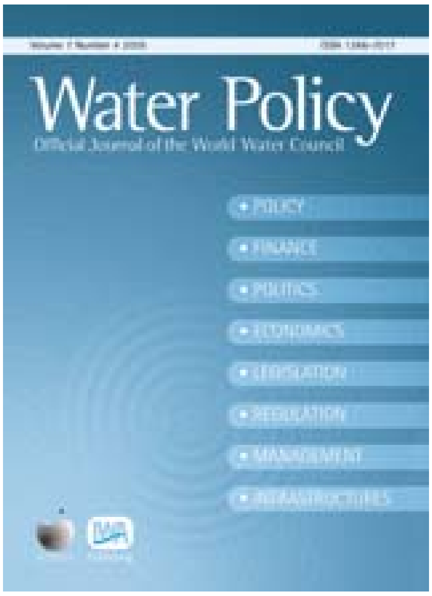
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Setting performance standards for regulation of water services: Benchmarking Latin American utilities

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Abstract

The aim of this study is to estimate both stochastic and mathematical programming efficiency cost frontiers for the Latin American water sector, by means of econometric and Data Envelopment Analysis techniques, using the ADERASA database. ADERASA is the Latin American association for water regulators, which has made a systematic job of data collection, among other initiatives.

This study fills a gap in the understanding of relative efficiency in the Latin American water sector, using a consistent database. First, we present a survey of the empirical literature related to cost and production frontiers in the water and sanitation sector. Second, once alternative specifications were chosen, models have been estimated and environmental variables included in an exploratory way. The coefficients have the expected signs and plausible values. Some consistency between methodologies is found.

This paper yields two results. The better knowledge of the underlying cost (or production) model is a first step to using benchmarking as a regulatory tool. The policy implications are relatively straightforward. With benchmarking technology it is possible to coordinate the action of different regulators, each with their own asymmetry of information. The key is setting indicative standards which constitute the basis of further discussion.

Keywords: Benchmarking; Latin America; Performance; Regulation

1. Introduction

In recent years, the regional association of Latin American water and sanitation regulators (ADERASA) has put a great effort into data collection in order to develop benchmark studies[1]. A database was compiled by ADERASA which contains homogeneous and good quality information for Latin American water and sewerage firms from the years 2003–2005.

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[1] ADERASA is also involved in other interesting initiatives; see www.aderasa.org.

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The aim of this study is to estimate both stochastic and mathematical programming cost functions and frontier studies from the data collected by ADERASA. Econometric and Data Envelopment Analysis (DEA) techniques were employed. The study fills a gap in the understanding of the relative efficiency of Latin American water and sanitation. To our knowledge, there is no other regional study attempting to do the same.

The lack of studies across countries for the region is one of the motivations for this paper. The possibilities open were many, given the recent advances in techniques and methodologies to study relative efficiency. In the past, the greatest obstacle to the development of this kind of study was the absence of a systematic database covering many countries and companies. With the third wave of results from the ADERASA survey, which is annual and started in 2003, the number of firms and operators surveyed is sufficient to develop a cross-sectional study for 2005. An analysis using panel data is yet impossible, given the incompleteness of the data from 2003 and 2004, either in observations or blanks in particular items of the survey; the possibility will be open when new data become available.

A detailed overview of the literature has been made, to recognize the set of variables that have been included in previous studies in other parts of the world. In the empirical part of the paper, all the variables included in the previous works are tested, in one way or another. From the survey, we also decided to make estimates at purchasing power parity (PPP) prices, in order to avoid artificial differences in costs and prices when estimating cost functions with firms from many countries. The survey was also useful to think of other variables not previously studied and to apply them to the estimates. In the survey, we apply the following criteria: studies were grouped by countries or regions, and also in chronological order.

We seek a better knowledge of the underlying cost (or production) model as a first step to using benchmarking as a regulatory tool. By using benchmarking technology, we see the possibility of coordinating the actions of different regulators, each with their own asymmetry of information, in search of setting standards that perform as a basis for further discussion.

Following this introduction, we make an exhaustive survey of the empirical literature related with cost and production frontiers in the water and sanitation sector. After that, in the third section, descriptive statistics of the database are presented. In the fourth section, models are estimated, both econometric and DEA, each differing in their specifications and the environmental variables included. A study of the consistency between methodologies is also made, as well as a study of the intra-methodology within the different models. In the fifth section the main results are shown. Finally, section six presents a conclusion.

2. A brief survey of the empirical literature

For England and Wales, the pioneering studies were by Price (1993), who estimated Operative Expenses (OPEX), and Stewart (1993a, b), which developed estimates of water cost functions for the OFWAT system. Bosworth *et al.* (1996a, b) extended the Stewart (1993a, b, 1994) studies, and examined the use of cost and production functions, discussing conceptual issues concerned with the functional form to be chosen, measurement problems, and the ideal type of basic information. Bottaso & Conti (2003) analyzed the evolution of operative costs efficiency in the English and Welsh sector, estimating a stochastic cost frontier for the period 1995–2001. Saal *et al.* (2004) estimated an input distance function, qualitatively adjusted, with stochastic frontier techniques for the period 1985–2000.

