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Abstract

In this paper, we assess the economic efficiency of Swiss water utilities. To reach this aim, we accessed a new and unexploited database, which counts 330 water utilities, representing about 55% of the drinking water distributed in Switzerland. The database spans over six years (2000-2005) and offers information on the type of the water production process, the characteristics of the network and the costs of water supply. This database presents an original opportunity to analyse the cost of water supply and to determine the efficiency of the water utilities. Such a study has never been done for Switzerland. We apply a stochastic cost function approach to measure cost inefficiency and to investigate the impact of environmental characteristics outside the control of the water utilities (e.g. type of water and customer density) on costs and inefficiency measures. Our results show that environmental factors have a significant influence on costs. Including exogenous variables in the analysis lowers industry inefficiency scores and provides indicators of managerial performance.

Keywords

Water utilities, benchmarking, stochastic cost function, performance, efficiency.

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1. Introduction and context

In this paper we report the preliminary results of an on-going research project on the measurement of the technical efficiency of Swiss drinking water utilities. Switzerland is an interesting case of study in several respects.

Firstly, the country possesses a relatively large water endowment and it is classified as a high water availability country. The main sources of drinking water are spring water (about 40%), underground water (40%) and lake water (20%)[1]. Although the situation is changing due to increasing pollution and urbanization, the water withdrawn is of relatively good quality. As a result, about 40% of the extracted water requires no further treatment before it is distributed and about a third requires UV or ozone treatment only.

Secondly, although the size of the country is relatively small (about 41'000 Km^2) and the population is of about 7.5 millions only, Swiss regions and thus water utilities face very diverse conditions and constraints. In particular, since about 70% of the inhabitants live in urban areas, population density is relatively high in the metropolitan areas, whereas it is quite low in the mountain regions, which represent about half of the Swiss territory. Moreover, climatic, topographic and water conditions are quite different from one region to the other.

Thirdly, Switzerland is a federal state and thus the responsibility of water supply is divided between the federal, cantonal and municipal levels (for a detailed discussion of water institutions in Switzerland, see Luís-Manso, 2005). The main responsibility of the Confederation is to set the legal framework for water protection and the drinking water quality standards, with a limited role in the financing of infrastructures within the context of water protection. Contrary to other countries, except for quality standards, no central water regulator exists in Switzerland, although there is a Price Supervisor who can also judge about water price levels. Drinking water provision and control are thus mostly within the competence of the Cantons, which however generally delegate those responsibilities to various degrees to the municipalities – from a very limited delegation as in the case of the Geneva Canton, to a relatively complete delegation, as in the case of the Valais Canton. In turn, municipalities can choose different management and organization structures. In particular, smaller municipalities favour sub-contracting of infrastructure maintenance and/or increasingly tend to group into inter-municipal associations, while bigger municipalities have a specific water service or an industrial service grouping water distribution with wastewater treatment, electricity and natural gas supply. As a result, the Swiss water distribution market is highly segmented, composed by about 3'000 water utilities often controlled by the municipality, acting as local monopolies[2]. In addition, the management structures are very different, the most widespread being non-autonomous entities under public law. Those entities are generally administrative units possessing distinct accounts from the other municipal units, but possess limit competencies in terms of financing, tariffs and human resources. In the recent past, especially in the big cities like Geneva, there is however a trend to assign greater autonomy to water operators, with the result that presently it is estimated that 10% of the suppliers are operating under public law, but quite autonomously. Other structures comprise utilities under private law, generally owned by the municipalities, which provide about 10% of water services, quite often along with other network services like electricity and natural gas. In Switzerland, the participation of the private

[1] Unless indicated otherwise, this section uses data from the Swiss Gas and Water Industry Association's Annual Statistical Reports (several years) and <http://www.trinkwasser.ch/>.
[2] Total network of water pipelines is estimated at about 53'000 Km.

sector is very limited and there is one privately owned water utility only, operating in the Canton of Zoug (in fact a multi-utility company).

As regards drinking water consumption, in 2001 over a total of about 1 billion m^3 of water distributed, households and small businesses accounted for 63%, industry 17%, public fountains and services 5%, own water utilities consumption 3%, and water losses 12%. Until the seventies, Switzerland witnessed increasing water consumption, followed by a decade of stabilization and then a decrease. At the beginning of the eighties, the mean water consumption was about 500 litres by habitant and day, while it was only 370 litres in 2005. In twenty years the water consumption by households decreased by about 20 litres and it is currently about 162 litres/hab./year. The industry also contributed to decreasing water consumption, by adopting new production processes and because of sector restructuration.

Summarizing, we can thus highlight that the drinking water market in Switzerland is highly segmented and characterized by a very large number of water utilities acting as local monopolies very often controlled by the municipalities. In addition to quite different management structures, water utilities are confronted with very diverse environmental conditions, such as costumer density, topography and water sources.

