TECHNICAL INEFFICIENCY IN MUNICIPAL WATER DISTRIBUTION SERVICE: A CASE STUDY FOR PORTUGAL

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Resumen

The main goal of this paper is to measure the cost inefficiency of Portuguese water delivery public service incorporating on the stochastic frontier some exogenous influences on efficiency. For this purpose, we employ a Cobb-Douglas stochastic frontier cost function to represent the technology of water distribution service. Empirical results show that firm-specific factors explain differences on mean efficiency between regions.

Palabras clave: Stochastic cost frontier; municipal water distribution; firm-specific factors; cost inefficiency.

Area temática: Economía Nacional e Internacional.

1. Introduction

Recently, empirical study of water regulated utility performance has become an important policy issue in many countries. A substantial amount of research has been conducted on cost structure and efficiency analysis in the water industry (see Bosworth (1994), Cowan (1997), Cubbin and Tzanidakis (1998), Crafts (1998), Lynk (1993), Ashton (1999), Stewart (1993), Price (1993), Garcia et al. (2001), Bhattachatyya et al (1995), Reynaud (2003) and Estache et al (2002)). Early studies used standard regression techniques and productivity indicators such as input-output relations (Gotlieb, 1963, Maidment, E. and Parzen, 1984) to attempt to analyse the sector. However, because the first approach assumes that all the firms are, on average, efficient and the second one does not considers the interaction between more than one input-output relation, the stochastic approach option raise as an alternative methodology. After Farrell (1957), who first proposed a method of measuring relative efficiency, numerous studies have been devoted to the use of the stochastic frontier methodology for estimating efficiency[1]. Originally proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), the stochastic frontier approach involves an unobservable random error composed by the inefficiency of individual firms and by a random variable, as it happens in a traditional regression model, which accounts for measurement error in the output variable, luck, weather etç. The use of cost estimation in water distribution sector has been greatly enhanced by the introduction of new methods for investigating sources of firm inefficiencies (Bhattachatyya et al (1995).

An alternative point of view deals with the idea that some exogenous variables do not influence the structure of the frontier but their variation may be associated with the variation in the level of the estimated efficiency (Kumbhakar Ghosh and McGuckin (1991) and (Battese and Coelli, 1995).

The purpose of the paper is to analyse the cost efficiency of public water service in Portugal, with a technical efficiency effects model Coelli et al. 1998). This paper enlarges previous research on water delivery service, focusing in a national European market: Portugal. To our knowledge, this is the first paper on the Portuguese water market. Moreover, we display an up date literature review. The motivation for present research is the following: First, the waste observed in water management services. According to the media, about 30% of purchased water, is lost between the capture and the consumption. This represents a great percentage of waste in the water management services. Second, the literature on water efficiency refers to a positive correlation between inefficiency levels and municipalities consumption dimension (Bhattachatyya et al, 1995). Finally, regional differences on inefficiency along the sample are expected, explained by differences in areas, population density, etç.

The remainder of the paper is organized as follows. The next section briefly reviews literature on efficiency related with cost estimation of water distribution sector. The third section explains the methodology and the model used in this study. Section IV presents general aspects of the Portuguese water supply industry. Description of data set, specification of the model and empirical results are presented in Section V. VI-Political Implications are derived. Section VII summarizes the findings of this research.

2. Literature Survey

A significant number of studies on water industry have been undertaken in the last four decades. The majority of these studies were U.S. applications. The first's studies (eg. Gotlieb, 1963) were mainly concerned with one particular class of a water resources system, namely, the public multipurpose development of surface water through storage dams, canals, and other large engineering structures (Ciriac-Wantrup, 1967). Some years later had been published a vast number of empirical studies applying non-frontier regression analysis to the problem concerned with the explanation of the differences in residential water consumption in U.S. cities (Wong, S. T., 1972, Foster and Beattie, 1981, Gibbs C., 1978 and Griffin et al., 1981).

Time series and multiple regression analysis were also used to develop statistical models from past data in order to forecast the amount of water used in a city (Maidment, E. and Parzen, 1984). Since the last years of 1977's, investigation has been increasingly interested on cost structure and efficiency analysis in water distribution service. Most of these studies are concerned with comparison of economic efficiency between private and public water companies[2]. To assess the relative efficiency of a company within an industry benchmarks or efficient frontiers have been estimated by different techniques. In the literature is found a lot of references to the utilization of DEA methodology in the economic analysis of the water sector: Byrnes, S. et al. (1985), Raffiee et al. (1993), Cubbin and Tzanidakis (1998)[3] and Thanassoulis, E. (2000).

[2] See Bruggink (1982), Lynk (1993), Bahattacharyya et al. (1995), Parker et al. (2001), Feigenbaum and Teeples (1983) Morgan (1977) and Crain and Zardkoohi (1978).
[3] The authors presented a comparison of the efficiency estimates by DEA and econometric regression models.

From econometric studies on water cost efficiency, the evaluation of the economic and productive performance, have been primordial. Asthon (1999) analysed the water and sewage industry in England and Wales with a translog cost frontier in relation to ten firms observed from 1989 to 1997. The output used was the number of households connected to a water distribution system. The inputs used were labour, consumables and capital, with the price of labour calculated as the ratio of yearly staff costs to the number of full-time equivalent employees. The price of consumables was defined as the ratio of level of spending on consumables, including power, materials, taxes, direct costs and servicing, to fixed costs. The price of capital was defined as the ratio of yearly spending on tangible fixed assets and depreciation to fixed assets.

Garcia and Alban (2001) analysed the cost structure of French water municipalities' utilities with translog cost function. Turning to other studies, a number of them have been concerned with the estimation of cost frontier functions for the water sector. Stewart (1993) estimated a variable cost function for a sample of water companies from United Kingdom. As explanatory variables he considered the volume of water delivery, length of the network, share of water delivery to non-domestic consumers and load factors.

