COSTS AND STRUCTURE OF TECHNOLOGY IN THE ITALIAN WATER INDUSTRY*

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Abstract

This paper analyses from an empirical point of view the technology underlying the Water industry. First, we study the impact of environmental and quality factors on the production process. Second, different functional forms are analysed in order to represent the technology. Overall results show that the coefficient of hedonic variables are significant and that the best functional form turns to be the transcendental logarithmic one. Finally, evidence on return to scale depends on the functional form adopted and on the inclusion of hedonic variables.

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1. Introduction

The Italian Water Industry is greatly fragmented: there are more than 6,000 companies with an average of 9,000 inhabitants served. Furthermore, if we consider that the 200 largest firms provide more than half of the total volume supplied, the undersizing of the other operators seems extremely serious. This situation generates inefficiencies that, especially in the South, hinders the matching of the demand and determines low levels of investments. The latter are fundamental to the renovation and enlargement of the existing facilities, to the improving of quality and productivity.

The reorganisation of the sector, based on the "Galli Act" (1994), aims at grouping small firms in order to reach the "optimal size" which should bring firms to enter the financial market and to increase productivity and profitability. The new law states also a tariff regulation that should lead to the improvement of the quality and the efficiency of the service. It is obvious that the study of the underlying technology is very important because it allows to evaluate the characteristics of the service and the existence of economies of scale.

The purpose of this paper is to analyse the technology of the water industry. The first aspect to be tested is whether and how environmental and qualitative characteristics affect the production process and the associated costs. The second is the identification of the functional form which is the most suitable to represent the underlying technology. The analysis is structured as follows. Section 2 describes the nature of water service. Section 3 justifies the study of the technology by means of a cost function. Section 4 presents the model and the data base. The traditional approach and the hedonic one are then compared (Section 5) and the functional form which best fits the technology of water industry is evaluated (Section 6). The economies of scale are analysed in Section 7.

2. The characteristics of water service

The water supply system can be divided into two components: production and delivery (transmission and distribution). Production involves the construction and the maintenance of plants such as wells, pumps and storage facilities. Moreover, the increased pollution of layers requires a further treatment cycle usually applied only to surface waters. Transmission pipelines connect the treatment plant to the pumping station and to the distribution system. The distribution works include the network which conveys the water to consumers, tanks and meters; in this phase it is also necessary to monitor the quality of the water and of the service as well as an administrative structure for the management of customers.

A firm can carry out one or all the phases; for each phase it can turn to the production of other operators. The different degree of vertical integration and the characteristics[1] of the area being served make water firms extremely heterogeneous. Moreover the heterogeneity regards the quality of the service both in terms of the characteristics of the water supplied (such as drinkability, taste and smell) and in terms of the service to users (average quantity delivered, interruption in supply, water pressure).

Since the different environmental conditions and the service quality affect the productive process, the analysis of the technology based on physical output (volume delivered) can be reductive while a multidimensional evaluation seems to be more suitable. On the other hand, the choice of the functional form which fits better the data becomes important: for example, a Cobb-Douglas technology, which is widely employed in empirical studies, defines a priori the hypotheses on substitutability of factors, returns to scale, output mix and therefore on the technology to be analysed.

[1] Nature of the supply source, characteristics of the input of water, population density and seasonal variation of the same.

3. The dual approach for the study of technology

The duality approach states that the analysis of the technology can be based on the study of the production function or of the associated cost function. The latter however, is clearly preferred, as can be seen in the empirical studies following the work of Shephard (1953). For a multioutput firm the estimate of the cost function avoids the estimate of several equations, one for each output. Moreover in the study of public utilities the assumption of exogenous outputs and factor prices seems to be appropriate. From an econometric point of view, the dual approach is preferred because the joint estimation of the cost function and the *cost-share* equations[2] increases the degree of freedom and enhances the statistical precision of the estimates.

4. The model and data

In order to analyse the technological structure of the water industry we use a cost function incorporating three inputs (labour, energy and capital- materials) and satisfying the condition of homogeneity of degree one in factor prices. Therefore, we have a three-equation system consisting of the cost function and two out of three[3] *cost-share* equations. The specification of the cost function is the Transcendental Logarithmic, that is a second order Taylor series expansion approximating an arbitrary twice differentiable cost function C=C(**Y**,**P**), with **Y** as the output vector and **P** as the factor prices vector.

The translog is written as:

$$\text{(1)} \qquad \ln C = a + \sum_i b_i \ln Y_i + \sum_j d_j \ln p_j + \frac{1}{2}\sum_i \sum_s e_{is} \ln Y_i \ln Y_s + $$
$$+ \frac{1}{2}\sum_j \sum_r g_{jr} \ln p_j \ln p_r + \sum_i \sum_j h_{ij} \ln Y_i \ln p_j + \varepsilon$$

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[2] According to "Shephard's Lemma" the derivative of the cost function with respect to factor price yield the demand for input.

