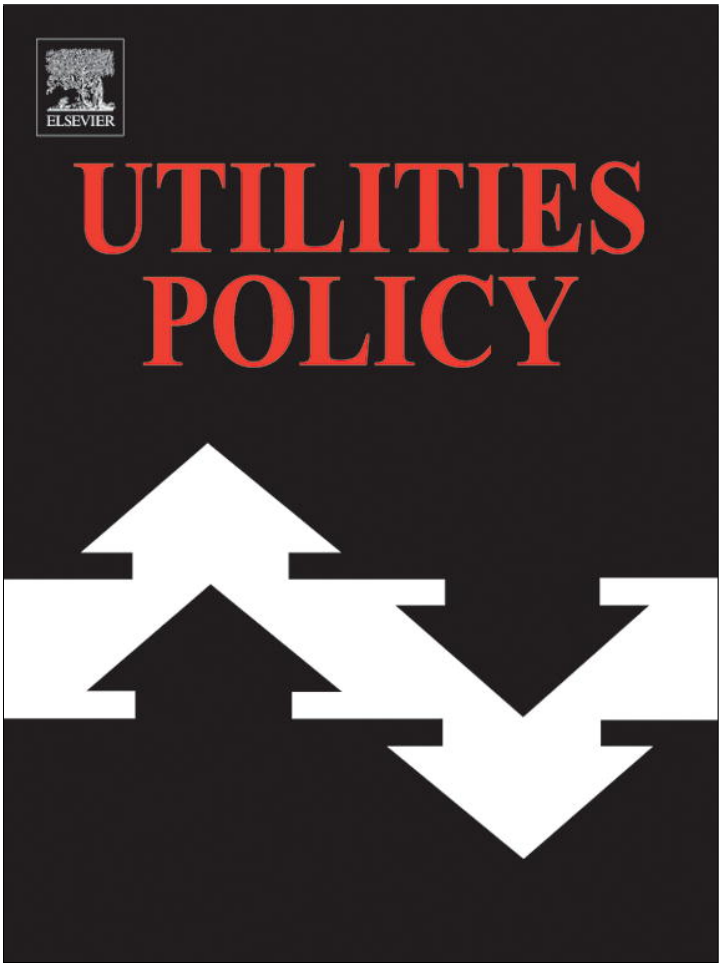
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Efficiency in Brazil's water and sanitation sector and its relationship with regional provision, property and the independence of operators

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ABSTRACT

The purpose of this paper is to assess the comparative efficiency of Brazil's water and sanitation sector. We run a Stochastic Frontier Analysis (SFA) model for a panel of 127 providers covering more than 70 percent of the country's urban population in the period 2003–2010. We use a database built on the National System of Sanitation Statistics (SNIS). The model is fitting and shows a modest efficiency average. The study has policy implications in the discussion of state-level run v. municipal-level run, government-owned v. private-provision, and corporatized providers v. dependent ones. The optimal industrial organization of the sector is discussed from the efficiency perspective. We find that regional and micro-regional firms' have lower costs than municipal providers. Administrative independence seems not relevant when explaining the cost structure, but ownership is. The joint provision of water and sanitation results in higher fixed costs compared to water-only operators. We find that there are not regional differences in cost structures. However, there are slight variations in the efficiency levels and in their dispersion in each region. Finally, inefficiency decreased at a rate of 4.9 percent per year during the time frame under study.

1. Introduction

From the early 1900s, the provision of water and sewerage services in Brazil had been organized through local public and private utilities. In 1971, the Water and Sewerage National Plan (PLANASA) was launched as a means to rationalize the planning, investment, tariff and credit policies of the industry. Its main goal was to increase geographical coverage in urban centers. During the period 1971–92, companies of regional scope were created at the state level – all state-owned – which replaced many former local-based ones. This organizational structure is still in place despite the dissolution of PLANASA in 1992; that is, from an initially designed decentralized local structure, the system has evolved into a centralized one with state-owned state-level companies which coexist with smaller scale firms.