Estache and Rossi (2002) used the parametric frontier methodology to estimate a frontier cost function for a sample of Asian and Pacific Region Water companies. As explanatory variables they considered the number of clients, daily production, population density in the area served, number of connections, percentage of water from surface sources, salary, number of hours of water availability, relation between residential sales and total sales in cubic meters and a dummy for the type of treatment. They compared the performance ranking from efficiency frontier measures to those obtained from productivity indicators.

Lynk (1993) used a stochastic frontier analysis to assess the efficiency on water only and water and sewerage of water industry of England and Wales. They used the price of labour, the water supply measured as supply per day, and the sewerage output measured as the trade effluent output per day, a time dummy and a regional dummy. Cost minimisation issue in water sector and the investigation of sources of inefficiency were analysed by Bhattacharyya, et al (1995)[4].

[4] They used US data on 190 public and 31 private urban water utilities.

3. Methodology and General Cost Model

During the last decade and applied to the study of infrastructure sector, we have assist to the increase of performance indicators in economic analysis. These performance indicators can be productivity indicators (simple ratio measures such as input-output relations) or production and cost frontier estimates. The first kind of indicators although is quite commonly used by regulators to assess the performance of firms, only considers a single input in isolation. The second kind of indicators permits the evaluation of unit's performance accounting for all factors of production simultaneously.

Farrell's (1957) seminal article on economic efficiency measurement in terms of realised deviations from an idealised frontier isoquant, led to the development of several approaches to efficiency analysis. According to the method chosen to estimate the frontier, we have mathematical programming, generically referred to as data envelopment analysis (DEA) Charnes et al. (1978), or the econometric estimation of the frontier. While the former approach (non-parametric) does not impose a particular functional form, the latter approach (parametric) does it. The problem with the DEA approach is that standard statistical theory to test hypotheses cannot be applied. This limitation was addressed with the specification and development of statistical econometric methods applied to frontier studies.

The econometric approach involves the specification of a parametric representation of technology. The early parametric frontier models proposed by Aigner and Chu (1968) and by Afriat (1972), are deterministic in the sense that they do not account for the possibility that random shocks may affect the firm; the error structure is a purely one side one and only reflects the inefficiency. The stochastic frontiers methodology (Kumbhakar et al. 2000), independently and almost simultaneously proposed by Meuseen and van den Broeck (June, 1977) Aigner, Lovell and Schmidt (July, 1977) and Battese and Corra (1977) is motivated by the idea that deviations from the frontier might not be entirely under the control of the firm; the economic performance of a firm is affected by the two components of the error term: a symmetric disturbance term, which allows for random variation and an asymmetric disturbance term, which represents inefficiency. Few years later, empirical frontier studies had attempted to identify factors which explain sources of inefficiency and two similar methodologies had been proposed: *the two-stage approach* (Pitt and Lee , 1981 and Kalirajan, 1989), and the *single-stage approach* (Kumbhalkar, Ghosh, and McGuckin (1991), Reifschneider and Stevenson (1991), Huang and Liu (1994)[5], and Battese and Coelli (1992, 1995). Researchers as Coelli, T. J. (1996), Battese, G. and Corra, S. (1997), Coelli, T., Perelman, S. and Romano, E. (1999), Battese, G. and Heshmati, A. and Hjalmarsson, L. (2000), Wang, H. and Schmidt, P. (2002), Kim, Sangho (2003)[6] contributed for the literature with empirical studies for the explanation of variation in efficiency. The main idea behind the *single-stage approach* is that the error component, which captures the effects of technical efficiency, has a systematic component $\delta' z_i$, associated with the firm-specific factors, and a random component ε_i. Following the contributions of Kumbhakar, Ghosh and McGucking (1991), and Battese and Coelli (1992, 1995) the general model is specified as:

$$\ln y_i = \ln f\left(x_i;\beta\right) + \varepsilon_i$$
$$\varepsilon_i = v_i + u_i$$
$$u_i = \delta' z_i + \xi_i$$

where y_i denotes the output (in the case of stochastic cost function, y_i is the cost) of the i-th firm;

x_i represents a (1xN) of<explanatory variables for the ith-firm;

β is a vector of unknown parameters to be estimated;

$\varepsilon_i = v_i + u_i$ represents the entire error of the model. The error term is composed of two parts: The statistical noise (v_i) is a two-sided disturbance which allows the frontier to vary randomly across firms and is assumed to follow a normal distribution N($0, \sigma_v^2$) and the other component (u_i)is a one-sided non-negative and unobservable random variable associated with the technical inefficiency of a firm, given the levels of output and inputs, which reflects the deviations from the frontier due to factors under the firm's control. This component is assumed to be independently distributed of v_i and the regressors and to follow a asymmetric distribution with variance σ_u^2 and a random error ξ. Various distributions have been suggested in the literature: Aigner, Lovell and Schmidt (1977) suggested an half-normal, Stevenson (1980) a truncated-normal, Green

[5] The authors allowed iterations between firm-specific variables and input variables.

[6] Coelli, T. J. (1996) used data on electricity generating plants in Australia to illustrate the single stage methodology; Battese, G. and Corra, S. (1997) considered data on wheat farmers from Pakistan to investigate the behaviour of technical efficiencies of the wheat farmers under three different models for the technical efficiency effects; Coelli, T., Perelman, S. and Romano, E. (1999), conducted a study, including three different models adjusted to account for environmental influences, about the comparative performance of 32 international airlines over the period (1977-1990); Battese, G. and Heshmati, A. and Hjalmarsson, L. (2000), adopted an unbalanced panel over the period 1984 to 1985 to investigate the effect of inefficiency over the labour-use in Swedish banks; Hattori, T. (2002), estimated and compared the technical efficiency of the US and Japanese electric sectors during the period 1982-1997, using an input distance function adjusted to account for environmental factors; Wang, H. and Schmidt, P. (2002) proposed a class of "one step" models based on one scaling property against the "two step" procedure; Kim, Sangho (2003), estimated a translog stochastic frontier production function to investigate sources of technical inefficiency in Korean manufacturing industries.

