti and Dupont, 2003[7]. With respect to returns to scale, as the above Table reveals, 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, contradicting the belief that the water industry is a natural monopoly for all output levels. The economies of scope results are also ambiguous.

4. Model specification

As seen in the previous Section, the empirical literature contains several cost function forms. Although the popularity of the *translog* specification is evident, "the usual estimation technique for the *translog* relies upon Shepherd's Lemma, a strict cost minimization proposition that is suspect in the case of regulated utilities" as Kwoka (2002:659) observes. Indeed, the *translog* form presupposes a firm's rational behaviour[8] and this is difficult to find in the water industry, where there is no competition and most utilities are publicly owned and operated, particularly in Portugal (see section 1).

[7] This article provides a detailed survey of empirical water utility performance studies from the United States, the United Kingdom and France, independently if the method is the cost function estimation or another one.

[8] Consistency with the production theory requires that to assume that 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.

Furthermore, it is pointed out, for example by Baumol (1977), Fuss *et al* (1978) and Baumol and Willig (1986), that in certain contexts, including the analysis of scope economies in the presence of firms producing zero outputs, the *translog* function is not capable of robustly representing the cost function unless modified for zero output values.

For our purposes, and because of data limitations, the cubic functional form seems to be the most adequate one. Not only requiring fewer behavioural assumptions, the cubic specification seems to be suitable for capturing fixed cost effects, which is an important issue in an industry supposed to be a natural monopoly. Moreover, from the estimated cubic cost function we can compare the costs of a horizontal integrated utility, which provides two outputs (water and wastewater services), with those of two specialised and separate utilities. This is why it does not seem appropriate to use a specification which compels assumptions on or transformations of zero outputs.

Our empirical study will search for three answers. First, it will try to find whether the industry is characterized by economies (or diseconomies) of scale. In other words, which is preferable from the cost minimization point of view: to have a single operator for water supply and/or sewerage services for several supply areas (municipalities), or to have various operators responsible for supplying such services for those areas?

Second, it tests whether there are economies of scope in the water industry, between water delivery and wastewater collection. And, third, it must answer if natural monopoly conditions are verified or not in the Portuguese water sector.

The Portuguese water industry's cost structure will thus be evaluated following a multi-product approach, considering two outputs: potable water delivered (y_{w}) and wastewater (sewage) collected (y_{s}).

Returning to equation (6) and adding the terms related to the variables other than output ones, and simplifying the notation for the coefficients, the model to be estimated becomes:

$$
\begin{aligned}
C\left(y_{w_m}, y_{s_m}, Z_i\right) = {} & \beta_0 + \beta_1 y_{w_m} + \beta_2 y_{s_m} + \frac{1}{2}\beta_3 y_{w_m}^2 + \frac{1}{2}\beta_4 y_{s_m}^2 + \beta_5 y_{w_m} y_{s_m} \\
& + \frac{1}{3}\beta_6 y_{w_m}^3 + \frac{1}{3}\beta_7 y_{s_m}^3 + \beta_8 y_{w_m}^2 y_{s_m} + \beta_9 y_{w_m} y_{s_m}^2 \\
& + \beta_{10} WDens_m + \beta_{11} SMeter_m + \beta_{12} Priv_m + \varepsilon_m
\end{aligned}
\tag{13}
$$

Where m is the index which identifies each municipality (operator), *WDens*, *SMeter* and *Priv* correspond to Z vector variables (described in the next section) and ε_m denotes the usual error term.

Although this model is not linear, with a redefinition of independent variables it is possible to use the Ordinary Least Squares (OLS) estimation method. Because cross-section data is used, White's variance-covariance matrix procedure for heteroscedasticity correction is applied. Setting $y_{ww} = \frac{1}{2} y_w^2$, $y_{ss} = \frac{1}{2} y_s^2$, $y_{ws} = y_w y_s$, $y_{www} = \frac{1}{3} y_w^3$, $y_{sss} = \frac{1}{3} y_s^3$, $y_{wws} = y_w^2 y_s$ and $y_{wss} = y_w y_s^2$, equation (13) becomes:

$$\begin{aligned} C\left(y_{w_m}, y_{s_m}, Z_m\right) = {} & \beta_0 + \beta_1 y_{w_m} + \beta_2 y_{s_m} + \beta_3 y_{ww_m} + \beta_4 y_{ss_m} + \beta_5 y_{w_m} y_{s_m} \\ & + \beta_6 y_{www_m} + \beta_7 y_{sss_m} + \beta_8 y_{wws_m} + \beta_9 y_{wss_m} \\ & + \beta_{10} WDens_m + \beta_{11} SMeter_m + \beta_{12} Priv_m + \varepsilon_m \end{aligned} \tag{14}$$

5. Data and estimation procedures

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 282 utilities.

Our dependent variable, total cost (C), was computed as the sum of direct costs of operation and management, financial costs (interest charges), raw water acquisition expenses (when it occurs) and other general costs, such as assets depreciation, INSAAR, 2005. Thus, it is a similar to what Rogers *et al* (2002) have termed "water supply costs"[9]. In relation to this it is important to note that 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[10] and environmental and economic externalities, as is usual in the empirical literature.

Constrained by the availability of data, we considered capital a quasi-fixed input, letting its effect be captured by *WDens* and *SMeter* variables. *WDens* was computed by dividing the number of customers of the water supply service (number of connections to

[9] Stephenson (2003:209) gives an extensive list of factors affecting water supply costs.
[10] 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.

the water network system) by the area of the municipality (in squared kilometres) in order to obtain a measure of customer density. Although *SMeter* provides information on the number of connections related to the wastewater service, we did not apply the same procedure as we did to the number of water supply customers, to avoid multicolinearity problems.

The third Z vector variable, *Priv*, refers to the form of the utility ownership and is a dummy variable which takes the value 1 if the utility is privately (totally or partially) owned, and the value 0 otherwise. With this variable we intend to find whether water utility costs structures vary systematically with the type of ownership.

Unfortunately, as mentioned earlier, there are no available data for input prices faced by the Portuguese water utilities, so we assumed that they face the same input prices. This assumption is not a very restrictive one because Portugal is a small country and so labour and energy input prices are similar across its regions. In addition, that assumption means that, as input prices can not 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 related to the variables used.

Table 2 – Sample descriptive statistics

Series	Mean	Std Error	Minimum	Maximum
Total Cost (€ 2002)	2576005.228	6097029.778	45245	59126742
y_w (10^6 m^3)	1.663578	3.836753	0	41.538359
y_s (10^6 m^3)	1.037427	2.547816	0	24.139965
WDens	119.104257	399.547875	0	3944.992332
SMeter	11966.60656	29124.03463	0	315670
PRIV	0.035971	0.186554	0	1

Source: Authors

As Table 2 reveals, the variability of the data is quite high. The volumes of potable water delivered and of wastewater collected range from 0 to 41,500,000 and from to 0 to 24,000,000 cubic meters, respectively. If we consider only the utilities that provide the service (i.e. ignoring the operators that do not provide one of the services, corresponding to the minimum values of zero, just mentioned), then the volume of water delivered ranges from 97,000 to 41,500,000 and the volume of wastewater from 17,000 to 24,000,000 cubic meters. The same occurs with data related to customers, when considering only the utilities that provide the service, the number of water supply services' customers ranges from 290 to 334,417 and the number of wastewater services' customers ranges from 238 to 315,670.

Table 3 provides some practical justification for the relevance of testing for the presence of economies of scope between water delivery and wastewater services in the Portuguese water industry.

Table 3 – Percentages of volumes, costumers and operators by type of organization (2002)

Type of Operator	Nr	Operators ($y_w + y_s$)	Operators (y_w + 0)	Operators (0 + y_s)	Volume y_w	Volume y_s	Customers y_w	Customers y_s
Municipality	223	72.3%	1.1%	5.7%	33.4%	29.2%	38.5%	47.2%
SMAS	36	10.6%	1.8%	0.4%	41.2%	43.7%	38.0%	39.5%
Firms	23	5.3%	2.8%	0.0%	25.5%	27.0%	23.5%	13.3%
Total	282	88.3%	5.7%	6.0%	100.0%	100.0%	100.0%	100.0%

Source: Authors, based on INSAAR.