Although there seems to be a general agreement that the Swiss water market has to be preserved from the liberalization pressures which are presently acting in other network industries, there is nevertheless a raising concern about their performance (e.g. see Kilchman, 2003). For instance, the Price Supervisor intervened in order to investigate the reasons for the very large differences in water tariffs (see Surveillance des prix, 1998 and 2001). He reported differences in total costs for m^3 of water delivered ranging from CHF 0.28 to 7.20 (median 1.35, mean 1.70) and in water tariffs ranging from CHF 0.07 and 3.35 (median and mean 1.3)[3]. Of course, in order to compare costs and prices, it is necessary to consider the different context in which water utilities operate, and in particular to assess their performance considering the exogenous parameters which can have an impact on costs and then on tariffs.

The aim of this paper is to contribute to the actual debate concerning the comparison of the performance of Swiss water utilities. In several countries it is now customary practice to benchmark the performance of network utilities for regulatory purposes, the best known examples in the water domain being the UK, the USA, The Netherlands, Germany and Italy (for a survey see e.g. Shuttleworth, 2005). Several indicators have been proposed in order to evaluate the performance, from relatively simple ratios such as the number of workers per unit of water delivered, to more complex ones (e.g. see Alegre et al., 2006; Parena, Smeets and Troquet, 2002). In the literature, benchmarking techniques are based on parametric methods developing cost and production functions or nonparametric approaches, based on data envelopment analysis (DEA) (for a comparison, see e.g. Cubbin and Tzanidakis, 1998). In this paper, we adopt a parametric approach and estimate a stochastic cost function in order to measure the technical efficiency of Swiss water utilities. To the best of our knowledge, this is the first attempt to implement this approach in the Swiss water distribution context.

The structure of the paper is the following. Section 2 discusses the theoretical approach and its empirical implementation. Section 3 defines the variables and presents the descriptive statistics of the sample. Section 4 discusses the results, concludes and highlights the future research questions analysed within our project.

[3] Presently, 1 CHF = 0.63 EURO.

2. Model specification and empirical implementation

In order to characterise the properties of the water distribution process and measure efficiency, it is necessary to assume the existence of a relationship between the production factors and the produced outputs, and that the relationship can be represented in mathematical terms. Given some regularity conditions and assuming that utilities minimise costs, it is possible to prove that the cost function is the dual of the production function. Therefore, the production structure can be characterised by using a production function or a cost function. However, from an empirical point of view, the use of a production or a cost function has different implications (cf. Berndt, 1991). Indeed, in the regressions with the production function, the level of production is of course endogenous, while the quantities of production factors are supposed to be exogenous. On the contrary, with the cost function, the production costs and the production factors are endogenous, while the output is exogenous.

In the context of water utilities, two main reasons favour the use of a cost function. Firstly, water utilities are submitted to regulatory rules which limit their ability to produce the output that maximises profit. In particular, water utilities have a legal obligation to serve all costumers, generally at a given minimum water quality standard[4]. Moreover, the profit of the Swiss water utilities is generally limited to the level that covers the costs of future investments in infrastructures. Secondly, given the most widespread management structures described above, Swiss water utilities are often constrained in the production factor prices, either at the institutional level (e.g. salaries) or by the market, and thus production factor prices can be considered as exogenous by the water utility. Consequently, we assume that water utilities take their main decisions principally regarding the optimal quantities of production factors. We thus concentrate on the cost function only.

In this paper, we decided to estimate total and variable cost frontiers. The total cost function can be written in general as:

$$TC = C(y_1, \ldots, y_Q, p_1, \ldots, p_J) = \min_{x_j \geq 0} \left(x_1 p_1 + \ldots + x_J p_J \right) \qquad (1)$$

where TC is the total cost, y_g represents the g^{th} output, x_j the j^{th} production factor and pj its price.

The total cost function possesses the usual properties (e.g. monotonicity, concavity in the price factors, homogeneity of degree one with respect to factor prices and outputs; see Chambers 1988). However, it should be noted that the use of a total cost function supposes that the producers are at their long term equilibrium and that they use their production factors at the level minimising total cost. In the case of the water utilities, such assumption is relatively strong, in particular with regard to their capital stock, which may not be at its optimal level for two main reasons. Firstly, modifications in the capital stock are relatively costly and thus the size of the main water utilities infrastructures is typically based on demographic and economic previsions, which can be wrong. Secondly, water utilities have to respond to all the demand, and thus in order to account for seasonal and unexpected demand variations (e.g. in case of fire), they typically dispose of excess capacities. For those reasons, we consider that the capital stock of the water utilities is fixed in the short term and only adjusting partially with respect to its long term equilibrium. In this latter case however, the total cost function (1) is not suitable. As an alternative, we can suppose that the water utilities minimise their costs, under the additional constraint that their dimension is given. In other words, we assume that the water utility minimises its costs adjusting only some of its production factors (the "variable"