Saal & Reid (2004) examined how regulations (both economic and environmental) have influenced the productivity growth of the water and sanitation industry in England and Wales. Saal & Parker (2005) employed a qualitatively adjusted input distance function and stochastic frontier techniques to estimate rates of growth in the productivity operations of the water and sewerage industry in England and Wales.

Fraquelli & Moiso (2005) analyzed Italian water sector reforms, with special emphasis on the cost efficiency frontier of the industry and on scale economies at the level of 'optimal territorial ambits'. In doing so, they estimated a stochastic cost frontier.

The cost frontier for Asia estimated by Estache & Rossi (1999) comprises 50 firms from a database of 1995, provided by the Asian Development Bank. Estache & Rossi (2002) went further, attempting to establish differences of efficiency between private and public operators.

Mobbs & Glennie (2004) ran DEA estimates with the ADERASA 2003 database, relating a weighted average of outputs to a weighted average of inputs. Romero (2005) is the most direct precedent to this present work; he used the ADERASA database for efficiency estimates, through cost functions.

Crampes *et al*. (1997) estimated a cost function for the Brazilian water sector. They employed the same variables used by Stewart (1993a, b). Moreira & Fonseca (2005) suggested evaluation criteria for the productivity estimates that emerged from DEA and stochastic frontier analysis. Tupper & Resende (2004) quantified the relative efficiency of water and sanitation firms at a state level in Brazil during the period 1996–2000. Sabbioni (2005) measured the relative performance of public water and sanitation firms in Brazil by means of econometric techniques. He applied a cost function approach as the more appropriate, based on the operative environment of operation, the ability to deal with multiple outputs, the absence of endogeneity problems, the availability of information and the technological specification.

Berg & Lin (2008) evaluated the consistency of the performance rankings of public Peruvian firms. Stochastic frontier and DEA analysis provided similar rankings. Lin (2005) examined how the introduction of quality variables affects the comparisons between public firms in Peru.

Estache & Kouassi (2002) analyzed the determinants of the levels of efficiency reached by 21 African public operators, using an estimation of a production frontier for the sector.

3. Empirical analysis of data

The database in use was compiled by ADERASA and contains information for Latin American water and sewerage firms for the years 2003–2005. Table 1 displays the number of water and sewerage providers surveyed by ADERASA by country and by year.

The panel is strongly unbalanced, and the amount of responses from every variable is heterogeneous. The quality and quantity of information improved notably in 2005, thus descriptive statistics on the database are concentrated in the year 2005, which is the basis for later estimates on relative efficiency.

Table 2 shows the descriptive statistics of the variables in the ADERASA database, some of which we used in the estimates for efficiency frontiers. Since the main objective of the study was to estimate cost frontiers, salaries and the price of other inputs are critical. Thus the number of valid observations falls from 127 to 70 in 2005.

In order to present a discussion systematically, the variables are grouped into the following categories: costs, outputs, inputs, and environment.

Table 1. Number of water and sewerage providers by country and by year, surveyed by ADERASA.

	Number of water and sewerage providers		
Country	2003	2004	2005
Argentina	18	8	8
Bolivia	3	1	3
Brazil	16	16	5
Chile	18	18	18
Colombia	0	8	38
Costa Rica	1	2	2
Ecuador	1	1	1
Honduras	1	1	1
Mexico	0	0	34
Nicaragua	1	1	1
Peru	9	9	10
Panama	1	1	1
Paraguay	1	3	4
Uruguay	0	0	1
Total	70	69	127

Sources: ADERASA and SNIS databases. For the years prior to 2005, Brazil's data comes from the SNIS database; from 2005, when the number of observations increased notably, Brazilian data originates from the ADERASA survey.

In the survey, there are two categories of OPEX (Operational Expenses, for water plus sewerage), both measured in US Dollars: (i) OPEXGE: direct OPEX plus general expenses, which excludes depreciation, interest and indirect taxes; (ii) OPEX: labor costs, fuel, electricity, chemicals, etc., from water and sewerage.

OPEX was used in the estimates. In 2005, this category represented 62% of OPEXGE, on average. The reason for using OPEX data is that they are more homogeneous.

There are three sets of possible variables to proxy output for every service, water and sewerage: (i) those related to clients and connections; (ii) those associated to population served; and (iii) those linked to production level.

Both kinds of clients (CLIW and CLIS) are highly correlated. They are also highly correlated with population coverage measures (COVW and COVS) and with water production (PROW). Given the high correlation between the variables, the estimates were run using CLIW as the output variable.

Of the main inputs, staff (L) approximates labor and length of water mains (NETW) and length of sewerage mains (NETS) are proxies of capital.