As one can see, approximately 88% of the utilities provide both services, and approximately 6% only one of them. Besides, as columns 4 and 5 reveal, it would not make sense to adopt any strategy relating to 0 output, since it corresponds to real cases, (around 12% of the number of operators). The fact that almost 88% of the operators provides both services justifies our multi-product approach.

6. Empirical results

Applying the methodology described before and using RATS 6.0 software we obtained the estimation results for the cubic cost function that was set out in equation (14), and these are reported in Table 4.

Table 4 – Estimation results

Coeff.	*Variable*	*Estimative*	*Std. Error*	*Signif.*
β_0	*Constant*	64211.623	163196.099	0.6940
β_1	y_w	1244187.902	286699.209	0.0000
β_2	y_s	-676192.784	202682.338	0.0008
β_3	y_{ww}	-290419.189	164045.222	0.0767
β_4	y_{ss}	838747.346	382211.891	0.0282
β_5	y_{ws}	-60065.582	217610.637	0.7825
β_6	y_{www}	9638.074	5798.269	0.0965
β_7	y_{sss}	-50606.318	22878.451	0.0270
β_8	y_{wws}	22054.745	6926.966	0.0015
β_9	y_{ssw}	-23937.407	7852.222	0.0023
β_{10}	*WDens*	-1161.085	1374.037	0.3981
β_{11}	*SMeter*	80.713	29.472	0.0062
β_{12}	*Priv*	1798860.313	867053.427	0.0380

Observations: 278[11]; Adjusted R^2= 0.89986.
Source: Authors.

The model considered seems to fit the data well, as indicated by the adjusted R^2 value of 0.90. Even though the estimated regression constant is not statistically significant, the overall constant, which corresponds to the fixed costs, i.e., the regression constant plus the product of the mean value of the other variables that have no interactions with the outputs by correspondent estimated coefficients, is positive, and a conjunct significance test for these variables confirms its statistical significance[12].

With respect to output variables, the estimation results indicate that, forepart from $y_{ws,}$ the other eight variables all have significant effects on total costs, at least at 10% level of significance. Unfortunately, although presenting the expected negative sign, the *WDens* variable is not statistically significant. Although private ownership is residual, the *Priv* variable is positively related to total costs and this variable is statistically significant.

In order to analyse marginal costs for each product and product-specific economies of scale, we simulated three levels of production: industry average, minimum efficient scale (MES), and large scale, say, twenty million m^3, considering the proportion $r = y_s / y_w$ fixed at the verified average. In addition, we computed both marginal and ray average costs, and the degree of economies of scope and scale for the composite product, as defined in Section 2.2, and for the scales of production specified above. These results are presented in Table 5.

[11] Because of a certain lack of information we have omitted four operators from our estimation procedures.

[12] $\chi^2(4) = 15.743279$.

Table 5 – Marginal, ray average costs and economies of scale and scope

Scale of production	Output (million m^3)			MC (€/m^3)			RAC (€/m3)	SP	Economies of scale (*SL*)		
	y_w	y_s	Y	y_w	y_s	Y			y_w	y_s	Y
Ind. average	1.663578	1.037427	2.701005	0.78	0.02	0.48	0.85	0.455	1.239	-18.892	1.747
MES	6.216154	3.876467	10.092621	0.28	1.14	0.61	0.61	0.217	1.436	0.525	1.000
Large	12.318215	7.681785	20.000000	1.43	0.86	1.21	0.74	-0.113	0.109	2.207	0.611

Source: Authors.

Comparing the marginal costs of water supply and wastewater collection shows that their relationship varies with the scale of production. Thus, for the industry average and for large scales of production, the marginal cost of water supply is greater than the wastewater collection's marginal cost, while for the MES it is cheaper to produce an extra m^3 of potable water than an extra m^3 of wastewater collection.