[4] But water utilities could provide drinking water of *better* quality than the standards. In this case, we could consider that water utilities produce two outputs. We are planning to integrate the quality aspects into the next steps of our research project.

factors), and considering as given the level of the other inputs (the "quasi-fixed" factors). Taking x_j as the J variable production factors and z_m the M fixed factors, the short term "variable" cost function can thus be defined as (see e.g. Lau, 1976):

$$VC = V(y_1, \ldots, y_Q, p_1, \ldots, p_J, z_1, \ldots, z_M) = \min_{x_j \geq 0}(x_1 p_1 + \ldots + x_J p_J) \tag{2}$$

As demonstrated by Chambers (1988), considering quasi-fixed factors in the production process does not change significantly the properties of the costs with respect to the variable factor prices and the level of the outputs. In addition, it should be noted that the variable and the total cost functions are of course not completely independent. Indeed, it is possible to define a short-term total cost function, defined as the variable cost (2) plus the costs associated with the quasi-fixed factors. If the latter are at their optimal level, then the short-term total cost function corresponds to the long-term one.

In order to estimate the cost efficiencies of the water utilities, we have to estimate a stochastic cost frontier and to specify the form of the total (1) and variable cost (2) functions. The stochastic cost function can be expressed in general terms as:

$$\ln C_{it} = \alpha + c(y_{it}, p_{it}; \beta) + v_{it} + u_{it} \tag{3}$$

Where C_{it} represents the total or the variable costs of firm i at time t, α the estimated constant, y_{it} the output, p_{it} the vector of factor prices and β the vector of coefficients to be estimated. The v_{it} is a random error term measuring white noise, while u_{it} is a non negative random variable interpreted as the cost inefficiency measure. u_{it} must take positive values, because firms cannot operate under the cost frontier. In the literature, there are various specifications concerning the inefficiency component of the error term u_{it}[5]. Following Battese and Coelli (1992) we use maximum likelihood to estimate the variable and total cost frontiers and we impose the following distributions on v_{it} and u_{it}. The v_{it} are assumed to be independently and identically distributed such as $N(0,\sigma^2_v)$ and independent of the u_{it}, which are independently and identically distributed as truncations at zero of the $N(\mu, \sigma^2_u)$ distribution. The parameterisation suggested by Battese and Corra (1977) is used for the loglikelihood function, meaning that σ^2_v and σ^2_u are replaced by $\sigma^2 = \sigma^2_u + \sigma^2_v$ and $\gamma = \sigma^2_u /(\sigma^2_u + \sigma^2_v)$. The γ parameter varies between zero and one and indicates the relative importance of noise and inefficiency. The higher the γ, the closer we come to a deterministic model, while a zero γ would take us back to a traditional average cost function model. From the estimation of the cost frontier, it is possible to calculate inefficiency scores. For the i^{th} firm in year t, cost inefficiency CI is defined as:

$$CI_{it} = \exp(u_{it}) \tag{4}$$

The u_{it} are not directly observed and need to be estimated using the conditional expectation of u_{it} given the observed values of ε_{it}, (with $\varepsilon_{it} = v_{it} + u_{it}$) (see Battese and Coelli, 1988):

$$CI_{it} = E[\exp(u_{it}) \mid \varepsilon_{it}] \tag{5}$$

Cost inefficiency estimates measure the distance that separates the firm from the cost frontier. The score of a perfectly cost efficient water utility would be one and its u_{it}, which accounts for inefficiency, would be zero. This utility would consequently operate on the cost frontier. At the other extreme, an infinite cost inefficiency score represents the worst case scenario and would occur if $u_{it} \rightarrow \infty$. More in general, the higher the CI coefficient, the higher the firm's cost inefficiency.

In the discussion until now, our cost frontiers only include output, price and quasi-fixed input variables, and thus we do not account for the environment in which the

[5] For details on the different estimation methods, see Kumbhakar and Lovell (2000).

firms operate. Although they are not under the management's control, environmental variables can have a substantial impact on the costs and thus on the firms efficiency levels. Therefore, it is very important to include such exogenous variables , especially in very heterogeneous markets. Indeed, as already mentioned, water utilities in Switzerland face very different production conditions, from the density of the area and the type of customers they serve, to the quality and accessibility of the adducted water. The management has no or only limited control over these environmental factors and they should certainly be included in the stochastic frontier model. However, we should note that in the literature there is no general consensus on the best approach in order to account for environmental variables. For instance, Coelli, Perleman and Romano (1999) use two different approaches.