Applying "Shephard's Lemma" the *cost-share* equations to be simultaneously estimated to (1) are:

$$(2) \qquad S_j = d_j + \sum_r g_{jr} \ln p_r + \sum_i h_{ij} \ln Y_i + \varepsilon_j .$$

The linear homogeneity in prices imposes that:

$$\sum_j d_j = 1, \quad \sum_r g_{jr} = 0, \quad \forall \ j, \quad \sum_j h_{ij} = 0 \quad \forall \ i;$$

the condition of symmetry requires:

$$e_{is} = e_{si} \qquad\qquad g_{jr} = g_{rj}$$

The estimate is made by the Zellner's seemingly unrelated regression technique[4] (that is a generalised two stage least squares method).

Our data are drawn from a cross-section of 173[5] Italian water companies, members of Federgasacqua, observed in 1991. It is worth noting that these firms represent only 3% of the firms operating in Italy; however in terms of the volume supplied they account for nearly 50% (2.9 billion cubic metres out of 6 billion supplied in Italy). Tables 1 and 2 provide some statistical figures on our sample. The weight of large firms, with a population above 250,000 units, accounts for almost 67% of the volume supplied by the whole; small firms (less than 10,000 inhabitants) account for 0.4%. As almost all the big Italian firms are included in our data base, whereas most of the very small firms and of the medium size firms are not present, the sample mean (18,860,000 cubic metres supplied and 164,369 inhabitants served), is greater than the population mean (1 million cubic metres and 9,000 inhabitants served).

5. The traditional approach or the hedonic one?

For the water industry, the traditional formulation of costs as a function of input prices and output (measured in terms of volume of delivered water) is not

[3] Since the factor shares sum to one, only two equations are linearly independent and can be used to obtain a nonsingular covariance matrix.

[4] If the system is estimated to converge, Zellner's estimates are asymptotically equivalent to maximum-likelihood estimates and therefore are invariant to equation deleted.

[5] Due to incomplete data, our sample consists of 150 observations.

suitable. The idea, put forward for the first time by Feigenbaum and Teeples[6] (1983), is that this public utility doesn't produce water from factors such as labour and capital. It is, on the other hand, more correct to consider water production as a process that transforms "the location (in space and time) of water and improves upon the quality of water inputs". Each firm is characterised by different typology as far as the inputs and output of water and the service provided are concerned; it is clear that the particular environmental conditions which the firm faces and the quality service affect the cost structure. Therefore the inclusion of " variables along with the physical output makes it possible to homogenise firms which, though equal in terms of the volume supplied, operate in different environmental conditions and produce different services. From an econometric point of view, the problem is the measurement of such factors in order to verify their role in explaining costs.

On the basis of the available data, four hedonic variables have been identified and introduced: the number of consumers (UT), a proxy of density obtained as ratio between population served and length of pipelines (DEN), the percentage of water input purchased by the firm (AA) and of the treatment costs (POT) on total cost. Three inputs have been used: labour, energy and capital-materials. The price of the latter variable has been computed by dividing the sum of depreciation and costs of materials by the length of the network (Km).

The generic cost function is therefore:

(3) $C = C(Y, \mathbf{Z}, \mathbf{P})$

with Y: volume of delivered water,

Z: vector of the hedonic variables,

P: vector of the input prices.

(3) is approximated with the *Transcendental Logarithmic*:

[6] These authors follow the pioneering theory put forward by Spady and Friedlander (1978) "Hedonic cost Function for the Regulated Trucking Industry", Bell Journal of Economics n. 9, 1978.

$$\ln C = a_0 + a_y \ln y + \sum_i b_i \ln z_i + \sum_j g_j \ln p_j + a_{yy} \frac{(\ln y)^2}{2} +$$

$$(4) \qquad + \frac{1}{2}\sum_i \sum_l b_{il} \ln z_i \ln z_l + \frac{1}{2}\sum_j \sum_s g_{js} \ln p_j \ln p_s +$$

$$+ \sum_i a_{yi} \ln y \ln z_i + \sum_j t_{yj} \ln y \ln p_j + \sum_i \sum_j s_{ij} \ln z_i \ln p_j + e$$

As AA and POT can take on values of zero, it is not possible the logging of these variables, so the Box-Cox[7] transformation has been applied.