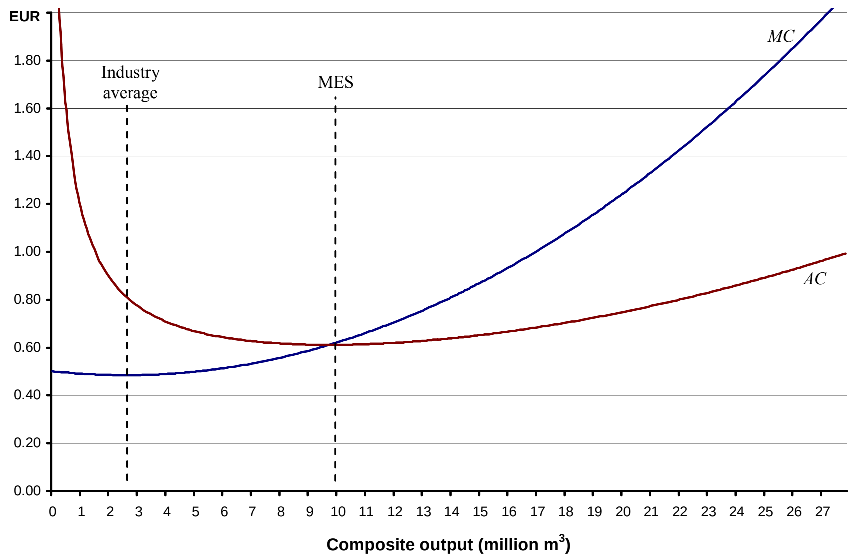
The marginal cost for y_W starts by falling and then rises, while the marginal cost for y_s has the opposite behaviour. Concerning product specific economies of scale, there are also different performances between y_w and y_s. Relative to water supply, there are positive and increasing specific economies of scale up to the MES, and for large scale production there are diseconomies of scale. Concerning wastewater collection, the industry average reveals strong specific diseconomies of scale, which attenuates with increasing production scale, allowing for increasing specific returns to scale for the large production scale considered.

The condition for cost complementarity (see inequality 8) becomes as: $y_W \leq 1.362 + 1.085 y_S$. It is then easy to verify that the cost complementarity condition is achieved in the industry average production scale, but it is not achieved either in the MES or for large production scales.

Regarding the composite product, economies of scale and scope are decreasing with production scales. However, as reported in Table 5, there are moderate economies of scale and scope up to the MES. For the large production scale suggested, there are diseconomies of both scale and scope.

Figure 2 shows the estimated marginal and ray average costs for the composite product and facilitates their interpretation.

Figure 2 – Marginal and ray average costs



As is clear, *RAC* has a U-shaped form and marginal cost increases with the composite product. It is also clear that the industry average production scale is lower, and a long way from the estimated MES. Therefore, more concentration in the water industry should be advantageous in terms of economic efficiency, since it would enable advantage to be taken of economies of scale.

Figure 3 shows three different *RAC* curves for the same number of different levels of *r*, including the industry average ratio ($r = 0.624$), and also the industry average level of the aggregated product and the estimated MES.