The variable L includes all the staff (normalized to full-time equivalent workers) of the operator. In the database, there is no detailed information on labor functions. In particular, there are no details available concerning network extension personnel and management or maintenance staff. This is particularly important, because if only OPEX is considered, those firms that are expanding networks (where capital expenses – CAPEX – are significant) will be relatively penalized in the efficiency measures.

There is no information on outsourced personnel. If a firm outsources a significant percentage of its staff, it will distort the efficiency measure related to firms that do not outsource. Finally, it would be desirable to divide personnel costs into the two services, water and sanitation, but the data is not currently available.

Table 2. Descriptive statistics of variables in ADERASA Database 2005.

Variable	Description	Unit	N	Average	Standard deviation
L	Staff	No.	121	575	1,005
NETW	Water network	Km	109	1,937	3,168
NETS	Sewerage network	Km	108	1,193	1,905
CLIW	Water clients	No.	127	177,847	546,139
CLIS	Sewerage clients	No.	127	180,793	363,228
COVW	Population served with domiciliary water service/total population	%	127	90.61	13.13
COVS	Population served with sewerage/total population	%	127	73.94	27.71
METW	Operative meters/water accounts	%	125	63.83	37.99
COVN	Population served with domiciliary water service/water network	Inhabitants/km	109	423	183
POPU	Resident population	Inhabitants	127	818,428	1,556,509
PROW	Water production	m^3/day	126	218,354	487,270
TRES	Treated sewage	m^3/day	117	36841	91733
UNDW	Underground water sources/total water sources	%	121	38.04	42.80
OPEX	Operational expenses	US$/1,000	121	94,866	695,819
W	Average salary	US$/year	74	17,757	25,294
R	Price index from other inputs	US$ year/1,000 clients	72	81.04	82.53
RESB	Residential billing/total billing	%	104	77.51	13.88
RESW	Residential water clients/total water clients	%	90	0.93	9.06
UNAW	Unaccounted for water/total water production	%	126	38.10	17.26
BREW	Water main breaks/water network length	No./km	60	2.36	4.19
COMP	Client complaints	No.	103	41,042	101,673

Source: taken from the ADERASA database.

NETW and NETS are highly correlated, whilst in some observations NETS values are inferior to NETW because of lower sewerage coverage.

A cost function relates expenses with outputs and input prices, and environmental variables can additionally be included, to be more specific in the assessment of the cost drivers. The frontier is built from such a cost function, and from this estimate the individual efficiency measures are derived. Input prices are, therefore, critical for the estimations. Since 2005, there is better information available on input prices, in particular for wages.

A measure of the average salary was constructed, dividing total labor costs on staff, following the practice adopted in the literature (Saal *et al.*, 2004). This measure, W, was valued at PPP, as was OPEX itself.

Because of a lack of more detail on input prices, a similar methodology developed by other authors (Saal *et al.*, 2004) was applied to capital. We made R an index number for the rest of the inputs. The variable was constructed by subtracting labor costs from OPEX. The result was divided on the number of clients. The variable R was also expressed in PPP values.

The omission of environmental variables distorts the results, whilst to generate them is difficult in a number of situations because of failures in basic information. It is worth mentioning, at the same time, that there is no consensus built on which variables to choose, whilst in other infrastructure sectors (electricity being the best example) there is a more established function formulation. Environmental variables that were considered, as an exploratory approach, included:

(i) Underground water volume (UNDW);
(ii) Unaccounted for water/total water production (UNAW);
(iii) Residential water clients/total water clients (RESW);
(iv) Water main breaks/water network length (BREW); and
(v) Client complaints (COMP).

All these variables highlight some kind of environmental condition which could be considered exogenous. For UNDW, those firms with access to underground sources are expected to have lower costs, and the sensitivity of costs with respect to UNAW, RESW, BREWW and COMP are expected to be positive.

Table 3 shows simple correlation coefficients between environmental variables themselves, and between those variables and OPEX. Simple correlation confirms the presumptions made with respect to UNDW, COMP and UNAW. The sign of RESW is the opposite to that expected but, as in the case of BREW (with the same sign as expected), the absolute value of the correlation is very low.

The range of possible environmental variables to test is very wide. Nevertheless, we have preferred a cautious approach, and have focused on the variables UNDW and UNAW, setting aside RESW and BREW (after the analysis made on correlations), and also avoiding the variable COMP, since complaints could be related to more idiosyncratic characteristics of the different countries of the sample, instead of to quality of service (which we tend to approach at the end with this variable).

All of the environmental variables are relevant but not all of them are significant for our research. In particular, it should be taken into account that, in RESW, there are two forces working in opposition: on the one hand, more non-residential clients would imply lower commercial costs but, on the other hand, non-residential clients tend to consume more services, thus increasing OPEX. Given this, the correlation between RESW and OPEX is not surprising. Besides, as long as the output variable chosen is water clients, the relevance of RESW is not so clear; by contrast, RESW is very useful when cubic meters is the relevant output[2].