The first approach assumes that the exogenous variables have a direct impact on the cost frontier, affecting the technology and the production structure, and therefore the shape of the frontier. In this case, the environmental factors are directly included into the cost frontier:

$$\ln C_{it} = \alpha + c(y_{it}, p_{it}, E_{it}; \beta) + v_{it} + u_{it} \quad (6)$$

where the variables are as in (5) and E_{it} represents the vector of environmental factors faced by firm i at time t. In this approach, every firm thus faces a different frontier, or benchmark, depending on the environment in which it operates, and the resulting inefficiency scores are net of environmental influences. In other words, by including the exogenous factors directly in the frontier, one adapts the level of the cost frontier to the utility's environmental conditions. For example, a utility faced with a particularly hostile environment will see the frontier measuring its performance to go up, thus lowering its inefficiency score. This approach has among others been used by Filippini, Hrovatin and Zoric (2007) in their study on the cost efficiency of the Slovenian water distribution utilities.

The second approach is quite different. It assumes that exogenous variables do not directly influence the frontier, but rather that they affect the cost inefficiency score. In this case, the environment does not affect the technology: all the firms share a unique cost frontier and are evaluated against the same benchmark. The exogenous variables are modeled to influence the distribution of the u_{it} and therefore the distance that separates them from the benchmark. Their effect is included in the inefficiency scores, which consequently are gross values. This approach was developed by Kumbhakar, Gosh and Mc Gulkin (1991), Reifschneider and Stevenson (1991), Huang and Liu (1994) and Battese and Coelli (1995) and it has for example been chosen by Fraquelli and Moiso (2005) in their study about the cost efficiency of the Italian water industry.

There are no compelling theoretical arguments to prefer one approach over the other. In this paper, we have opted for the first approach, allowing for the exogenous variables to directly influence the shape of the frontier. This choice might seem arbitrary, but we believe that the environmental background of the Swiss water utilities is so heterogeneous that it is likely to affect their technology and production structure.

In the empirical application it is then necessary to specify the form of the costs functions to be estimated. In the literature, several studies use a Cobb-Douglas cost function (e.g. Antonioli and Filippini, 2001). Although its simplicity and easily interpretable results, the Cobb-Douglas specification imposes unnecessary restrictions on the production technology, in particular regarding economies of scale. For this reason, the majority of studies use a translog cost function, which is more flexible and also contains the Cobb-Douglas specification as a special case. The translog cost function corresponds to a second degree Taylor approximation in the logarithms of an arbitrary cost function, with some restrictions in the parameters in order to respect the main desired properties (e.g. symmetry and homogeneity). Of course, the main disadvantage of the translog is related to its definition: since it is a local approximation, the results are reliable only close to the approximation point. Given that some properties of the translog cost function are not imposed (in particular concerning its curvature), they should be verified ex post, based on the estimated coefficients.

For Swiss water utilities, we specify a one output, four input translog function, including five exogenous environmental factors, which takes the following form:

$$
\begin{aligned}
\ln\left(\frac{CT_{it}}{pMA_{it}}\right) = {} & \alpha + \beta_Y \ln Y_{it} + \beta_{pL} \ln\left(\frac{pL_{it}}{pMA_{it}}\right) + \beta_{pE} \ln\left(\frac{pE_{it}}{pMA_{it}}\right) + \beta_{pK} \ln\left(\frac{pK_{it}}{pMA_{it}}\right) + \beta_{dens} \ln DENS_{it} + \\
& \beta_{load} \ln LOAD_{it} + \beta_p D_{PUMP} + \beta_h D_{HOUSE} + \beta_l D_{LAKE} + \tfrac{1}{2}\beta_{YY} \ln Y_{it} \ln Y_{it} + \\
& \tfrac{1}{2}\beta_{pLpL} \ln\left(\frac{pL_{it}}{pMA_{it}}\right) \ln\left(\frac{pL_{it}}{pMA_{it}}\right) + \tfrac{1}{2}\beta_{pEpE} \ln\left(\frac{pE_{it}}{pMA_{it}}\right) \ln\left(\frac{pE_{it}}{pMA_{it}}\right) + \tfrac{1}{2}\beta_{pKpK} \ln\left(\frac{pK_{it}}{pMA_{it}}\right) \ln\left(\frac{pK_{it}}{pMA_{it}}\right) + \\
& \tfrac{1}{2}\beta_{densdens} \ln DENS_{it} \ln DENS_{it} + \tfrac{1}{2}\beta_{load} \ln LOAD_{it} \ln LOAD_{it} + \beta_{YpL} \ln Y_{it} \ln\left(\frac{pL_{it}}{pMA_{it}}\right) + \\
& \beta_{YpE} \ln Y_{it} \ln\left(\frac{pE_{it}}{pMA_{it}}\right) + \beta_{YpK} \ln Y_{it} \ln\left(\frac{pK_{it}}{pMA_{it}}\right) + \beta_{Ydens} \ln Y_{it} \ln DENS_{it} + \beta_{Yload} \ln Y_{it} \ln LOAD_{it} + \\
& \beta_{pLpE} \ln\left(\frac{PL_{it}}{PMA_{it}}\right) \ln\left(\frac{PE_{it}}{PMA_{it}}\right) + \beta_{pLpK} \ln\left(\frac{pL_{it}}{pMA_{it}}\right) \ln\left(\frac{pK_{it}}{pMA_{it}}\right) + \beta_{pLdens} \ln\left(\frac{PL_{it}}{pMA_{it}}\right) \ln DENS_{it} + \\
& \beta_{pLload} \ln\left(\frac{PL_{it}}{pMA_{it}}\right) \ln LOAD_{it} + \beta_{pEpK} \ln\left(\frac{PE_{it}}{pMA_{it}}\right) \ln\left(\frac{PK_{it}}{pMA_{it}}\right) + \beta_{pEdens} \ln\left(\frac{PE_{it}}{pMA_{it}}\right) \ln DENS_{it} + \\
& \beta_{pEload} \ln\left(\frac{PE_{it}}{pMA_{it}}\right) \ln LOAD_{it} + \beta_{pKdens} \ln\left(\frac{PK_{it}}{pMA_{it}}\right) \ln DENS_{it} + \beta_{pKload} \ln\left(\frac{PK_{it}}{pMA_{it}}\right) \ln LOAD_{it} + \\
& \beta_{densload} \ln DENS_{it} \ln LOAD_{it} + \beta_T T + v_{it} + u_{it} \qquad (7)
\end{aligned}
$$