Figure 3 – Ray average cost curves

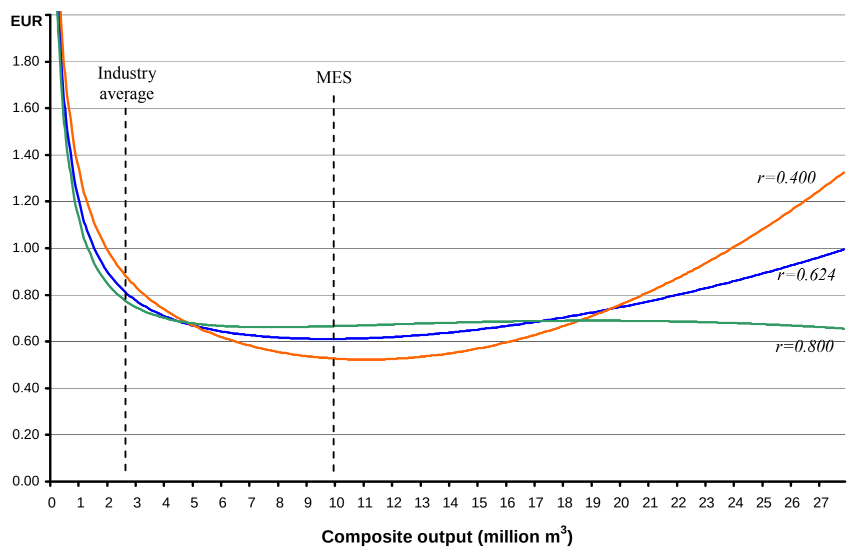


Figure 3 also shows that the gap between the industry average level and the MES depends not only on the level of the production scale but also on the composition of the aggregated output, in other words, on the *r* ratio values. This means that we cannot conclude that there is an *r* value which guarantees that its corresponding *RAC* is the minimum for all the relevant output range.

However, it is possible to say that, for the smallest production scales, up to 4.7 million cubic meters, of the composite output (corresponding to the range where the industry average lies), roughly speaking, the less the ratio *r*, the higher the corresponding *RAC*. This means that, up to approximately 4.7 million cubic meters of the composite output, it is better to produce water collection output quantities close to potable water quantities. For medium production scales, say between 4.7 and around 17 million *Y* (corresponding to the range that where the MES average lies), there is a direct relationship between *r* and *RAC*, and for the highest production scales it seems again to be better to produce similar quantities of the two outputs considered.

To sum up, the above tables and figures show that the average industry production scale is below the estimated MES, meaning that the agglomeration of small and medium neighbourhood municipal systems should allow cost savings and improve economic efficiency, as concluded by Martins *et al* (2006) in their study on the estimation of Portuguese water utilities' cost function, with a different cost specification and only for water supply services.

Sufficient conditions for subadditivity of costs are not found throughout the range of output production for the model tested, which does not permit the Portuguese water industry to be defined, in Baumol's words (Baumol, 1977:812), as a "natural monopoly (for) all output vectors".

7. Conclusions

While the results obtained have to be interpreted with caution, because estimates of costs may require more detailed data, they are quite helpful even when interpreted as rough approximations. It is also important to note that it is very difficult to obtain an estimated cost function for a representative water utility owing to the heterogeneous environment which characterizes the Portuguese water sector. However the cubic cost function specification used seems to fit the data well, and proved to be a flexible functional form for that type of context, when there are important data restrictions.

Although we have used the most recently collected data for the Portuguese water sector, there are no available data for some relevant variables, such as labour, energy and capital input prices. So the analysis presented here does not offer definitive answers. Nevertheless, the results obtained generally agree with the empirical literature and allow us to highlight some general conclusions.

One of the main conclusions of this study is that the average production scale for the Portuguese water sector is below the estimated minimum efficient scale, which is a pro-aggregation argument for small and medium sized contiguous water supply and sewerage systems. Considering the recovery of costs principle, imposed by WFD, the advantages of such agglomeration would be transferred to users through the likely reduction in the tariff levels. Large utilities, however, appear to have moderate overall diseconomies of scale, contradicting the general belief that in water markets economies of scale persist almost indefinitely.

Secondly, there are small economies of scope from the joint production of water supply and wastewater collection for the average utility and up to the minimum efficient scale, meaning that it could be advantageous in terms of technical efficiency for those utilities to provide both services. In other words, although limited, there is some scope for horizontal integration. For large utilities, however, there are diseconomies of scope and scale, and so separation of the two activities seems to be the best choice.

Another general conclusion is that the sufficient conditions for subadditivity of costs are not verified throughout the range of output production. Therefore it is not possible to define the Portuguese water sector as a natural monopoly for all output vectors.

The results obtained also make it possible to make some regulatory recommendations concerning market structure. The regulator should promote an appropriate market structure. In some cases it seems clear that merging small local water utilities into a single operator would be advantageous, while in other cases the introduction of some kind of competition should be encouraged, since the largest utilities are characterized by diseconomies of scale. But IRAR's limited power to impose or to eliminate barriers to entry into the water industry restricts its role in the promotion of competition, when this is recommended. This means that the regulatory authority should be given a more effective role in the Portuguese water industry, especially in terms of putting all the operators under its regulatory control.

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