4. Methodology

The possible options are to estimate a production function or a cost function (see Sabbioni, 2005, for a comparison of both criteria), and to obtain efficiency scores from econometric or mathematical programming approaches; we chose to estimate a cost function and employed both approaches. Moreover, we made some consistency checks between results from the different methodologies.

One advantage of the cost function over the production function approach is the flexibility to adopt different specifications, particularly in cases where a firm produces more than one product. Moreover, the estimate of production function allows a measure of technical efficiency to be obtained but ignores resource allocation problems. The estimate of cost frontiers, on the other hand, gives information on cost differentials due to technical and resource allocation inefficiencies. To separate these two effects, it is necessary to formulate some additional assumptions.

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[2] We owe these observations to Emilio J. Lentini.

Table 3. Simple correlations between environmental variables.

	Simple correlation coefficient					
	OPEX	UNDW	COMP	UNAW	RESW	BREW
OPEX	1.000					
UNDW	−0.249	1.000				
COMP	0.493	−0.119	1.000			
UNAW	0.093	0.337	0.116	1.000		
RESW	−0.005	0.236	−0.053	0.063	1.000	
BREW	0.015	−0.183	0.064	0.078	−0.415	1.000

Source: taken from the ADERASA database.

The main advantage of non-parametric methods (also known as DEA methods) is that no *a priori* functional form is imposed on the data. The main disadvantage of this approach is the use of only a subset of the available data for the frontier estimate (those which actually determine the frontier), while the rest of the observations are ignored.

The third methodological decision was to choose a stochastic frontier as the econometric approach because of its desirable properties (less sensitivity to outliers, and less arbitrary determination of inefficiency) with respect to the alternative deterministic approach.

In traditional cost analysis the problem faced by a firm is to minimize total costs subject to delivering a given level of output. The solution to this problem generates an optimal set of inputs, which depend on output level and input prices. In the same way, it is possible to estimate the cost function of the firm, which depends only on output level and input prices.

The resulting cost model specification is given by:

$$C = f\,(Y, Z, P_L, P_K) \tag{1}$$

where $C =$ total cost, $Y =$ output, $Z =$ n-dimension vector of other exogenous variables, $P_K =$ price of capital inputs, and $P_L =$ price of labor inputs.

The most common specification is the Cobb–Douglas function where the inefficiency term (ε) enters the model as a multiplicative factor (which becomes additive in the logarithmic form):

$$C = AP_l^{\beta 1} P_k^{\beta 2} Y^{\gamma 0} \Pi_i Z_i^{\gamma i} \ \exp^{\varepsilon} \tag{2}$$

Applying logarithms to both sides we obtain:

$$c = \alpha + \beta_1 p_1 + \beta_k p_{2k} + \gamma_0 y + \sum_i \gamma_i z_i + \varepsilon \tag{3}$$

where β_1 and γ_i are parameters to be estimated, and small cases represent logarithms of the variables which in Equation (2) are levels in capital letters.

A firm with the min(ε_{i}) will be 100% efficient. For this firm ε_i equals zero and therefore exp(ε_{i}) equals one. The larger the inefficiency of a particular firm, the larger the term ε_I, and the resulting efficiency measure will be closer to zero.

In the case of stochastic frontiers, the cost function is similar to the one presented in Equation (3), only the error term ε is no longer equal to inefficiency but is decomposed into two terms:

$$\varepsilon_i = u_i + v_i \tag{4}$$

where $u_{\mathrm{i}} > 0$ and v_i is not restricted. The v_i term captures the effects of statistical noise which are assumed to be independently and identically distributed with a Normal Distribution (0, σ_v^2). The u_i error term represents cost inefficiency and is assumed to be distributed independently of v_i and the explanative variables. Several statistical distribution have been proposed for the inefficiency term, such as: half-normal, truncated-normal, gamma and exponential. The most common distribution used in empirical tests is the half-normal.

Most water utilities are required to provide services at a fixed tariff, meeting the demand. Since output is exogenous, firms maximize benefits by minimizing costs of producing a given level of output. A cost frontier is therefore a natural choice, since there is also another advantage over the production frontier: it deals better with multiple outputs.

With regard to the *Z* vector, in practice, the costs of regulated public utilities depend on a variety of factors in addition to output levels and input prices. In the comparisons, analysts want the relative ranking to reflect managerial decisions rather than the unique characteristics of service territories (such as topography, hydrology and customer density) or historical policies and regulatory decisions which are beyond managers' control.

The effect of exchange rate fluctuations could significantly impact on unit costs and perceived efficiency, masking changes in costs. PPP is one method to correct this problem. PPP states that the exchange rate between two countries should equal the ratio of the countries' price levels for a fixed basket of goods and services. Thus, purchasing parity prices are based on a sample of goods and services (the basket) which is selected to be representative of the gross domestic product (GDP) for each country. If purchasing parity prices specific to water industry expenditure were available, they might differ from these, although probably not substantially (OFWAT, 2002).