(1980) an exponential and Meeusen and van den Broeck (1977) suggested a gamma distribution. Following the methodology proposed by Kumbhakar et al. (1991) and extended to panel data by Battese and Coelli (1995), the inefficiency effects model to be estimated is used to explain different levels of inefficiency among municipalities. So, the asymmetric part of the entire error is an explicit function of K explanatory variables Z associated with firm-specific factors, which may explain the fall from the frontier. The one-sided error term is specified as:

$$\left[u_i = \delta_0 + \sum_k^M \delta_k Z_{ki} + \xi_i\right]$$

where δ_0 and δ_k are parameters to be estimated and ξ is a random error defined by the truncation of the normal distribution such that $\xi_i \geq -[g(z_i;\delta)]$, Z_i is a kx1 vector of firm-specific factors which may influence the efficiency of a firm. Some special cases may occur: If z_i contains only the value one (it means, only a constant term) and the coefficients of all other z-variables are zero or $\delta_1=0.....\delta_k=0$ (with k= number of i firm specific factors), then the model reduces to the truncated normal specification proposed by Stevenson's (1980) where the $\mu=\delta_0=1$. On other hand, if $\delta_0 = \delta_1 = ... = \delta_k = 0$ this specification collapses to the Aigner, Lovell and Schmidt (1977) half normal stochastic frontier model with zero mean ($\delta_0=0$). The parameters of inefficiency model are simultaneously estimated with those of the frontier cost function using maximum likelihood procedure: β and δ coefficients are estimated together with variance parameters which are expressed in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2)}$ where parameter γ has a value between zero and one. Using the estimated parameters and variances, municipality-specific estimates of cost inefficiencies measures are calculated using the procedure suggested by Jondrow et al. (1982) and the expression of Battese and Coelli, (1993) for the conditional expectation of $\exp(-u_i)/\varepsilon_i$:

$$\begin{aligned} TE_i &= E[\exp(-u_i/\varepsilon_i)] \\ &= \left\{\exp\left[-\mathrm{u_i} + \frac{1}{2}\sigma_*^2\right]\right\}\left\{\phi\left[\frac{u_i}{\sigma_*} - \sigma_*\right] / \phi\left[\frac{u_i}{\sigma_*}\right]\right\} \end{aligned}$$

where $\phi(.)$ represents the distribution function of the standard normal random variable,

$$u_i = (1-\gamma)\left[\delta_0 + \sum \delta_j z_{ji}\right] - \gamma\varepsilon_i$$

and

$$\sigma_*^2 = \gamma(1-\gamma)\sigma^2$$

According to different specifications for the determinants of efficiency variation, four versions of the specified model had been considered and tested:

Table 1: Different Specifications for the Inefficiency Effects Model

Model II-A	*Only with a regional component; without network and geographical characteristics.*
Model II-B	*Only with network and geographical characteristics and without regional component.*
Model II-C	*Only with geographical and regional component; without network characteristics.*
Model II-D	*Only with network characteristics; without geographical and regional components.*

4. The Portuguese Water Supply Industry

Given the recent attention for the role of water service in a regulatory environment, there is a need for more empirical knowledge on the water cost structure. This study is concerned with the investigation of the main sources of regional cost inefficiencies in municipal water distribution service in Portugal, using a parametric frontier approach[7]. Over the past thirteen years had occurred in Portugal important economics and socials changes that affected water use per person and lead to an increase in the percentage of the population served: Between the mid-1970 and the end-1990, the percentage of population supplied by water systems, rose from 46% to almost 90% (PNA, 2001).

As others network industries (electric power, telephone, urban transport) Portuguese water distribution is also characterized by local natural and public monopolies. Production, treatment and distribution of water in Portugal have traditionally been a public enterprise. Local authorities (municipalities) conduct, most of the cases, the water service within each of the seven regions of the country: *Norte, Centro, Lisboa e Vale do Tejo, Alentejo, Algarve, Açores e Madeira*.

Since 1993, and with the introduction of a new regulation in the water sector, we have assisted to the delegation of municipal management responsibility to private specialized firms. The movement towards privatization of water supply service with alternative contracting schemes (private concession (about 5%), mixed enterprises (2%) has instigated some public controversy. In 2000 the Portuguese water delivery system was

[7] For non-parametric efficiency approaches of public sector, see Pedraja et al. (2001) and Rugiero, J. (1996).

composed of 307 municipalities with 93% (285) of them publicly owned distributors that provide potable water to their communities. Only about 6% of municipalities do not pump water from underground and/or surface sources and about 23% are not responsible for water treatment. In table 1 we show some indicators of water supply structure:

Table 1: Regional Characterization of Portuguese Water Variables (2000)

REGIÃO	Distribution of Water Produced (%)	Water Losses (%)	Consumption/per capita (m^3/habitant/year)
NORTE	23%	33%	51
CENTRO	14%	36%	53
LVT	41%	33%	78
ALENTEJO	5%	42%	59
ALGARVE	7%	39%	109
AÇORES	4%	51%	88
MADEIRA	5%	36%	130

Source: *Instituto Nacional de Estatistica, 2000.*

Norte and Lisboa e Vale do Tejo represent the most significant regions in terms of water produced and Madeira is the region with higher level of consumption per habitant. The indicator for water losses in distribution pipes is significant in all regions, assuming about 36% of total water pumped at national level.