The cost-share equations are therefore :

(5) $$S_j = \gamma_j + \sum_s \gamma_{js} \ln p_s + \tau_{yj} \ln y + \sum_i \sigma_{ij} \ln z_i + \varepsilon_j \qquad j = L, E, M.$$

To ensure that the cost function (4) is linearly homogeneous in factor prices, the following restrictions are imposed:

(6) $$\sum_j \gamma_j = 1, \qquad \sum_j \tau_{yj} = 0, \qquad \sum_j \sigma_{ij} = 0 \quad \forall \ i, \qquad \sum_j \gamma_{js} = 0 \qquad \forall s$$

Symmetry is guaranteed by:

(7) $\gamma_{js} = \gamma_{sj}$, $\beta_{il} = \beta_{li}$

The variables are normalised around (that is divided by) their own sample mean. Table 3 shows the Zellner's estimates of the system made up of (4) and two cost-share[8] equations (5), under conditions (6) and (7), both for the hedonic model and the traditional one.

The adjusted R^2 indicates that the hedonic function fits better the data. When we exclude the hedonic variables, the estimate on Y (volume of delivered water) changes from 0.634 to 0.92. The increase in this coefficient is probably due to the fact that, in the traditional specification, it summarises all the effect explained by the hedonic variables. The preference for the hedonic approach is, therefore, motivated by the possibility of analysing the links between costs and each

[7] This enables the passage from a generic variable *x* to a *x** variable:

$$x^* = \begin{cases} \dfrac{x^\alpha - 1}{\alpha} & \alpha \neq 0 \\ \ln x & \alpha = 0 \end{cases}$$

As $\lim_{\alpha \to 0} \frac{x^\alpha - 1}{\alpha} = \ln x$, *x**, for small values α, approximates the ln*x*. As the Box-Cox function has been used, (4) is more appropriately a *Generalised Transcendental Logarithmic*.

[8] Refer to notes 2 and 3.

quantitative and qualitative variable and of avoiding the bias on the physical output variable.

The joint hypothesis of zero coefficients for the hedonic variables has been tested by the likelihood ratio test. Since the χ^2 is equal to 320.546 the null hypothesis is rejected.

The two approaches have been also compared under the hypothesis of a Cobb-Douglas technology. In the traditional model (see table 3) the adjusted R^2 is lower, 0.90 against 0.97, and the coefficient on Y is 0.91 instead of 0.67. Also in this case the likelihood ratio test points toward the rejection of the null hypothesis of zero coefficients for the hedonic variables.

6. Which functional form for the technology of water industry?

The Translog estimates (see table 3) are highly satisfactory. The model explains 97% of the variability of the costs; 24 out of 44 independent variables are statistically significant. Among the hedonic indicators taken into account only the percentage of the treatment costs (POT) and that of water purchased by the firm (AA) are not significantly different from zero. The coefficients on the other service characteristics have the expected sign: the increase (ceteris paribus) in the number of consumers turns into the increase in costs, whereas the increase in population density leads to a saving on costs.

Cost elasticity [9] with respect to factor prices, at the sample mean, is for labour, energy and capital-materials equal respectively to 0.42, 0.11 and 0.47. The second order coefficients of factor prices are all significant, highlighting that the

[9] For the translog cost elasticity with respect to output is:

$$\varepsilon_{c,y} = \alpha_y + \alpha_{yy} \ln y + \sum_i \alpha_{yi} \ln z_i + \sum_j \tau_{yj} \ln p_j$$

that of cost with respect to hedonic variables is:

$$\varepsilon_{c,i} = \beta_i + \sum_l \beta_{il} \ln z_l + \alpha_{yi} \ln y + \sum_j \sigma_{ij} \ln p_j \qquad i = \text{UT, DEN, AA, POT.}$$

The cost elasticity with respect to input price j is:

$$\varepsilon_{c,j} = \gamma_j + \sum_s \gamma_{js} \ln p_s + \tau_{yj} \ln y + \sum_i \sigma ij \ln z_i \qquad \forall\, j = L, E, M$$

As the variables are normalised around the sample mean, the elasticity of cost with respect to a given variable, $\varepsilon_{c,\bullet}$, at the expansion point coincides with the first order coefficient of the same variable.
It is worth noting that for each input $\varepsilon_{c,j}$ coincides with the respective cost-share equation S_j (5).

variation of input prices affect the cost factor shares, and in turn the optimal input mix (so we can deduce an elasticity of substitution different from one).

Up to now the analysis led us to choose the hedonic specification. The next step is to test which functional form is more suitable for representing the technology underlying the water industry.

Starting from Generalised Translog (4) we can derive four models obtained by imposing respectively: unitary elasticity of substitution between the inputs, homotheticity in the inputs, homogeneity in the output and finally the joint constraints of homogeneity and unitary elasticity, that is the Cobb-Douglas technology.

The hypothesis of unitary elasticity of substitution between the inputs implies for the equation (4) the condition of zero second order coefficients for prices:

(8) $\gamma_{js} = 0 \qquad \forall\, j, s$.

The Allen-Uzawa partial elasticity of substitution between the factor j and the factor s is for the Translog function:

$$\phi_{js} = \frac{\gamma_{js}}{S_j S_s} + 1$$

so an elasticity of substitution equal to one requires $\gamma_{js} = 0$.