Making the assumption that firms are price takers on input markets and that output is exogenously determined seems correct. This appears to be appropriate for a regulated industry where firms are relatively small players on input markets and are required to satisfy market demand at a price set by the regulator.

Every DEA model tries first to determine which productive units from the sample rest on the envelope surface – the efficient frontier. The DEA then yields an exhaustive methodology to analyze relative efficiency, evaluating each firm and measuring its performance against the frontier. Productive units yielding on the envelope surface are considered 'efficient' in DEA jargon, while the remaining are labeled as 'inefficient', and the analysis provides a measure of the relative (in)efficiency.

The selection of a particular DEA model implies a decision on the shape of the efficient frontier and on the concept of distance (inefficiency) to use. The first decision to be made has to be an assumption on scale returns. There are basically two alternatives: constant returns to scale (CRE) and variable returns to scale (VRE). The selection of a concept of distance is related to choosing an orientation for the model: to a proportional reduction of inputs (the output level remaining constant), or to a proportional increase in outputs (given the inputs), or neither of them (input-oriented, output-oriented, or non-oriented, respectively).

The theoretical specification of the model CRE oriented to inputs consists of a constrained optimization problem such as the following:

$$\min_{\theta,\lambda} \theta \tag{5}$$

$$\text{subject to} \quad y_j \leq \lambda \boldsymbol{Y}, \quad \lambda \boldsymbol{X} \leq \theta x_j, \quad \lambda \boldsymbol{Z} = z_j, \quad \text{and} \quad \lambda \in R^J_+$$

where $\boldsymbol{Y}$ is a matrix $N \times r$ of the firm outputs (N denoting the number of firms and r the number of outputs); $\boldsymbol{X}$ is a matrix $N \times m$ of inputs (m indexes being the inputs considered); $\boldsymbol{Z}$ is a matrix $N \times s$ containing all the information on S environmental variables from N firms; y_j, x_j and z_j are the observed vectors of outputs, inputs and environmental variables of the firm under analysis respectively; and, finally, λ is a vector of intensity parameters (λ_1, λ_2, …, λ_N) which allows the convex combination of the observed inputs and outputs (to construct the envelope surface).

This problem yields as a solution the proportion (θ) in which the observed inputs and the costs of the firms under analysis could be reduced if the firm were efficient.

The efficiency measures obtained are indexes of productive efficiency, known as Debreu–Farrell measures. Since every measure is the reciprocal of a distance function, the measures have some desirable properties. The representation of the technology with distance functions, allow multi-product and multi-input situations, unlike traditional production functions. So, they avoid the need of adding outputs or inputs before analysis.

To obtain a VRE model of any orientation, just one additional constraint needs to be added to the former specification: $\Sigma_j \lambda_j = 1 \ \forall \ j = 1, \ldots, N$.

This constraint ensures that an inefficient unit is only compared with productive units of a similar size. Without this constraint, the unit under analysis could be compared with others materially greater or smaller.

All of the precedent algorithms should be solved N times, once for every firm in the sample. The θ value yielded as solutions (one for each productive unit), are called θ^* (where '*' denotes an optimal value); this is the efficiency measure of the unit under analysis. If a radial contraction of the inputs is possible, $\theta^* < 1$, the productive unit is inefficient and $[(1 - \theta^*) \times 100]$ measures the percentage reduction that could be applied in costs and inputs. For example, if $\theta^* = 0.80$, the productive unit could reduce its input use by 20.

The VRE model is the more desirable option, since it does not constrain any possible scale returns. However, CRE versions were also computed for all the models since, in some cases, with VRE the smaller and less productive units tend to appear as 100% efficient, simply because they have no peers to make comparisons.

5. The estimates

One disadvantage of a cost function estimate is the difficult task of obtaining input price information. With the 2005 database two measures of price inputs for labor unit costs and 'capital' unit price (more properly a price index of non-labor inputs) could be constructed. The former was built as an average salary for each firm (variable W) from information on global labor costs and total staff. Capital unit price was calculated by dividing the non-labor costs on total water clients (variable R).

Because the database includes firms from different countries, it is worth mentioning the treatment applied to monetary variables. Local currency information was expressed in US dollars using the average exchange rate for 2005. To make a correct comparison, all values were converted by purchasing power parities.

Remember that the model structure has two parts: the core of the model and the environmental variables. Correctly selecting the latter is a key element of characterizing the context in which they operate, allowing fair comparisons to be developed. Bearing this in mind, a carefully selection of both core and environmental variables was made.

Amongst the core variables, OPEX is the dependent, and CLIW, W and R the explanatory (independent) ones. In all cases, monetary variables were expressed in PPP. Different explanatory variables were tested, though not all of them were finally included in the model.

To determine the model, the parametric approach (econometrics) was selected, since that methodology allows hypothesis testing. The objective was to reach the most robust model or models, achieving it with the desirable statistical properties.