5. Empirical analysis (*Data description, Model Specification and Empirical Results)*

Data Description

The water distribution service data used in this study consist of a cross-section of 267 municipalities only with public service of water delivery, located in seven Portuguese regions and surveyed in 2000. The main data source used for this study is annual statistics, made available by a State Institution - *Instituto Nacional de Estatística (INE*). Financial and physical data information on the water process is used for the estimation of the stochastic cost frontier for Portuguese municipal water delivery service.

Variables in the cost frontier model – Following Stewart, M. (1993), Estache, A. and Rossi, Martín, (2002), data on operational costs (COSTS) were used to construct the dependent variable of the cost model. This variable includes total annual expenditures[8] and is defined as the sum of the product of input prices and quantities for aggregate labor and capital. For the output (Q) we considered the total annual volume of water

[8] In 1000€.

sales (in millions of cubic meters). Because estimation of a cost function requires data on input prices and as it has been difficult to obtain the prices of labour and capital, we used two proxies variables for the specification required: the average price of labour (PL) obtained dividing total wage expenses to the labour input[9] and a proxy for the price of capital (PK) obtained dividing the total expenses with capital investment to the some of the 0,6xlength of the pipe with the 0,4xnumber of well[10]. For the deterministic part of the model we also considered *technical variables* (not all of them were included in the final model). For the *inefficiency effects model* we considered two types of variables: *network* and *environmental* variables (Z variables) as they were hypothesized as influencing municipal efficiency level.

A summary of statistics concerning the X and Z variables included in the general[11] stochastic frontier cost model is listed in table 4:

Table 4: Descriptive Statistics

Descriptive Statistics for Variables in the Deterministic Cost Frontier Component				
Description of Variables	**Sample Mean**	**Sample Standard Deviation**	**Minimum**	**Maximum**
Costs-Operation and maintenance costs (millions of €)	776046,7	827816,8	38442	6601086
Q-Volume of Water Sales (millions of cubic meters)	1188838	1883081	25000	21300000
PL-Price of Labor (millions of €)	12271,6	22995	397,6	295639
PK- Price of Capital (millions of €)	4653,5	5084,8	64,1	40811,5
CLI- total number of costumers served[12]	19069,91 (total number=5091667)	1295,48	418	148594,1
DENC- density of connections by km of pipeline (DENC)[13]	59,8	4,5	3,77	629,41
ABAS- Ratio between population with metered water and total population	0,82	0,007	0,38	1
(Qd)[14]-Ratio between domestic sales and total sales in cubic meters	0,82	0,13	0,38	1
REC[15]- Output indicator as the ratio between total revenues and total costs total revenues/total costs	1,1	1,36	0,039	17,91
CAPT*- Volume of water pumped(millions of cubic meters)	*1881610*	*178596,2*	*0*	*31470000*
CONT*- Number of connections	*8785,2*	*11621,1*	*311*	*106554*

Descriptive Statistics for Variables Explaining Inefficiency				
Description of variables	Sample Mean	Standard Deviation	Minimum	Maximum
LEN- Length of the pipes (Km)	205,9	225	10	1730

[9] It is defined as total number of workers.

[10] Another process to obtain the price for the materials is proposed by Garcia and Thomas (2001): the authors used the total expenses of different inputs such as stocking, maintenance work and subcontracting divided by the distributed water volume.

[11] In a first stage and for the selection of the main drivers of operating expenditure we considered two variables not all of them included in the final cost model:i)Volume of water pumped(millions of cubic meters);ii) Number of connections.

[12] The total number of costumers served had been also employed by Estache et al. (2002), Antonioli et al. (2001) and others.

[13] The density of connections had also been employed by Stewart (1993) Price, (1993) Crampes et al. (1997), Estache et al. (2002) Bhattacharyya et al., (1995).

[14] The volume of water put through the distribution network had been also used by Stewart (1993), Crampes et al. (1997), Bosworth (1994), Crafts (1998), Hunt and Lynk (1995) and others.

[15] Crampes (1997) used the relation between operational expenditures and revenues.

LOSS – Water losses (m^3/year) as the difference between total water pumped and total water delivered	-0,11	6,32	-103	0,90
SIZE - Size of the distribution area in km^2	1465,272	284,83	8,0	308843,4
DENP - Density of costumers per km^2	152	304	7	2627
DT1 - Type of water extraction (Dummy variable)	23 with only surface collection			
DIRI – Number of managers with high schooling	0,77	0,86	0	7
R's (1,2,3,4,5,6 and 7)				

Network variables are represented by the length of the pipes (in km) and by an indicator of water losses in the distribution pipes. *Environmental variables*, expressing geographical influences and regional components, include a) the size of the distribution area in km^2; b) the density of costumers per km^2; c) a dummy[16] for the type of water extraction; d) the number of managers (as a regional specific management factor) with high schooling[17] ; e) a dummy for each region[18].

On average, residential and commercial water sales (Qd) represented 82% of the total sales[19], ranging from a low of 0,38 to a high of 1. The great variability found on the volume of water sales (range from a low of 25000 millions of cubic meters to a higher of 21300000 m.c.m.) and on operation and maintenance costs (range from a low of 38442 millions/€ to a higher of 6601086 millions/€) reflects the municipalities' size heterogeneities. The average proportion of total revenues on total costs (an output indicator) was closed to the unit although the existence of an extensive range of variation. Most (244) of the 267 surveyed municipalities had a mixed type of water input-sources (groundwater-superficial water sources) and only 23 had water input from surface sources.

[16] This variable accounts for the effect on variable cost due to source diversity: it takes the value 1 if the unit only use superficial and the value 0 if the unit uses the combination of the two sources: ground water-surface source. Surface sources that water is directly extracted from lakes, rivers and reservoirs. Ground water sources means that it is necessary to use pump out water from the subsoil. And generally requires extensive use of pumping. The knowledge of the kind of source is important as ground water requires less treatment than surface water and so may occur different implications on costs.
[17] This information is related to the year of 1996.
[18] r= 1,…..6 because the effect of the last region is in the independent term.
[19] This variable had been introduced as an indicator of the market structure.