where y_{it} is the quantity of water delivered by utility i at time t, P_L is labour price, P_E the energy price, P_{MA} the material price, P_K the price of capital (or CAP the stock of capital in the variable cost frontier), DENS is consumer density and LOAD the load factor. D_{pump}, D_{house} and D_{lake} are dummy variables measuring the percentage of adduction that requires pumping of the water, the part of households among the customers and measures if water is adducted from lakes and rivers, respectively. Finally, T is a time trend.

All monetary amounts were deflated to 2003 constant Swiss francs using the producer's price index of the Federal Office of Statistics. The costs and factor prices are normalized by the material price to guarantee homogeneity in input prices and $\beta_{jn} = \beta_{nj}$ imposes symmetry. The variable cost function is the same as in (7), except that it includes the capital level instead of the price of capital. In the next section we discuss the definition of these variables more precisely.

3. Data, variables and descriptive statistics

This study uses a database of the Swiss Gas and Water Industry Association (SGWA), which contains originally information about 330 water utilities, over the period 2000 to 2005. The database results from a detailed survey done by the SGWA each five years (thus in our case in 2000 and in 2005), and a shorter survey which is conducted each year. The database offers information on the type of the water production process, the network characteristics, customer attributes and the costs of water supply. It should be emphasized that the database does only include about 10% of the about 3'000 existing Swiss water utilities. However, the utilities included in the survey accounted for about 55% of the water distributed in Switzerland in 2005. This implies that larger water utilities are overrepresented in the database. We should nonetheless highlight that, as shown in Table 1, the distributors included in the database still differ widely in terms of size, structure, water resources, geological characteristics of the distribution area, production processes and customer demand and are situated all across Switzerland. As already mentioned, most of them are public companies owned by the municipalities, some acting also as electricity and gas distributors.

Since in the original SWGA database there are a lot of missing values in the years 2000 and 2001, especially those necessary in order to measure labour cost, we decided to exclude the observations in those years from our sample. After eliminating some aberrant values that were clearly invalid as well as outliers, our final sample is an unbalanced panel containing data on 113 water distribution utilities and a total of 291 observations over the years 2002 to 2005.

The output is measured as the total quantity of water supplied to the customers in thousands of cubic meters. As shown in Table 1, the sample contains water utilities of very different size: the mean quantity of delivered water is 3.8 million cubic meters, the median 1.3 with a relatively large standard deviation of about 9 million cubic meters. The smallest utility only distributes 94 thousand cubic meters of water, while the biggest delivers over 67 million cubic meters.

Variable costs are calculated by summing labour costs, energy costs, material expenses and “other expenses”. Total costs are obtained by adding depreciation and interests. In Table 1, we again observe that water utilities are very different. The mean annual total cost is about CHF 6.1 millions, while the median is 1.6, with a very high standard deviation of CHF 17.8 millions. Total costs vary between a minimum of CHF 122’000 and a maximum of CHF 129 millions.

The price of labour is defined as total labour costs divided by the number of employees. Unfortunately, the database contains only the number of employees working part time and full time, but no information is given on the full time equivalent of people employed. We thus calculate the full time equivalent assuming that part time employees are working half-time on average.