Some variables arose from the database as good candidates (from the theoretical or empirical point of view) to explain phenomena, but the lack of sufficient numbers of observations or, in some cases, doubts on the quality of the data, suggested that they should not be included for now; such variables included:

- total costs (there are problems of consistency);
- management and commercial costs;
- outsourced costs (currently no confident information on third party services);
- costs of power used for operation and maintenance activities;
- physical units of electricity consumption;
- differences on regulatory framework, which could isolate qualitative elements acting on costs.

5.1. The parametric approach (econometrics)

The best estimates explain OPEX as depending on CLIW, W and R (model A). UNDW and UNAW (models B and C) were included as environmental variables reflecting, respectively, the proportion of underground water to total water and unaccounted for water as a proportion of total production.

All models were estimated with data from 2005. The specification was a Cobb–Douglas in logarithms[3]. For the stochastic frontier, the method used was maximum likelihood (ML), with two

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[3] In economics, the Cobb–Douglas functional form of production functions is widely used to represent the relationship of an output to inputs. It was proposed by Knut Wicksell (1851–1926), and tested against statistical evidence by Charles Cobb and Paul Douglas in 1900–1928. For production, the function is $Y = AL^{\alpha}K^{\beta}$, where, Y = total production (the monetary value of all goods produced in a year); L = labor input; K = capital input; A = total factor productivity; α and β are the output elasticities of labor and capital, respectively. These values are constants determined by available technology. The Cobb–Douglas function form can be estimated as a linear relationship using the following expression: $\log_e(Y) = a_0 + \sum_i a_i \log_e(I_i)$ where, Y = output; I_i = inputs, i.e. K, L. a_i = model coefficients. For costs, the function is similar, but y represents costs and the explanatory variables are output and input prices.

alternative assumptions on the residuals: normal/exponential (MLE) and normal/half normal (MLH). The results are presented in Table 4.

The models presented in the Table 4 are characterized by a two part estimation error: one regarding statistic noise, and the other being the inefficiency term.

The models behaved in a satisfactory way. The sign of the coefficients was as expected, according to theory. The variables included are significant, jointly and individually, in order to explain the variability of the OPEX (with the exception of UNDW in the MLEB model).

Since all the variables are expressed in logarithms, the coefficients are to be understood as elasticities, that is, before a percentage change in the explanatory variable under consideration, the coefficients yield the percentage change in OPEX.

Environmental variables which seem statistically significant are relevant for the study; their exclusion could lead to a specification error.

The Cobb–Douglas specification could be questioned, because of its restrictive assumptions. In this sense, it would be desirable to estimate a trans-logarithmic cost function, but there are not sufficient data (to date) to test the specification. It could form an extension of the current study when more observations become available.

Although, from a strictly statistical point of view, the models satisfy desirable properties, for its regulatory use more caution is needed because of the robustness of the model and of its capability to recall relative efficiency.

Some work needs to be done on data improving and on the inclusion of more variables which will properly allow the identification of regulatory differences between countries, provide more details on input prices, give a better proxy for quality of service, and variables which address differences in topography, weather, etc. The probable empirical relevance of these dimensions is supported by the literature surveyed.

In Table 5, the efficiency levels obtained from the stochastic methodology are presented. The table shows the average level of efficiency, its standard deviation, the minimum and maximum of each different.

Table 4. Alternative models of stochastic frontiers under each methodology: MLE (Normal/Exponential) and MLH (Normal/Half Normal), with OPEX as the dependent variable.

Independent variables: (all in logs)	MLEA	MLHA	MLEB	MLHB	MLEC	MLHC
CLIW	0.957[a]	0.935[a]	0.981[a]	0.901[a]	0.926[a]	0.905[a]
	(0.024)	(0.023)	(0.021)	(0.000)	(0.022)	(0.022)
R	0.688[a]	0.621[a]	0.697[a]	0.574[a]	0.684[a]	0.605[a]
	(0.063)	(0.057)	(0.052)	(0.000)	(0.059)	(0.057)
W	0.183[a]	0.235[a]	0.156[a]	0.203[a]	0.191[a]	0.264[a]
	(0.066)	(0.063)	(0.051)	(0.000)	(0.059)	(0.056)
UNDW			−0.053	−0.101[a]		
			(0.086)	0.000		
UNAW					0.247[a]	0.269[a]
					(0.067)	(0.077)
CONSTANT	−6.816[a]	−6.894[a]	−6.867[a]	−6.120[a]	−6.201[a]	−6.360[a]
	(0.348)	(0.373)	(0.287)	0.000	(0.353)	(0.391)

[a] Significant at 1%.

Table 5. Levels of efficiency by model (stochastic frontiers).

Model	Average	Standard deviation	Minimum	Maximum
MLEA	0.760	0.149	0.126	0.945
MLEB	0.749	0.170	0.103	0.944
MLEC	0.782	0.143	0.163	0.950
MLHA	0.683	0.153	0.166	0.934
MLHB	0.713	0.199	0.303	1.000
MLHC	0.728	0.124	0.260	0.929

Efficiency measures from this model have a reasonable variability between operators, which is good, but they are not definitive measures on efficiency or relative inefficiency with regulatory application; more observations and more detailed modeling could improve the latter significantly.