Model Specification

For the estimation of cost-inefficiency of public water service of Portuguese municipalities, a frontier cost function is required[20]. The cost frontier function is approximated by the following Cobb-Douglas specification:

$$\ln\left(COSTS_i\right) = \beta_0 + \beta_1 \ln Q_{1,i} + \beta_2 \ln PL_{2,i} + \beta_3 \ln PK_{3,i} + \beta_4 \ln CLI_{4,i} + \beta_5 \ln DENC_{5,i} +$$
$$\beta_6 ABAS_{6,i} + \beta_7 Qd_{7i} + \beta_8 REC_{8i} + \varepsilon_i$$
$$i = 1,\ldots.N = 267.$$
$$\varepsilon_i = v_i + u_i$$

Where i indicates a Portuguese municipality; "ln" refers to the natural logarithm, the β_i are unknown parameters to be estimated, COSTS represents the dependent variable to be estimated; Q represents a measure of output or the level of water sales[21], PL and PK are proxies for the prices of labor and capital, CLI, DENC, ABAS, Qd and REC are technical variables which affect the technological shape of the frontier and $\varepsilon_i = v_i + \mu_i$ represents the composed error of the model: A two-sided disturbance (v_i) assumed to follow a normal distribution $N(0, \sigma_v^2)$ and the other component (u_i), associated with the technical inefficiency of a firm, is a one-sided non-negative and unobservable random variable with an asymmetric distribution (for this study we used a normal truncated distribution[22]) and variance given by σ_u^2 .So, we specified the cost-efficiency term through network and environmental variables (also called z variables or exogenous inefficiency effects) included as explanatory variables in order to analyse the impact of them on the inefficiency effects model. In this situation, the dependent variable and the technical inefficiency effects are both modelled in terms of other explanatory variables. Hence, the technical inefficiency component of the stochastic frontier is modelled in terms of network, regional and geographical characteristics. The full model for the inefficiency structure is:

$$m_i = E(u_i) = \partial_0 + \partial_1 LnLEN_i + +\delta_2 LOSS_i + \delta_3 SIZE_i + \delta_4 DT1_i + \delta_5 DENP_i + \delta_6 DIRI_i + \delta_7 R1_i +$$
$$\delta_8 R2_i + \delta_9 R3_i + \delta_{10} R4_i + +\delta_{11} R5_i + \delta_{12} R6_i$$
$$i = 1,\ldots. N = 267 .$$

[20] A frontier cost function defines minimum costs given output level, input prices and the existing technology. The properties are that it is concave and linearly homogeneous in input prices, non-decreasing in input prices and output and non-increasing with respect to capital stock.

[21] As output variable, Stewart (1993) used the volume of water sold expressed in ml/d[21], Price (1993), used the share of total water distributed to non residential users and the average pumping, expressed in relation to water delivered, Crampes et al. (1997) used the volume of water produced, Estache et al. (2002) used daily production of water and the relation between residential sales and total sales in cubic meters and Bhattacharyya et al., (1995) used the total quantity of water sales – commercial sales, residential sales and other sales - in millions of gallons per year).

[22] We had test the adequacy of a truncated distribution against a semi-normal distribution.

With the above model specification we seek determinants of efficiency variation which may explain the variance of the inefficiency error. *Since inefficiency is caused by factors internal to the firm, it is quite likely that firm-specific factors would explain the cost of inefficiency* (Bhattacharyya et al., 1995). To analyse the goodness of the choice of the z variables or exogenous inefficiency effects, four versions of this Model had been considered according to different specifications for the determinants of efficiency variation:

*Model -A-*The technical inefficiency component of the stochastic frontier is modelled only in terms of regional component without network and geographical characteristics. It is only assumed for the inefficiency effect model the regional identification or the inclusion of R_1, R_2, R_3, R_4, R5, R_6 as being regional components:

$$m_i = E(u_i) = \partial_0 + \delta_1 R_{1i} + \delta_2 R_{2i} + \delta_3 R_{3i} + \delta_4 R_{4i} + + \delta_5 R_{5i} + \delta_6 R_6$$
$$i = 1, \ldots N = 267.$$

*Model -B-*The technical inefficiency component of the stochastic frontier is modelled in terms of network and geographic characteristics without regional component. It is assumed the inclusion of network and geographic characteristics as explanatory variables of the inefficiency effect model:

$$m_i = E(u_i) = \partial_0 + \partial Ln_1 LEN_{1i} + + \delta_2 LOSS_{2i} + \delta_3 SIZE_{3i} + \delta_4 DT1_{4i} + \delta_5 DENP_{5i} + \delta_6 DIRI_{6i}$$
$$i = 1, \ldots N = 267.$$

*Model -C-*The technical inefficiency component of the stochastic frontier is only modelled in terms of geographic and regional components:

$$m_i = E(u_i) = \partial_0 + \delta_1 SIZE_{1i} + \delta_2 DT1_{2i} + \delta_3 DENP_{3i} + \delta_4 DIRI_{4i} + \delta_5 R_{5i} +$$
$$\delta_6 R_{6i} + \delta_7 R_{7i} + \delta_8 R_{8i} + + \delta_9 R_{9i} + \delta_{10} R_{10i}$$
$$i = 1, \ldots N = 267.$$

*Model -D-*The technical inefficiency component of the stochastic frontier is only modelled in terms of network characteristics without the inclusion of geographic and regional components:

$$m_i = \partial_0 + \partial Ln_1 LEN_{1i} + + \delta_2 LOSS_{2i}$$
$$i = 1, \ldots N = 267.$$

Empirical Results

Next table present maximum likelihood estimates of the parameters and the respective t-ratios for the general Model, obtained with FRONTIER 4.1 (Coelli, 1996)[23]:

[23] This program was employed to simultaneously estimate the parameters of the stochastic cost frontier and the technical inefficiency effects model.