The hypothesis of homotheticity means that the optimal input mix is constant with the scale; in (4) this is equivalent to impose zero values for the coefficients measuring the interaction between output and factor prices:

(9) $\tau_{yj} = 0 \quad \forall\, j, \quad \sigma_{ij} = 0 \quad \forall\, i, j.$

Homogeneity is a particular case of homotheticity and implies return to scale which are invariant to the production mix (in our case, assuming the hedonic variables as outputs, regardless of the quantity, quality and environmental characteristics for the firm) and to the scale itself. In addition to the homotheticity constraints (9) it is necessary to set the second order coefficients of the output equal to zero, therefore in (4) it will be:

(10) $\tau_{yj} = 0 \quad \forall\, j, \quad \sigma_{ij} = 0 \quad \forall\, i, j, \qquad \alpha_{yy} = 0, \qquad \beta_{il} = 0 \quad \forall\, i,l.$

When we consider the joint hypothesis of homogeneous and unitary elasticity of substitution technology we obtain a Cobb-Douglas functional form.

A first look at the results suggests that the technology underlying the water industry is not characterised by the conditions of "regularity" in the costs (therefore in the production function) with respect to the combination of inputs, the output mix and the scale. For a closer analysis however, we have estimated the models where the respective constraints are imposed. We have then compared them with the model without restrictions (Translog).

Notwithstanding the adjusted R^2 is the same for the five models, the likelihood ratio test (table 3) permits to reject the hypothesis of a technology characterised by unitary elasticity of substitution, homotheticity, homogeneity and Cobb-Douglas properties.

7. Analysis of scale economies

The study of economies of scale is particularly important in the context of the reorganisation of the Italian water industry. One of the central points of the Galli Act is in fact the elimination of fragmentation both in terms of number of operators (around 6,000) and in terms of the management of the whole water cycle (production and distribution, sewage collection, purification). The creation of large sized firms is the possibility of exploiting economies of scale. It is worth noting that, beyond the economic reasons, the reorganisation is motivated by the necessity of a more rational use of the water resources. That is why the grouping of firms must be defined within the Water Basins in which the Italian territory has been divided.

The empirical studies on distribution service have generally found increasing returns to scale that gradually vanish and give rise to decreasing economies (Visco Comandini, 1985, Feigenbaum and Teeples, 1983, Crain and Zardkoohi, 1978, Hines, Clark and Stevie, 1981); constant returns to scale have been found however in Giardina and Battiato 1983, Pola and Visco Comandini (1987).

The analysis carried out in this work highlights that the results obtained in the empirical literature depend on the choice of the model, consequently on the hypothesis of the underlying technology.

In the case of a single output firm a measure of economies of scale are reflected by the output elasticity of cost:

$$(11) \quad \varepsilon_{C,Y} = \frac{dC}{dY}\frac{Y}{C} = \frac{MC}{AC}$$

The firm experiences increasing, constant or decreasing returns to scale if $\varepsilon_{c,y}$ is less than, equal to or greater than one.

In the multiproduct case we can consider two distinct measures: ray economies of scale and product-specific economies of scale. The first indicates how total costs increase when every output increases by the same percentage; in formula:

$$\varepsilon^{R}_{C,Y} = \frac{\sum_i Y_i \frac{\partial C}{\partial Y_i}}{C}$$

Product specific economies of scale measure how costs change with each output, the quantities of the other products being constant. Defining the average incremental cost AIC as the increase in total cost associated with the production of a given output, as compared with not producing it at all, divided by that output, the measure of product specific economies of scale is:

$$\varepsilon^{PS}_{Y_i} = \frac{MC_i}{AIC_i}$$

The inclusion of hedonic variables in the cost function along with physical output permits us to consider different measures of economies of scale. The elasticity of cost with respect to output (here defined economies of output) indicates the increasing in costs when volumes supplied are expanded while keeping hedonic variables fixed. If volumes and number of users are expanded proportionally, the increase in costs associated with the expansion of the firm is measured by:

$$(12) \quad \varepsilon_S = \varepsilon_Y + \varepsilon_{UT}$$

where $\varepsilon_{Y} = \frac{\partial C}{\partial Y}\frac{Y}{C}$ and $\varepsilon_{UT} = \frac{\partial C}{\partial UT}\frac{UT}{C}$

If we assume that a larger firm-size implies the proportional increase of volume delivered and customers served, then ε_S gives us a measure of economies of scale. Let us remember that in our models the elasticity of cost with respect to a given variable is the derivative of cost function with respect to the same variable (see note 9). Furthermore the reciprocal of the elasticity of cost is equivalent to the returns to scale.

For each of seven model presented in this work, the cost elasticities at the sample mean (with respect to volumes delivered, volumes plus customers, density) are indicated in table 5. In all the cases the first order coefficient on Y indicates the presence of output economies, the latter slightly reduce passing from the translog function towards the constrained models.