The energy price is computed as energy expenses divided by energy consumption. The third input is materials. As in the estimations we are using log transformations of the variables, we merged material and “other expenses” together, because the latter contains very diverse kind of expenses and is equal to zero for a non negligible number of utilities. We follow Garcia and Thomas (2001) in constructing a price index for material and other expenses by dividing them by the quantity of water delivered. This procedure seems acceptable, given the heterogeneity of the costs included in the material and other expenses categories and the lack of more pertinent data.

To define capital stock one can either use a capacity measure as in Filippini (1994) or a cost measure applying the perpetual inventory technique as for example in Nelson (1989). Although the latter method is theoretically more appropriate, we cannot apply it due to the lack of appropriate data. Therefore, as done in other studies, we use the total network length as the capital stock measure. Data on network length is collected each five years only (in our case in 2000 and 2005). For those utilities which have missing data in 2000 or in 2005, we extrapolated it by assuming a linear investment path. From Table 1, we can highlight again the great diversity of water utilities: the mean network length is about 153 km, with a standard deviation of 275 km. The water utility with the smallest water network has 10 km of pipelines only, while the greatest network is about 1’798 km long. The capital price is then computed by dividing capital costs (interests plus depreciation) by the capital stock.

Concerning the four exogenous environmental variables, we define customer density as the number of customers per meter of network. The effect of customer density on costs is ambiguous. On the one hand, high population density can for instance cause congestion problems or may imply more difficulties for digging water and building the network, but on the other hand it requires less capital (for example shorter pipelines per household) to distribute water to consumers that live close to each other. Water utilities face very different consumer densities, ranging from only 0.02 to 0.78 customers per meter of pipeline. The variation of customer density is due to the fact that some water utilities operate in metropolitan areas, while others distribute water to rural areas.

The load factor is the maximum amount of water distributed per customer per day divided by the mean amount of water supplied per customer per day. The load factor is related to variation in water demand. We expect that a water utility submitted to larger variations in demand will have higher costs.

Another environmental variable is the percentage of pumped water over total water adduction. It is introduced in the model as a dummy variable that equals one if the utility has to pump more than 50% of its water and zero otherwise. Ceteris paribus, we expect that a water utility which relies more on pumped water should have higher costs.

In order to account for the type of water customers, we also include the percentage of water delivered to households as a dummy that takes the value one if this percentage exceeds 60% and zero otherwise. A relatively high proportion of households as customers should increase costs, compared to a water utility that dominantly supplies firms, which typically represent bigger customers.

The last environmental variable measures the part of the water adduction that comes from lakes and rivers. It is a dummy variable that is set to zero if no water comes from lakes or rivers and one otherwise. We expect that the use of water from lakes and rivers induces higher costs, because this type of water requires more treatment.

Table 1. Descriptive statistics

Variable	Measurement unit	Mean	Median	SD	Max.	Min.
Total cost	CHF (10^3)	6'145	1'589	17'800	129'000	122
Variable cost	CHF (10^3)	4'161	1'074	10'500	67'600	56
Output	10^3 m^3 / year	3'804	1'267	9'039	67'813	94
Labour price	10^3 CHF /worker/year	97.6	91.2	39.9	261.4	40.1
Energy price	CHF /kWh/year	0.14	0.13	0.08	0.80	0.04
Material price	CHF/10^3 m^3 water/year	628.71	536.22	426.31	2'984.83	43.61
Capital price	CHF	7.89	6.40	7.04	47.26	0.05
Network	Km	152.7	78.5	274.5	1'797.8	10.6
Customers	thousands	25.1	9.2	59.3	440.3	0.7
Density	Customers/network unit	0.14	0.12	0.07	0.78	0.02
Load factor	-	1.60	1.53	0.33	2.98	0.69
Pumped water	% of total water delivered	74.9	88.1	30.7	100.0	0.1
Households	% of total water delivered	57.0	57.0	17.0	100.0	19.0
Lac / river water	% of total adduction	10.0	0.0	26.0	100.0	0.0

4. Results and discussion

The cost frontier parameters and the efficiency scores are estimated using FRONTIER 4.1. Table 2 presents the results of the estimation of the total and variable cost functions described in (7), as well as the estimates of the coefficients of total and variable cost functions that include no environmental factors. Because all variables were normalized at their sample median and are in logarithms, the first order coefficients can be interpreted as frontier cost elasticities for the median water utility.

Before discussing the results, we should note that we tested the functional form of the models. The likelihood ratio tests reject the Cobb-Douglas in favour of the translog in all four models[6]. Furthermore, the models excluding exogenous variables are both rejected when tested against their counterpart which account for the environment, emphasizing the importance to include heterogeneity in the estimations. The estimated share of the inefficiency variance in the variance of the composed error term is always very high (over 90% in the four models), a first indication of the presence of inefficiency effects. Indeed, a likelihood ratio test rejects the absence of inefficiency effects ($\gamma = 0$)[7].