Table 5: Maximum Likelihood Estimates of Cost Frontier Model

Parameter and variable	Variable	Model with inefficiency effects and (normal-truncated)	
		Coefficient	**t-ratio**
B_0	intercept	0,43	5,80
B_1	lnQ	0,11	1,79
B_2	lnPL	0,33	8,18
B_3	lnPK	0,43	12,68
B_4	lnCLI	-0,12	-1,20
B_5	DENC	0,002	1,04
B_6	ABAS	-2,87	-3,95
B_7	Qd	2,89	3,97
B_8	REC	-0,06	-2,98
σ^2		-0,13	8,34
γ[24]		0,9999999	158,05
δ_0	intercept	-3,55	-4,19
δ_1	lnLEN	0,46	10,13
δ_2	LOSS	0,18	1,65
δ_3	SIZE	0,33	3,06
δ_4	DT1	0,090	0,90
δ_5	lnDENP	0,32	3,42
δ_6	DIRI	0,10	2,61
δ_7	R1	-0,09	-0,05
δ_8	R2	0,12	0,70
δ_9	R3	0,13	0,69
δ_{10}	R4	0,08	0,43
δ_{11}	R5	0,51	2,32
δ_{12}	R6	0,13	0,70
LLF			*-108,76*

These estimates are asymptotically efficient. The *OLS* estimated values had been used as starting values in the interactive process to obtain the *ML* estimates for Model presented in table 5. These estimates are obtained in a way that all the values are unbiased estimates of the unknown coefficients, except the value for the intercept which is biased because of the non zero expectation of u_i. Most of the β estimates and δ estimates are statistically significant. Estimate of γ parameter reach 0,9999999 implying that almost all variability is associated with technical inefficiency[25]. The adequacy of a truncated distribution for the efficiency error component against a semi-normal distribution[26] is tested using likelihood-ratio tests[27].

Almost of the ML estimates for the coefficients associated with input prices, output and technical variables, are significantly different from zero at the five percent level. From the t-ratios we can see (table 5) that only three of them are not significant: i) total annual

[25] The γ-parameter can take any value between 0 and one, depending upon the relative contribution of noise and inefficiency. In this case, the *ML* estimate for γ is almost 1 (0,9999999) which indicates that the majority of residual variation is due to the inefficiency effects or that the random error is near to zero and that the stochastic frontier is not significantly different from the deterministic frontier.

[26] We had tested the null hypothesis (H_0: μ=0) that the simpler half-normal model was a good representation of the data, given the truncated-normal model (Model II) through a generalized-ratio test. We adopted the generalized truncated-normal model, although the test statistic was significant and the null hypothesis of μ=0 accepted (LL= 110,19).

[27] All relevant hypotheses were tested using the generalized likelihood-ratio statistic $\lambda = -2\{\ln L(H_0) - \ln L(H_1)\}$, where $\text{Ln}(H_0)$ and $\text{Ln}(H_1)$ are the values of the log-function under the null and alternative hypotheses, respectively. This statistic has asymptotic chi-square distribution, with degrees of freedom equal to the number of restrictions imposed under the null hypothesis, except when we need to test $H_0 : \gamma = 0$ (the model is equivalent to the traditional average function without the technical inefficiency effect u_i. When the null hypothesis is true, then the variance of the inefficiency effects is zero and so the model reduces to a traditional mean response function with γ=0 lying on the boundary of the parameter space. In this situation, the respective likelihood-ratio statistic has asymptotic distribution which is a mixture of chi-square distributions, namely $\frac{1}{2}\chi_0^2 + \frac{1}{2}\chi_1^2$ (Coelli, 1995).

volume of water sales (in millions of cubic meters), ii) number of costumers served and iii) density of connections by km of pipeline. The negative signs founded for the estimated coefficients β_4 (number of costumers) and β_6 (ratio between people with metered water and total population), indicate that increases in the population served or in the proportion of population with metered water, will result in a decrease in the value of the full cost. The negative sign of the proportion of total revenues on total costs is also conform what one would expect, given that an increase in this proportion will result in a decrease in the total costs. The positive signs on the estimate of the coefficients of capital price and labour price were as expected. The estimate coefficient associated with the ratio between domestic sales and total sales in cubic meters, is significant and shows also a positive sign. About the t-ratios associated with the estimates for the parameters associated with the inefficiency error term, we find that some of them are not significant. So, the maximum likelihood estimates for water losses (LOSS), for the type of extraction of water (DT1)[28] and for the four regions (Norte, Centro, Lisboa e Vale do Tejo and Algarve) are not statistically significant at 5% level (the t-ratios are less than the absolute value of (1,96). Only two of the coefficients for the regions (Alentejo and Madeira) have t-ratios larger than 1,96 in absolute value. The estimated coefficient associated with the length of the pipe (δ_1) has a non expected positive sign. It was expected that technical efficiency would increase with the length of the pipe, rather than decrease, because of scale economies. A number of statistical tests were carried out to identify the impact of exogenous influences such as network variables (length of the distribution pipe and proportion of water losses in the distribution system) and environmental variables (geographical component or municipal size area and regional component or municipal density of costumers and regional location) on the full inefficiency model (12 z variables). In table 6 we show maximum likelihood estimates (Green, 1980), t-ratios and values log-likelihood functions associated with the four different versions of the full inefficiency model:

Table 6: The Impact of Exogenous Influences (Network, Geographic and Regional Components)

Parameter	Variable	Model -A only with regional component (without network and geographic characteristics)		Model-B only with network and geographic characteristics (without regional component)		Model-C only with geographic and regional components (without network characteristics)		Model -D only with network characteristics	
		Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio

[28] The positive sign on the estimated coefficient of the dummy variable (δ_4) associated with the type of water extraction, was as expected as the cost of water delivery and treatment depends to a large extent on the types of water-input sources. (Bhattacharyya et al, 1995).