The proportional increase in physical output and number of customers doesn't show cost elasticity different from one (at the sample mean) in all the different functional forms. The non hedonic translog and Cobb-Douglas highlight weak economies of scale[10].

The use of the translog permits to calculate the cost elasticity in different points. The estimate of the hedonic model shows that in our sample the cost elasticity with respect to output is a function of number of users and density

(13) $\varepsilon_{C,Y} = 0.634 + 0.148 \ln UT + 0.175 \ln DEN$

The density being fixed to the sample mean (graphic 1), we found that economies of output (equal to the reciprocal of (13)) are equal to 1.57 in the expansion point (29,505 consumers), 14.32 in the minimum point (661 consumers) and 0.904 in the maximum point (727,284 consumers).

The cost elasticity with respect to output and users is:

(14) $\varepsilon_{C,Y} + \varepsilon_{C,UT} = 1.012 + 0.148 \ln Y + 0.148 \ln UT + 0.04 \ln DEN$

The reciprocal of (14) is a measure of economies of scale. Graphic 2 shows that economies of scale[11] are high (2.38) in the minimum point (350,000 cubic

[10] In the traditional specification we can't distinguish between economies of output and economies of scale.

[11] The number of customers and density are fixed at the sample mean.

metres delivered); in the maximum point (393,960,000 cubic metres) there are instead diseconomies (0.68).

It is important to analyse these results in the light of the Italian water industry. The "average firm" in our sample in fact serves more than 160,000 inhabitants. As the average size of Italian firms is 9,000 inhabitants, it is clear that the "sample mean point", which we refer to, is rather relevant. Table 2 shows that in our sample there are 25 firms with a population served greater than 150,000, value that is not very different from the Italian situation. So we can conclude that most of the 6,000 operators is classifiable as smaller than the mean and is in the range where it is possible to enjoy increasing economies of scale.

Two further observations need to be made. The analysis of returns to scale should be completed with that of economies of density. The literature on network firms stresses the role of the size of the area served on costs. The coefficient on DEN is statistically significant and negative in all the hedonic models, suggesting that total costs decrease when the density increases. If large firms operate in high density areas, density is an important factor in the study of costs and in the definition of the “optimal size”.

Finally it is worth noting that economies of scale in our study refers mainly to delivery costs. This phase has certainly less opportunity of exploiting economies of scale differently from the purification phase and managerial and financial activities. Therefore it is in the integrated management of the whole water cycle, which is foreseen by the “Galli Act”, that lies the possibility of enjoying considerable economies.

8. Conclusions

The analysis of the technology underlying the water industry carried out in this work has shown that the hedonic specification is the most accurate. The comparison between the traditional approach and the hedonic one leads to the rejection of the null hypothesis of zero coefficients on hedonic variables.

Moreover, the comparison between the various functional forms points to the transcendental logarithmic specification and to the absence of "regularity conditions" of costs (that is of production) with respect to the combination of inputs, to the product mix and scale.

The analysis of returns to scale, which is particularly important in the light of the reorganisation of the Italian water industry, depends both on the choice of functional forms different from the translog and on the exclusion of the hedonic variables. When environmental and quality factors are not taken into account, the estimates for firms of any size show constant, instead of variable, economies.

Table 1: Volume delivered, customers and population served by the firms of our sample

	Minimum	**Average**	**Maximum**
Volume Delivered (000 cubic metres)	131	18,860	393,960
Population served	1169	164,369	4,620,808
Customers	661	29,505	727,284

Table 2: Number of firms per class of population served

Population	**Firms**	**Volume Delivered (000 cubic metres)**	**Percentage on Total of Volume Delivered**
0 - 10,000	16	10,689	0.37
10,000 - 20,000	23	35,962	1.27
20,000 - 60,000	48	206,898	7.32
60,000 - 100,000	21	186,837	6.60
100,000 - 150,000	17	213,419	7.54
150,000-250,000	10	275,302	9.74
250,000 - 500,000	7	283,450	10.02
500,000 - 1,000,000	3	201,804	7.14
> 1,000,000	5	1,414,621	50
Total	**150**	**2,828,982**	**100**

Table 3: Comparison between hedonic and non hedonic cost function for the Translog specification and the Cobb-Douglas one