Brazil is divided into 27 states and 5564 municipalities. Even though the Brazilian Constitution (1988) established that water and sewerage provision was a municipal concern, approximately 75 percent of the country's population is served by the 27 state-level companies (one is private). To date, 4002 municipalities have reached concession agreements with state-level companies currently serving approximately 119 million people in urban areas, 936 municipalities have a local-level provision serving approximately 40 million people in urban areas and in between 18 municipalities receive the service from 6 micro-regional providers accounting for 0.7 million people.[1]

Thus, although a municipal jurisdiction model was constitutionally established, the agglomeration model initially promoted by PLANASA prevailed. In 2007, the Basic Sanitation Law N. 11,445 was enacted, which laid down both the national operation principles as well as the general framework for each state to carry out its specific implementation strategy. Along this line, the law provided for the creation of social monitoring instruments and institutionalized the regulatory agencies. In 2012, a total of 23 state regulatory agencies existed, all enjoying law enforcement power in the water and

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[1] See DIAGNÓSTICO DOS SERVIÇOS DE ÁGUA E ESGOTOS – 2011 in http://www.snis.gov.br/PaginaCarrega.php?EWRErterterTERTer=101.

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sanitation sector; most of these agencies were authorized to supervise other services as well.

The Basic Sanitation Law also enables the municipalities to group themselves into regional consortiums for the provision of water and sanitation services. It is based on the rationale of strong scale economies providing the service and hindering the small municipal companies from achieving universal coverage. For all intents and purposes, this did no more than legalize an already common practice (i.e. the delegation of the provision from municipalities to the states).

The choice of municipal-level versus regionally-integrated water utilities has an economic nature – a cost/benefit decision – targeting an optimal agglomeration scale. Along the same line, the choice between an administratively independent provider or a municipal department operating the service is subject to a cost/benefit analysis as well. On the one hand, when the provision of a service is carried out by a small municipal-owned utility or a municipal department, its operation under the municipality's structure can result in cost savings in areas such as headcount expenses, office space, transportation vehicles, and so on. These situations are not detailed in the database used for this paper. On the other hand, the provision of a service through either an independent municipal company or a regulated private firm can produce gains arising from the incorporation of professional management, business-oriented practices, non-politically biased managerial decisions, and tariff settings that more closely match the inherent cost structure.

Then, we will distinguish providers: i) by its jurisdiction (state-level, municipal, micro-regional; ii) by its property condition (private or state-owned), and iii) by its dependency (dependent of a municipality, independent–corporitized-provider).

Given the preceding heterogeneous landscape, the goal of this paper is to estimate the costs frontier of the water and sanitation service providers in Brazil and thus to determine their relative efficiency. In doing so, we seek to answer the following questions:

- Are there significant differences between state-level companies or municipal and micro-regional companies in terms of efficiency or cost structures?
- Does private provision of the service impact on costs or efficiency levels?
- Does independence of service providers from the public administrations ("corporatization") have any impact on costs? As a by-product we can assess:
- Which is the efficiency level of the industry and its evolution over time?
- How does water-only providers compare with water and sanitation ones in terms of costs?
- The states are grouped in five regions, with marked differences in development, demography, and social indicators. Do cost structures vary in different regions of the country?

Answering the above questions we hope to shed some light on the optimal industrial organization of the water and sanitation sector. Policies such as agglomeration vs. fragmentation, or corporatization of dependent providers could benefit of the efficiency analysis. For example, if regional independent firms had the highest relative efficiency, we could argue for both an agglomeration of small providers as well as for an institutional division between public administration and the entities that provide the services. Or, non-independent service providers might appear to be more efficient, but the results could be biased because of cost-sharing with the public administration.

Likewise, if evidence is found of either a higher relative efficiency or a lower cost structure for private firms, it might, in turn, be beneficial to study further the business practices that trigger these differences.

The joint provision of water and sanitation services, on the one hand, makes it possible to achieve scope economies via costs-sharing, but at the same time it increases total costs due to greater investments in sewerage provision. Thus, this paper will analyze their net effect.

Another issue concerns differences in economic development and Brazil's cost of living since these may be reflected in cost structures when accounting for geographical differences.

Lastly, the sector under study has experienced significant investments in recent years. Thus, it would be interesting to examine whether efficiency has changed upwards together with modernization.

We use the Stochastic Frontier Analysis (SFA) based on data from the National Water and Sanitation Information System (SNIS).

Following this introduction, Section 2 surveys previous publications in the field; Section 3 explains the method, the model and the data used; Section 4 discusses the results, and Section 5 concludes.