The output, labour price, energy price (except for the total cost function that takes environmental influences into account, where the energy price is significant at the 10% level) and capital price coefficient all possess the expected sign and are statistically significant at the 5% level.

As shown in Table 2, the coefficient associated to the capital stock in the variable cost function is positive. Filippini (1996) refers to two alternative explanations for this phenomenon. The first explanation suggests that the coefficient of the capital stock is positive in cases where the industry is overcapitalized because it does not minimize costs in the long term. The second explanation is an econometrical one and highlights the multicollinearity problem arising from the inclusion of the often highly correlated output and capital stock into the function. The first argument is particularly relevant for the Swiss water distribution sector because water utilities have to meet all the demand and to dispose of large reserves to account for seasonal and unexpected demand variations (e.g. in case of fire). They thus dispose of excess capacities and are overcapitalized.

The estimates of the coefficients for the load factor carry the expected sign since higher demand variation is usually associated with higher costs. The coefficient is however not statistically significant. As expected, the percentage of pumped water is positive and highly significant in the variable cost model (but not in the total cost model). Surprisingly, the percentage of water adducted from lakes and rivers has no statistically significant impact on total and variable costs.

The coefficient associated with the percentage of households among the customers also displays a positive sign and is statistically significant at the 10% level in the total cost model. The density parameter estimates are more difficult to interpret. They have a statistically significant positive impact on variable costs. This suggests that congestion problems that arise in metropolitan areas are dominating the advantages of distributing water to a densely populated area. The opposite seems to be true in the total cost case, were the density parameter is negative and significant.

A negative but small coefficient associated with the time trend parameter suggests that costs are slightly decreasing over time, this downwards trend being significant at the 10% level for the two total cost models.

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[6] Detailed results of the tests are available upon request.

[7] The LR test statistic has a mixed chi-square distribution, critical values have been taken from table1 in Kodde and Palm (1986).

Table 2: Results

	VC without environment			VC with environment			TC without environment			TC with environment		
α	-0.55	***	*-13.83*	-0.55	***	*-15.72*	-0.48	***	*-11.24*	-0.45	***	*-10.96*
β_y	0.79	***	*35.60*	0.64	***	*16.48*	0.79	***	*46.19*	0.82	***	*41.21*
β_{pL}	0.31	***	*17.20*	0.28	***	*15.15*	0.23	***	*9.48*	0.23	***	*9.52*
β_{pE}	0.07	***	*4.08*	0.11	***	*5.78*	0.06	***	*2.71*	0.05	*	*1.91*
β_{pK}	_		_	_		_	0.25	***	*20.49*	0.27	***	*22.56*
β_{cap}	0.18	***	*5.78*	0.34	***	*7.61*	_		_	_		_
β_t	-0.01		*-1.28*	-0.01		*-1.00*	-0.02		*-1.64*	-0.02	*	*-1.89*
β_{dens}	_		_	0.24	***	*5.05*	_		_	-0.15	***	*-4.23*
β_{load}	_		_	0.03		*1.08*	_		_	0.04		*0.93*
β_p	_		_	0.08	***	*4.24*	_		_	0.03		*1.34*
β_h	_		_	0.02		*1.30*	_		_	0.04	*	*1.84*
β_l	_		_	0.04		*1.57*	_		_	-0.03		*-0.90*
β_{yy}	-0.04		*-0.74*	0.22	**	*2.57*	0.11	***	*7.29*	0.10	***	*5.24*
β_{pLpL}	0.20	***	*4.70*	0.11	***	*2.95*	0.12	*	*1.88*	0.10	*	*1.77*
β_{pEpE}	0.14	***	*3.86*	0.05		*1.38*	0.04		*0.71*	0.02		*0.35*
β_{pKpK}	_		_	_		_	0.09	***	*8.70*	0.10	***	*8.87*
β_{capcap}	-0.15	**	*-2.09*	0.30	**	*2.43*	_		_	_		_
$\beta_{densdens}$	_		_	0.40	***	*3.89*	_		_	-0.15	**	*-2.07*
$\beta_{loadload}$	_		_	0.18		*1.40*	_		_	-0.15		*-0.89*
β_{ypL}	-0.10	***	*-3.37*	-0.09	**	*-2.23*	-0.05	**	*-2.20*	-0.07	***	*-3.17*
β_{ypE}	0.03		*1.07*	-0.01		*-0.35*	-0.02		*-0.67*	-0.03		*-1.31*
β_{ypK}	_		_	_		_	-0.02		*-1.52*	-0.01		*-1.11*
β_{ycap}	0.12	**	*2.18*	-0.24	**	*-2.54*	_		_	_		_
β_{ydens}	_		_	-0.34	***	*-4.03*	_		_	-0.01		*-0.15*
β_{yload}	_		_	0.17	**	*2.40*	_		_	0.08		*1.58*
β_{pLpE}	-0.10	***	*-2.90*	-0.02		*-0.58*	-0.01		*-0.16*	0.01		*0.28*
β_{pLpK}	_		_	_		_	-0.07	***	*-3.20*	-0.05	**	*-2.12*
β_{pLcap}	0.05		*1.32*	0.07		*1.50*	_		_	_		_
β_{pLdens}	_		_	-0.05		*-0.96*	_		_	-0.01		*-0.12*
β_{pLload}	_		_	-0.07		*-1.44*	_		_	-0.14	*	*-1.94*
β_{pEpK}	_		_	_		_	0.03		*1.58*	0.00		*-0.25*
β_{pEcap}	-0.02		*-0.52*	0.07		*1.34*	_		_	_		_
β_{pEdens}	_		_	-0.01		*-0.12*	_		_	0.06		*1.25*
β_{pEload}	_		_	0.10	**	*2.11*	_		_	0.14	**	*1.96*
β_{pKdens}	_		_	_		_	_		_	0.01		*0.26*
β_{pKload}	_		_	_		_	_		_	-0.04		*-0.95*
$\beta_{capdens}$	_		_	0.43	***	*3.95*	_		_	_		_
$\beta_{capvload}$	_		_	-0.19	**	*-2.40*	_		_	_		_
$\beta_{densload}$	_		_	0.00		*-0.03*	_		_	-0.05		*-0.47*
σ^2	0.05	***	*5.89*	0.04	***	*6.71*	0.05	***	*7.54*	0.04	***	*7.28*
γ	0.96	***	*174.51*	0.94	***	*100.60*	0.92	***	*55.38*	0.92	***	*49.24*
μ	0.44	***	*8.12*	0.37	***	*9.11*	0.45	***	*9.39*	0.40	***	*7.09*
LL	261.81		_	290.54		_	205.66		_	235.34		_
n	291.00		_	291.00		_	291.00		_	291.00		_