Variables	Coeff.	Translog Hedonic	Translog Non Hedonic	Cobb-Douglas Hedonic	Cobb-Douglas Non Hedonic
Constant	α_0	-0.040 (-1.316)	0.0047 (0.118)	-0.03 (0.973)	0.0087 (0.214)
Y	α_y	0.634* (8.693)	0.92* (35.35)	0.673* (15.717)	0.908* (42.98)
UT	β_{UT}	0.378* (5.304)		0.323* (7.739)	
DEN	β_{DEN}	-0.353* (-4.224)		-0.464* (-9.046)	
AA	β_{AA}	0.0013 (0.075)		0.0006 (1.428)	
POT	β_{POT}	-0.018 (-1.069)		0.0005 (1.132)	
PL	γ_L	0.42* (37.009)	0.40* (40.199)	0.39* (47.223)	0.41* (48.507)
PE	γ_E	0.11* (13.283)	0.14* (19.026)	0.15* (23.215)	0.15* (24.109)
PM	γ_M	0.47* (47.693)	0.46* (48.031)	0.46* (53.265)	0.44* (50.568)
PL2	γ_{LL}	0.1* (5.105)	0.063* (2.988)		
PE2	γ_{EE}	0.022**** (1.580)	0.053* (3.882)		
PM2	γ_{MM}	0.171* (13.537)	0.123* (10.291)		
PL*PE	γ_{LE}	0.024*** (1.752)	0.004 (0.254)		
PL*PM	γ_{LM}	-0.124* (-9.684)	-0.007* (-5.216)		
PE*PM	γ_{EM}	-0.047* (-5.092)	-0.057* (-7.068)		
PL*Y	τ_{YL}	-0.016 (-1.016)	0.008**** (1.611)		
PL*UT	$\sigma_{UT,L}$	0.022 (1.413)			
PL*DEN	$\sigma_{DEN,L}$	0.135* (6.505)			
PL*AA	$\sigma_{AA,L}$	-0.00009 (0.585)			
PL*POT	$\sigma_{POT,L}$	0.0006* (3.692)			
PE*Y	τ_{YE}	-0.0002 (-0.014)	-0.003 (-0.784)		
PE*UT	$\sigma_{UT,E}$	-0.008 (-0.718)			
PE*DEN	$\sigma_{DEN,E}$	0.013 (0.865)			
PE*AA	$\sigma_{AA,E}$	-0.00025*** (-2.116)			
PE*POT	$\sigma_{POT,E}$	-0.0004** (-2.843)			
PM*Y	τ_{YM}	0.016 (1.182)	-0.005 (-1.094)		
PM*UT	$\sigma_{UT,M}$	-0.014 (-1.023)			
PM*DEN	$\sigma_{DEN,M}$	0.148* (-7.952)			
PM*AA	$\sigma_{AA,M}$	0.0002 (1.120)			
PM*POT	$\sigma_{POT,M}$	-0.0003**** (-1.859)			
Y2	α_{YY}	-0.143 (-1.548)	0.0002 (0.011)		
UT2	$\beta_{UT,UT}$	-0.13 (-1.292)			
DEN2	$\beta_{DEN,DEN}$	0.208 (1.461)			
AA2	$\beta_{AA,AA}$	0.0004 (0.123)			
POT2	$\beta_{POT,POT}$	-0.0004 (-1.041)			
Y*UT	$\alpha_{Y,UT}$	0.148**** (1.632)			
Y*DEN	$\alpha_{Y,DEN}$	0.175*** (1.982)			
Y*AA	$\alpha_{Y,AA}$	-0.0002 (-0.154)			
Y*POT	$\alpha_{Y,POT}$	-0.0002 (-0.288)			
UT*DEN	$\beta_{UT,DEN}$	-0.135*** (-1.831)			
UT*AA	$\beta_{UT,AA}$	-0.0002 (-0.237)			
UT*POT	$\beta_{UT,POT}$	0.0008 (1.043)			
DEN*AA	$\beta_{DEN,AA}$	-0.002** (-2.365)			
DEN*POT	$\beta_{DEN,POT}$	0.002** (2.365)			
AA*POT	$\beta_{AA,POT}$	-0.00003* (-3.992)			
$\bar{R}^2$		0.971	0.908	0.97	0.908
χ^2		Hedonic vs Non Hedonic Translog	320.546	Hedonic vs Non Hedonic Cobb-Douglas	188.173

t-statistics are in parentheses.

* Significant at 1‰, ** Significant at 1%, *** Significant at 5%, **** Significant at 10 %