2. Literature background

In order to assess efficiency in the water and sanitation sector, previous studies – surveyed in Abbot and Cohen (2009), Walter et al. (2009), Worthington (2013) and Berg and Marques (2012) – have estimated production or cost frontier using parametric or non-parametric technics. The former group applies mainly Stochastic Frontier Analysis technics (SFA, from hereon) while the second one uses mathematical programming, mainly Data Envelopment Analysis (DEA).

Most parametric studies chose a flexible functional form for the costs or production frontier with the idea of imposing the fewest arbitrary restrictions. In this sense, the Translogarithmic function satisfies quite well this criteria, while the Cobb–Douglas functional form is a special case of it.

Thus, we estimate a translog stochastic frontier cost function for which every firm has to minimize their costs subject to provide the service to customers.

Efficiency had been studied in relation to specific policies such as privatization, the consolidation or fragmentation of firms, or the strength of regulatory body.

The difference in relative efficiency between state-level companies or municipal and micro-regional companies that we deal with is related to the economies of scale literature. The studies surveyed find that the number of connections where economies of scale were found ranges from 100,000 (Fraquelli and Girardone, 2003) to 766,000 (Mizutani and Urakami, 2001), through to one million (Fraquelli and Moiso, 2005), but most of these studies had not employed frontier efficiency measurement techniques. Two worth mentioning exceptions are Filippini et al. (2008) and Corton (2011) and are the closest studies to this one.

Our concern about the public/private provision relates to the group of papers evaluating the impact of ownership. To mention a few, Feigenbaum and Teeples (1983), Bhattacharyya, Harris, Narayanan and Raffiee (1995), Estache and Rossi (2002), Renzetti and Dupont (2003), Kirkpatrick et al. (2004) and Saal et al. (2007) discusses the issue. As a conclusion, no clear results emerge from ownership, and they seem very sensitive to data availability and technics utilized.

The impact independence of service providers from the public administrations ("corporatization") on costs could be considered a subgroup of the impact of ownership literature into efficiency. The point here is whether the strong budget constraint entailing independence improves efficiency performance. Nonetheless, no paper reviewed had tackled this issue specifically. In this sense, our paper allows us to distinguish between improvements in efficiency due to private incentives and those derived from budget constraints.

Finally, given that we estimate a cost frontier, as a byproduct economies of scope could be analyzed and related to Mobbs and Glennie (2004), Martins et al. (2006), Revollo Fernández and Londoño (2008).

With regards to water and sanitation services in Brasil, Table 1 presents past studies in chronological order.

Several similarities and differences emerge from the comparison of our paper with those in Table 1. From the methodological point of view, we use SFA to estimate a total operating cost function (OPEX) in a panel of 127 providers along the period 2003–2010; this is in line with most of the six studies. The panel structure of information allows us control for firm heterogeneity, contrary to cross sectional papers (Faria et al. (2005) or Sabbioni (2007)).

Campos (2011) has a long panel structure but as Tupper and Resende (2004) he only considers regional enterprises. Our inclusion of local providers allows us to distinguish differences in costs structures or efficiency between government levels.

We considered a general translog cost function, which is a flexible one, in order to impose the fewest arbitrary restrictions on the underlying technology. On the contrary, although Cobb–Douglas function is much simpler, it imposes the same economies of scale for the whole range of data, contradicting the findings on economies of scale reviewed by Abbot and Cohen (2009). Besides, as long as the Cobb–Douglas is a special case of the Translog it can be tested whether it fits the data or not.

To summarize, our model includes 127 providers, in a balanced panel of 1016 observations, for the period 2003–2010, and we estimate a cost translog. Our dependent variable is OPEX. Unlike Campos (2011), which is the more recent study and the one which incorporates more periods, we integrate our sample with regional, local and microregional providers.

3. Method, models, and data

3.1. Method and models

We assume that providers have to supply a fixed number of customers with an exogenously determined tariff. Given this, profit (or social surplus) maximization comes through cost minimization of producing some exogenously given output level (in this case the

Table 1
Efficiency frontier studies for the Brazilian water and sanitation industries.