B_0	intercept	0,74	1,13	4,03	7,62	3,85	2,64	0,86	1,84
B_1	lnQ	0,16	2,44	0,20	3,61	0,11	1,61	0,19	4,23
B_2)	lnPL	0,32	7,75	0,32	9,92	0,38	9,17	0,29	8,99
B_3	lnPK	0,32	10,21	0,44	14,59	0,29	8,78	0,47	16,60
B_4)	lnCLI	0,49	6,82	-0,24	-6,26	0,038	0,20	0,11	1,87
B_5	DENC	-0,0008	-0,36	0,002	1,53	0,005	1,77	0,001	0,79
B_6	ABAS	-4,12	-5,74	-2,72	-4,04	-4,59	-2,12	-2,38	-2,09
B_7	Qd	3,98	5,54	2,75	4,49	4,41	2,04	2,37	1,98
B_8	REC	-0,097	-4,08	-0,059	-3,50	-9,07	-3,75	-6,61	-3,21
σ^2		0,25	11,18	0,14	8,80	0,21	11,04	0,15	10,59
γ		0,10	6,16	0,999999	212,0	0,73	1,15	0,99999	33,99
δ_0	intercept	-1,34	-12,15	-3,65	-5,17	-3,24	-2,39	-0,33	-1,18
δ_1	lnLEN	-	-	0,46	15,4	-	-	0,49	12,79
δ_2	LOSS	-	-	0,25	2,32	-	-	0,12	1,32
δ_3	SIZE	-	-	0,36	8,90	0,56	3,13	-	-
δ_4	DT1	-	-	0,09	0,93	0,20	1,74	-	-
δ_5	lnDENP	-	-	0,34	6,26	0,42	2,44	-	-
δ_6	DIRI	-	-	0,10	3,16	0,13	3,63	-	-
δ_7	R1	1,54	9,30			0,09	0,54	-	-
δ_8	R2	1,60	7,91			0,20	1,15	-	-
δ_9	R3	1,49	16,41			0,19	1,09	-	-
δ_{10}	R4	0,63	2,45			-0,10	-5,44	-	-
δ_{11}	R5	1,93	10,27			0,50	2,32	-	-
δ_{12}	R6	1,69	7,58			0,32	1,58	-	-
LLF		-188,61		-118,64		-174,33		-127,82	

Several hypotheses concerning the four versions of Model are presented in table 7. From this table it is evident that the full inefficiency model is the most adequate for the sources of inefficiency as all the four versions are rejected:

Table 8: Versions of full Model - Specification Tests

Hypothesis	λ -Statistic	Critical Value (α=0,05)	Decision
a) H_0: Model -A	159,7	12,59	Rejected
b) H_0: Model -B	19,76	12,59	Rejected
c) H_0: Model -C	131,14	5,99	Rejected
d) H_0: Model -D	38,12	18,31	Rejected

Hence, the full inefficiency model without restrictions is selected and generalized likelihood-ratio tests for several hypotheses concerning different situations are summarised in table 9:

Table 9: Full Inefficiency Model - Specification Tests

Restrictions	**Model description**	**Log-likelihood**	**Likelihood-ratio test (λ)**	**X^2 critical value (5%)**	**Decision**
A. None	Cobb-Douglas with 8 regressores, 12 variables in the inefficiency model and a normal truncated distribution for u_i	-108,76			
B. $\gamma=\delta_0=\delta_1=\ldots==\delta_{12}=0$	Average response function or no inefficiency effects	-199,34	181,15	$\chi^2_{14} = 23{,}7$[29]	Rejected
C. $\delta_0=0$	Cobb-Douglas with 8 regressores, 12 variables in the inefficiency model and an half-normal distribution for u_i	-110,19	2,86	$\chi^2_1 = 3{,}84$	Accepted

[29] This critical value is from table 1 of Kodde and Palm (1986) for the degrees of freedom equal to 14.

In situation A we have the full cost frontier with an error component; the total cost is assumed to be explained by input prices (Labour and capital), volume of sold water and by some technical variables. This specification includes exogenous influences upon the inefficiency term, which affect the average behaviour of the inefficiency term. In situation B, it is consider the null hypothesis that there is no technical inefficiency in this water sector, which means that the OLS estimates are all unbiased and the model is specified as an average function. It is assumed the absence of exogenous influences upon the technical inefficiency component. The likelihood ratio testing procedure is used to test the hypothesis that environmental/geographical factors have not a significant influence upon the degree of technical inefficiency or that there is no technical inefficiency in Portuguese water service. This hypothesis is equivalent to imposing the restrictions that all δ-parameters and the scalar parameter,γ, are equal to zero: $\gamma = \delta_0 = \delta_1 = ... = \delta_{11} = 0$.[30] The generalized likelihood-ratio statistic for testing the null hypothesis that all environmental/geographical factors have no significant influence upon the degree of technical inefficiency is calculated to be $\lambda = 181{,}15$. This value is comparable with the upper five per cent point for the χ^2_{14}. Hence the null hypothesis of no technical inefficiency effects in public water service in Portugal is rejected. In situation C efficiency component is assumed to follow a half-normal distribution. When efficiency component is assumed to follow an half-normal distribution, the log-likelihood function value of this restricted model is -110,19 and the value of the likelihood ratio statistic is calculated to be 2,86. Although the value does not exceed the χ^2_1 critical value, we preferred the normal-truncated distribution to model the inefficiency component of the entire error.