Table 4: Cost functions under different hypotheses on technology

Variables	Coeff.	TRANSLOG	UNITARY ELASTICITY	HOMOTHETICITY	HOMOGENEITY	COBB-DOUGLAS
Constant	α_0	-0.040	-0.046	0.047	0.006	-0.03
Y	α_y	0.634*	0.648*	0.669*	0.691*	0.673*
UT	β_{UT}	0.378*	0.366*	0.343*	0.301*	0.323*
DEN	β_{DEN}	-0.353*	-0.383*	-0.414*	-0.523*	-0.464*
AA	β_{AA}	0.0013	0.016	0.018	0.0004	0.0006
POT	β_{POT}	-0.018	-0.013	-0.010	-0.0007	0.0005
PL	γ_L	0.42*	0.41*	0.40*	0.39*	0.39*
PE	γ_E	0.11*	0.11*	0.13*	0.13*	0.15*
PM	γ_M	0.47*	0.48*	0.47*	0.48*	0.46*
PL2	γ_{LL}	0.1*		0.101*	0.069*	
PE2	γ_{EE}	0.022****		-0.008	0.077*	
PM2	γ_{MM}	0.171*		0.048**	0.115*	
PL*PE	γ_{LE}	0.024***		-0.022	-0.015****	
PL*PM	γ_{LM}	-0.124*		-0.079*	-0.054*	
PE*PM	γ_{EM}	-0.047*		-0.031***	-0.062*	
PL*Y	τ_{YL}	-0.016	-0.013			
PL*UT	$\sigma_{UT,L}$	0.022	0.014			
PL*DEN	$\sigma_{DEN,L}$	0.135*	0.039***			
PL*AA	$\sigma_{AA,L}$	-0.00009	-0.0002			
PL*POT	$\sigma_{POT,L}$	0.0006*	0.0006*			
PE*Y	τ_{YE}	-0.0002	-0.0007			
PE*UT	$\sigma_{UT,E}$	-0.008	-0.009			
PE*DEN	$\sigma_{DEN,E}$	0.013	-0.025****			
PE*AA	$\sigma_{AA,E}$	-0.00025***	-0.0004****			
PE*POT	$\sigma_{POT,E}$	-0.0004**	-0.0004****			
PM*Y	τ_{YM}	0.016	0.013			
PM*UT	$\sigma_{UT,M}$	-0.014	-0.004			
PM*DEN	$\sigma_{DEN,M}$	0.148*	-0.010			
PM*AA	$\sigma_{AA,M}$	0.0002	0.0005***			
PM*POT	$\sigma_{POT,M}$	-0.0003****	-0.0002			
Y2	α_{YY}	-0.143	-0.09	-0.102		
UT2	$\beta_{UT,UT}$	-0.13	-0.026	0.034		
DEN2	$\beta_{DEN,DEN}$	0.208	0.10	-0.06		
AA2	$\beta_{AA,AA}$	0.0004	0.0003	0.0004		
POT2	$\beta_{POT,POT}$	-0.0004	-0.0002	-0.0002		
Y*UT	$\alpha_{Y,UT}$	0.148****	0.07	0.082		
Y*DEN	$\alpha_{Y,DEN}$	0.175***	0.186***	0.19***		
Y*AA	$\alpha_{Y,AA}$	-0.0002	-0.0002	0.0001		
Y*POT	$\alpha_{Y,POT}$	-0.0002	-0.0001	0.0008		
UT*DEN	$\beta_{UT,DEN}$	-0.135***	-0.132****	-0.129****		
UT*AA	$\beta_{UT,AA}$	-0.0002	-0.0004	-0.0005		
UT*POT	$\beta_{UT,POT}$	0.0008	0.0006	0.0006		
DEN*AA	$\beta_{DEN,AA}$	-0.002**	-0.0023**	-0.002***		
DEN*POT	$\beta_{DEN,POT}$	0.002**	-0.0016****	0.0012		
AA*POT	$\beta_{AA,POT}$	-0.00003*	0.00004*	-0.00003*		
$\overline{R}^2$		0.971	0.970	0.974	0.971	0.97
χ^2 Translog vs			113.567	73.776	113.326	203.127

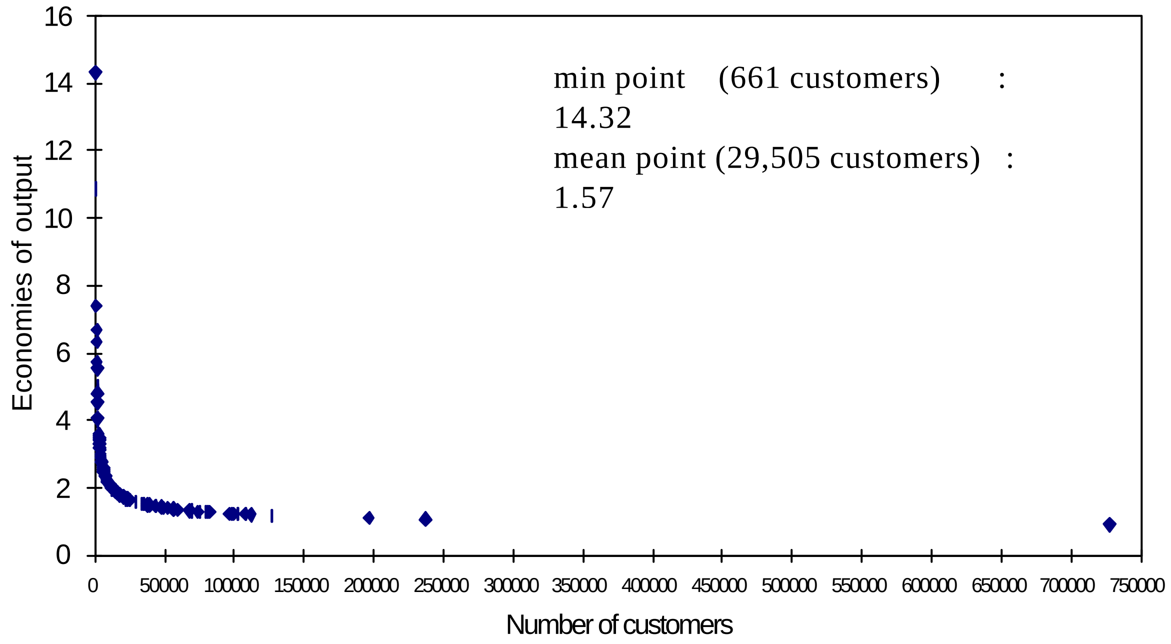
* Significant at 1‰; ** Significant at 1%; *** Significant at 2.5%; **** Significant at 10 %