There are four conditions which in principle are desirable in benchmarking studies: sample size, comparability, a common regulator (or regulation) and, abundant data. To date, the database in use does not accomplish all these conditions.

The current number of observations is good but the blanks in the database in previous years prevent us estimating with panel data; instead the study has been made based on a cross section of the year 2005.

With respect to the issue of comparability, the firms are located in different countries, cities and regions, each one very different from the others. Population density, technology in use and a set of additional dimensions need to be considered. The inclusion of environmental variables allowed this issue to be solved. The conversion of monetary values to PPP is another effort in the direction of making fairer comparisons. The inclusion of the exploratory environmental variables do not noticeably increase the average efficiency and its standard deviation, but minimum levels of efficiency rise in all but one estimate and can be attributed to the presence of the environmental variable.

With regard to a common regulator, that condition is not accomplished. However, it could be sufficient with the inclusion of some measures, which can proxy the different regulatory environments, quality standards, and the character of public or private firms, etc. To incorporate the differences in regulation more precisely, it will be useful to make a comparative study of the regulations, which could allow the extraction of qualitative details. The incorporation of these details exceeds the scope of this paper, since the data have not been produced yet.

The fourth condition (the need for abundant data) will be solved with the continue improvement of the ADERASA database and the addition of new observations.

5.2. Non-parametric approach (DEA)

As can be seen in the formulation of the problem, we chose to model the environmental variables (z_j) as neutral and not as discretionary variables (over which a firm has no control). In this option, each firm is compared only against a hypothetical firm, which operates in the same environment as the firm under evaluation. The main advantage of this option is that it does not imply an *a priori* judgment of the kind of influence of every environmental variable over efficiency.

We chose an approach of resource conservation (input oriented), and we present a group of models in Table 6. As they are cost efficiency models, the only input used was OPEX. As output, the water client was considered in all cases which, as mentioned in the econometric estimates, has a high correlation with other possible output measures such as volume of water produced or coverage.

Table 6 also shows the different alternatives chosen. The models with CRE are RCEA, RCEB and RCEC, each adding a different environmental variable. Finally, the same models were calculated with VRE; their names are RVEA, RVEB and RVEC, each one with a different environmental variable.

As can be seen, the average of the efficiency measures in Table 7 is greater in the VRE model, which is expected due to the return of scale assumption. This model tends to identify a greater number of firms as relatively more efficient. The variability of results, in turn, is reasonable.

5.3. Consistency analysis

In a tariff review, the initial regulatory task implies assessing whether the productivity gains used to set the new price cap are specific to a firm and if it they are based on past profits. If they are, a firm will not have powerful incentives to make cost reductions, since it would yield a lower tariff. An alternative for a regulator is to measure the efficiency gains in a way such that they do not rest under the control of the firm, as is done in yardstick competition, in which prices can be set with reference to the aggregate performance of the industry.

If a firm has a cost efficiency measure of 0.8, for instance, it means that it could produce the same output level with 80% of its current costs: there are firms doing this (those with cost efficiency measure of 1.0, or 100%). This implies that the price cap should be based on 80% of the current costs, not on 100%. Following this route, only 100% efficient firms could recover its capital opportunity costs, while others will have a lower return.

Table 6. DEA model specifications and relative efficiency results.

	CREA	CREB	CREC	VREA	VREB	VREC
Outputs	CLIW	CLIW	CLIW	CLIW	CLIW	CLIW
Inputs	OPEX	OPEX	OPEX	OPEX	OPEX	OPEX
Environment	None	UNDW	UNAW	None	UNDW	UNAW
Orientation	Inputs	Inputs	Inputs	Inputs	Inputs	Inputs
Returns to scale	Constants	Constants	Constants	Variables	Variables	Variables

Table 7. Levels of efficiency by model (DEA frontiers).

Models	Average	Standard deviation	Minimum	Maximum
CREA	0.263	0.149	0.056	1
CREB	0.367	0.211	0.093	1
CREC	0.316	0.206	0.064	1
VREA	0.323	0.211	0.093	1
VREB	0.518	0.281	0.103	1
VREC	0.441	0.273	0.117	1

In this context, an efficiency assessment at the firm level depends both on the methodology employed and on the selection of the explanatory variables. The regulators applying benchmarking could have problems if the different possible analyses yield contradictory results. One solution is consistency analysis. This imposes certain basic conditions which should be accomplished in order to assess the utility of results for regulatory authorities. The advantage of consistency analysis is that it does not make the choice of methodology mandatory. The regulator can avoid the choice and, instead, use many different techniques and cross-check the different results.