Cost inefficiency

The results show the existence of differences on regional statistics for cost-inefficiency scores. Lisboa e Vale do Tejo is the most cost-inefficiency region (87,9%) followed by Algarve (87,5%), Centro (87%) and Norte (85%). Alentejo is the most cost efficiency region (72,8%), followed by Açores (73,5%) and Madeira (74,9%). The standard-deviation from the mean is higher in Açores (27,5%) and lower in Centro (9,1%). As Bhattacharyya et al. (1995), we used total municipal quantity of water delivery as an indicator of size of the water distribution utility to investigate the impact of the size of

[30] When $\gamma = 0$, it means that the deviation from the frontier is entirely explained v_i.

the utility on cost-inefficiency level. In table 10 we report the estimates of mean cost-inefficiency by different size classes of water delivery units:

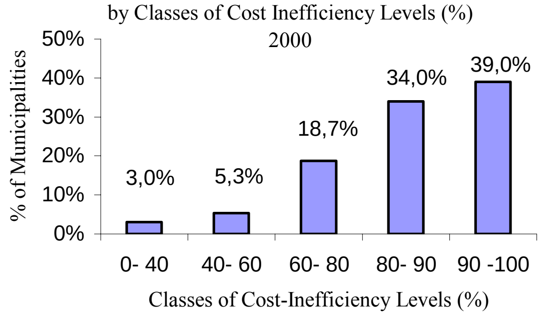
Table 10: Mean of Cost-Inefficiency by Municipal Size

Water Delivery (in cubic meters)	No. of Municipalities	Cost of Inefficiency (%)
≥25 000-⟨100 000	4	62,3
≥100 000-⟨500 000	120	83,7
≥500 000-⟨1 000 000	56	76,3
≥1 000 000-⟨2 000 000	40	90,9
≥2 000 000-⟨3 000 000	18	93,5
≥3 000 000-⟨4 000 000	18	92,1
≥4 000 000	11	95,5
Total Mean Cost-Inefficiency	81,2 (16,2)	

[a] Standard deviation is in parentheses.

These results confirm Bhattacharyya et al. (1995) empirical finding that as the size of the units increases, the higher is the level of cost-inefficiency[31].Total cost-inefficiency for the entire sample is 81,2% and the mean deviation of cost-inefficiency scores from the frontier cost is 16,2%. The level of cost-inefficiency is lowest for small-scale operations or for firms producing between 25 000 and 500 000 cubic meters. Cost-inefficiency level shows a significant increase from the first size-class till the second size-class or the modal class (units delivering between 100 000 and 500 000 cubic meters): cost-inefficiency rises from 62,3% in the first size-class to 83,7%. Municipalities delivering more than 1 000000 cubic meters of water (39%), show levels of cost-inefficiency higher than 90%. Most of the municipalities (70%) lie in the classes where the cost-inefficiency is higher and only 3% of municipalities are located in the class with lowest level of inefficiency as Figure 1 shows:

Figure 1: Percentual Distribution of Portuguese Municipalities by Classes of Cost Inefficiency Levels (%) 2000



[31] Investigating the behaviour of cost-inefficiency in publicity and privately owned urban water firms, Bhattacharyya et al. (1995) found that for small-scale operations, privately owned water firms were more cost efficient and for large-scale operations, publicity owned water firms were more cost efficient.

6. Policy Implications

There are a number of important similarities in the municipalities under study. Water supply service is under public control in them all and the responsibility of providing water lies only with municipalities. Furthermore, as this empirical analysis shows, local water management authorities face not only a problem of technical cost inefficiency in the delivered water process, but also an ecological problem due to the regional pipeline waste of the resource. According to a basic principle of water management which states that *supply is renewable but limited and should be managed on a sustainable use basis* (Grigg, 1998), we need fundamental changes (Gleick, 2000 and Klink, 1999) in how authorities think water policy that ensure, besides the economic perspective of cost-effective exploration, i) the developing of a new ethic of water uses, involving all the entities of water market; ii) the preservation of the natural ecological cycle of water; iii) the consideration of the environmental costs problem; iiii) more coordination between decision-makers and more public participation on water issues; iiiii) finally, it is need more general information about economic, social and geographical context of the operating units in order to reach total water resources management or the integrated water management (Mitchell, 1990 and Kirpich, 1993).

7. Conclusions

The purpose of this research was to study the effects of exogenous variables such as network and environmental characteristics upon the municipals' technical efficiency cost levels of Portuguese public water distribution service. The analysis was based on a Cobb-Douglas stochastic cost frontier model that allowed for the incorporation of an inefficiency effects model, with the cost-inefficiency component following a truncated normal distribution. A number of statistical tests were carried out to choose the explanatory variables for the inefficiency effects model. We selected an inefficiency effects model without restrictions or with network and environmental variables. Although the literature on the growth of firms suggest that large firms have an advantage over small firms because of their market power and economies of scale (Kim, S., 2003), the empirical results shows a positive relation between municipal size (measured as the total volume of water consumption) and technical inefficiency costs. Results also suggest that when the number of costumers with metered water, the proportion of population with metered water and the proportion of total revenues on total costs increase, it will result in a decrease in the value of the full cost. The capital price and labour price variation were as expected affecting positively the value of the cost. Increases on the proportion of domestic sales of water on total sales (in cubic meters) and on the proportion of total revenues on total costs will result in a decrease in the value of total costs.

Estimated coefficients for the explanatory variables of the inefficiency effects model indicated that technical inefficiency varied significantly according to municipals' network and environmental variables. We found a non expected positive sign for the estimated coefficient associated with the length of the pipe. It was expected that technical efficiency would increase with the length of the pipe, rather than decrease.

The general conclusion is that efficiency incentives should be applied to Portuguese municipalities with public water delivery service and that further investigation on efficiency of public service is an important issue.

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