TABLE 5: Cost elasticity and economies in the different models (calculated at the sample mean)

	Hedonic Specification					Non Hedonic Specification	
	Translog	Unitary Elasticity of Substitution	Homotheticity	Homogeneity	Cobb-Douglas	Translog	Cobb-Douglas
$\varepsilon_{C,Y}$	0.634	0.648	0.669	0.691	0.673	0.92	0.908
Returns to output	1.58	1.54	1.49	1.45	1.48	1.08	1.10
$\varepsilon_{C,Y}+\varepsilon_{C,UT}$	1.012	1.014	1.012	0.992	0.996		
Returns to scale	0.99	0.986	0.99	1.008	1.004		
$\varepsilon_{Y,DEN}$	-0.353	-0.383	-0.414	-0.523	-0.464		

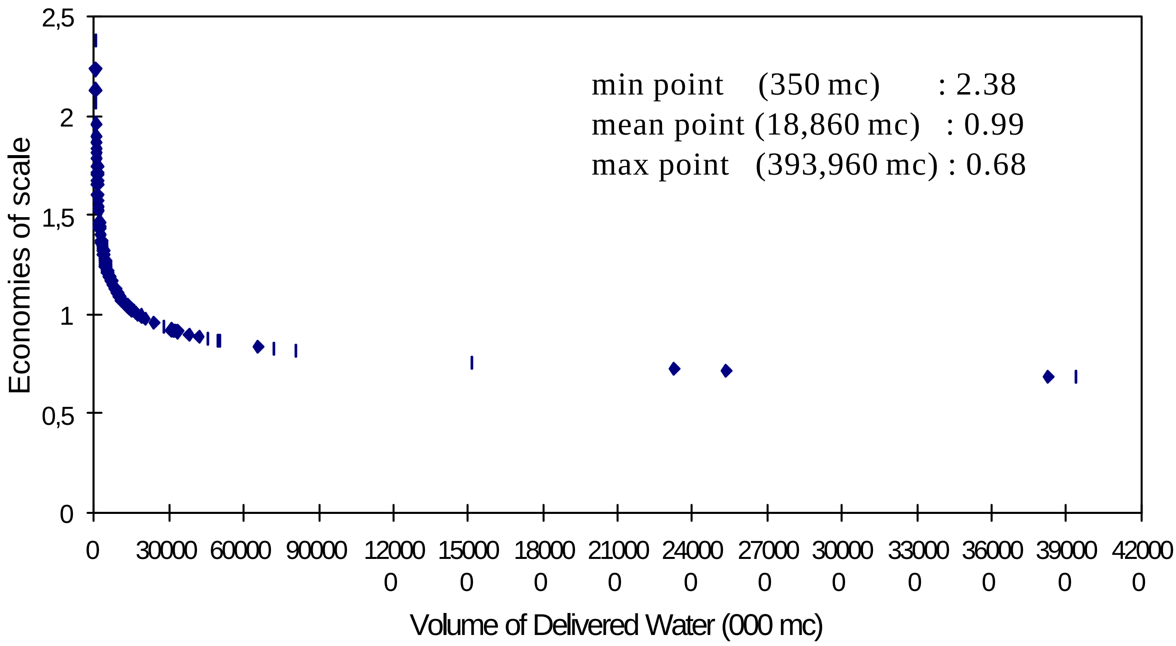
Graphic 1: Economies of output for the hedonic translog

$$E_{C,Y} = 0.634 + 0.148 \ln UT + 0.175 \ln DEN$$



Graphic 2: Economies of scale for the hedonic translog

$$E_S = E_{C,Y} + E_{C,UT} = 1.012 + 0.148 \ln Y + 0.148 \ln UT + 0.04 \ln DEN$$



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