Consistency conditions, as Bauer *et al*. (1998) suggested, demand that the different methodologies: (i) yield similar distributions of the efficiency measures; (ii) generate similar unit rankings; (iii) identify the same units as the 'best' and the 'worst'; (iv) produce efficiency measures stable over time; (v) are reasonably consistent with other performance measures (such as those of partial productivity); and (vi) are consistent with the conditions which the industry as a whole faces.

To implement a mechanism such as that suggested demands at least the accomplishment of the first consistency condition (i.e. similar distributions of the efficiency measures). If that condition is not reached, the mechanism should not be applied because the measures seem in some sense to be subjective and non-confident.

In general, it could be said that the first consistency condition is partially achieved and that the differences between averages are mainly due to model specification. The efficiency measures obtained from econometric models do not differ amongst themselves more than a ten percent in average. For DEA, instead, the efficiency average increases when more environmental variables are added. The efficiency averages obtained with DEA are lower than those obtained with econometric estimations.

Even if the efficiency levels are not consistent between the different models, it is possible that the models generate similar rankings of firms according to their efficiency measures, accomplishing the second consistency condition, which in turn could help to identify the X-factor between firms. Tables 8 and 9 show the

Table 8. Spearman's correlation coefficients for selected econometric models.

	MLEA	MLEB	MLEC	MLHA	MLHB	MLHC
MLEA	1.000					
MLEB	0.913	1.000				
MLEC	0.900	0.896	1.000			
MLHA	0.905	0.905	0.903	1.000		
MLHB	0.586	0.610	0.586	0.601	1.000	
MLHC	0.908	0.885	0.905	0.911	0.583	1.000

Table 9. Spearman's correlation coefficients for selected DEA models.

	CREA	CREB	CREC	VREA	VREB	VREC
CREA	1.000					
CREB	0.879	1.000				
CREC	0.927	0.888	1.000			
VREA	0.935	0.880	0.991	1.000		
VREB	0.701	0.782	0.752	0.778	1.000	
VREC	0.720	0.729	0.783	0.800	0.651	1.000

Spearman correlation coefficient between rankings established by pairs of models for both specifications. All the correlations are positive and significantly different from zero at the 5% level.

With respect to the other consistency conditions, we are obliged to be cautious. We do not expect the rankings to be definitive, and also to be consistent in this first approximation to the problem (the second condition). Also, we cannot compare measures over time, since this is the first estimate. Some partial productivity measures were advanced and they make sense with the efficiency measures derived from econometrics and DEA, but partial productivity measures, by their very nature, do not yield definitive rankings. Finally, the last consistency condition forces us to pay more attention to the differences in the structure, regulation and performance of the services, since they are located in different countries with remarkable differences in history, tradition and practice.

6. Conclusions

The aim of this study was to estimate both stochastic and mathematical programming cost functions and frontier studies with the database developed by ADERASA. Econometric and DEA techniques were employed in the estimates. The study fills a gap in the understanding of the relative efficiency of the Latin American water and sanitation sector.

The econometric estimates were developed first, as a guide for the construction of DEA models later. Different proxies of outputs, inputs, input prices and environmental variables were studied. The monetary variables were converted to PPP values. Salaries and an index of non-labor costs were included as input prices; in both cases, the values were the result of processing global amounts from the ADERASA survey, in line with literature practice.

To measure comparative efficiency levels, estimates of cost frontier functions were developed, representing the total cost of production depending on output levels, input prices and environmental variables. These allowed the estimating of productive or total efficiency.

The methodologies used were either econometrics or DEA. Regarding the econometric approach, it could be concluded that the estimates are satisfactory. The signs of the coefficients were as expected, according to theory. The variables included were significant jointly and individually to explain the variability of the OPEX at the usual confidence levels. Significant environmental variables were also found, even though their introduction was only regarded as exploratory. With the 2005 data, the estimate results were robust in many different specifications.

Once the econometric models were estimated, the following step was to apply the DEA method to the same set of variables (outputs, input prices and environmental). Two possibilities were considered: CRE and VRE.

A common problem faced by regulators applying benchmarking is the large quantity of methodologies as various alternatives for modeling. The problem is more acute if the different methodologies offer contradictory results. To cope with these problems, a consistency analysis of the results is needed.

For the estimates presented in this paper, an internal consistency analysis was performed, concluding that at a general level the intra-methodology comparison yielded similar results.

Some work needs to be done to improve the databases, and improving the standardization of quality indicators and differences in regulatory environment. The policy implications are relatively straightforward. The operators control most of the specific information needed for regulatory purposes and normally they have no incentives to disclose it. Operators will object to particular results and methodologies. But this is to be expected and it is good if the discussion focuses on data, estimates and methodologies. Regulation is a game which operators, governments and users play in order to secure their participation in the revenue of the sector. A remarkable amount of the inputs involved concerns information. Every instrument that improves the ability of the regulator to discuss with the operators makes sense. With benchmarking technology, it is possible to coordinate the actions of different regulators, each with their own asymmetries of information. The key is setting indicative standards from the benchmarking analysis which will constitute the basis of further discussion.

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