Notes : t-statistics in italics
*** statistically significant at 1%; ** 5%, * 10%

Cost inefficiency scores are presented in Table 3. The scores from the models including environmental variables are net measures and can be interpreted as indicators of managerial performance. Net scores give a measure of how efficient the utilities would be if they all operated in similar environments. The average scores can be interpreted as a measure of industry inefficiency in the Swiss water distribution sector. As expected, the scores are higher when exogenous variables are not included into the model. This means that the inefficiency of water distribution utilities is overestimated if we fail to account for heterogeneity. Indeed both variable and total cost inefficiency amounts to approximately 60% for the model that includes no exogenous variables, while net inefficiency is estimated to be around 50%. Water utilities are also very different in their inefficiency scores. The most efficient ones being almost on the cost frontiers, while the least efficient have costs more than two times the efficient level. It should be noted that even in the calculation of net inefficiencies, not all exogenous effects have been accounted for and thus part of the score is probably still due to unobserved heterogeneity and not to inefficiency. The standard deviation of the inefficiency estimates is also higher when environmental variables are not included.

The cost efficiency rankings of the water distribution utilities are very similar in the models that take environmental factors into account and in those who do not. Indeed, the Pearson correlation coefficients between the two models are of 0.90 and 0.94 for the variable and total cost function, while the Spearman rank correlation coefficients amount to 0.86 and 0.93, respectively. However, the ranking differs substantially between the variable and total cost models, Spearman correlation coefficient being 0.4 and 0.46 for gross and net inefficiency values. This highlights the importance of carefully choosing between variable and total cost functions, especially if the rankings are to be used for regulation purposes. As it seems farfetched to suppose that water distribution utilities operate at their long term equilibrium, a variable cost function approach appears to be the appropriate choice to measure the cost efficiency of these firms.

Table 3 : Cost inefficiency estimates

	VC without environment	VC with environment	TC without environment	TC with environment
Mean	1.63	1.49	1.62	1.51
Median	1.61	1.45	1.61	1.51
SD	0.29	0.24	0.28	0.25
Maximum	2.38	2.16	2.52	2.36
Minimum	1.01	1.02	1.03	1.02

5. Conclusion

In this paper, we have estimated efficiency scores for Swiss water distribution utilities. We found that environmental factors affect the costs of water utilities and impact on estimated efficiency but less than traditional factors. Our results further show that rankings of the water distribution utilities are very similar in the models that take environmental factors into account and in those which do not, but differ substantially between the variable and total cost models.

As mentioned earlier on, this study is part of an on-going research project on the measurement of the technical efficiency of Swiss drinking water utilities. In our project, in addition to incorporating new data and additional variables, we are actually extending the approach presented in this paper in several directions. In order to test for the robustness of our results, we are investigating alternative stochastic frontier specifications, particularly Greene's (2005) true-fixed and true-random effects models. Moreover, we are planning to measure and discuss the performance of Swiss water utilities by applying a non parametric approach using data envelopment analysis (DEA).

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