Authors	Operators	Period	Technique	Approach	Inputs and input prices	Cost variables	Outputs	Environmental variables
Tupper and Resende (2004)	20	1996–2000	DEA and SFA	Production	Labor cost, OPEX, Other costs of operation		Volume, Sewage treatment, served population (water), served population (sewerage)	Density of water network, density of the sewerage network, water network transmission losses
Faria et al. (2005)	279	2002	SFA	Production Cobb–Douglas	Network, Headcount		Delivered volumen (actual)	Dummy government owned firms and regional dummies (north, northeast, midwest, southwest and South)
Seroa da Motta e Moreira (2006)	104	1998–2002	DEA	Production			Water production, water supply (in volume and connections, sewage collection (in volume and connections, sewage treatment	Per capita income, rate of olliteracy, urban population share, number of served municipalities, dummies for public management, regional jurisdiction, sewage collection,
Sabbioni (2007)	280	2002	SFA	Cost Cobb–Douglas	Wages	OPEX	Output volumen, sewage collected, population accessing water, population accessing sanitation, sewerage connections	Dummies by region, dummy for block purchase of water, population density, micrometering, average consumption per household
Sabbioni (2008)	1163 (observations, variable number of operators considered in every year)	2000–2004	SFA	Cost	Wages	OPEX	Output volumen, connections	Network, percentage of urban population, micrometered volume, fluorinization (proxy for quality), dummy for sewerage, dummy for regions
Souza et al. (2008)	342	2002–2004	SFA	Cost Cobb–Douglas	Price of capital, wages	Total cost	Volume	Dummy private firms, regional dummies
Campos (2011)	23	1998–2008	SFA	Cost Translog	Wages, fixed capital price, energy price, third party services price, average price of other operational expenses	Total cost	Water production and collected sewage	Population served with water and sanitation, network length for water and sanitation, water volume, volume of treated sewage, total number of municipalities served

Source: Compiled by the authors

number of customers), subject to the available technology (i.e., the production function). The solution to this optimization (cost minimization) problem is a cost function:

$$\text{Min} \sum_i w_i x_i(y, w; Z) = \text{TC}(y, w; Z, D) \tag{1}$$

Where Y is the output vector, W is the vector of input prices and Z and D are vectors of environmental characteristics.

In this framework, the cost frontier represents the minimum expenses that can be achieved, so observed cost cannot be less than minimum possible cost, this is:

$$w^T x \geq \text{TC}(y, w; Z, D) \tag{2}$$

In particular, the potential each firm has to reduce costs -holding output constant- is referred as cost efficiency and it is represented by the ratio of minimum to actual costs:

$$\text{CE} = \frac{\text{TC}(y, w; Z, D)}{w^T x} \leq 1 \tag{3}$$

We can equalize the previous equation as follows:

$$\text{CE} = \frac{\text{TC}(y, w; Z, D) \cdot \exp(u)}{w^T x} \tag{4}$$

Given that the actual functional form of costs is unknown, we propose the following general translog costs function to be estimated:

$$\begin{aligned} \text{lnTC} = {} & \ln \alpha + \beta_y \ln y + \sum_{m=1}^{M} \gamma_m \ln w_m + \sum_{l=1}^{L} f_l \ln z_l \\ & + \frac{1}{2}\beta_{yy}(\ln y)^2 + \frac{1}{2}\sum_{i=1}^{M}\sum_{j=1}^{M}\gamma_{ij} \ln w_i \ln w_j + \frac{1}{2}\sum_{i=1}^{L} \\ & \times \sum_{j=1}^{L} f_{ij} \ln z_i \ln z_j + \sum_{m=1}^{M} \gamma_{ym} \ln y \ln w_m \\ & + \sum_{l=1}^{L} f_{yl} \ln y \ln z_l + \sum_{i=1}^{M}\sum_{l=1}^{L} h_{ml} \ln w_m \ln z_l + \sum_{d=1}^{D} \delta_d D_d \\ & + v_{it} + u_{it} \end{aligned} \tag{5}$$

This function is a second order Taylor approximation of the indirect costs function plus the error term (e) expressed as the sum of two terms: $v_{it} + u_{it}$. The first one is a random error with distribution iid $v_{it} \sim N(0, \sigma_v^2)$ in order to account for possible noise, data typing or reporting errors and the second one is the *inefficiency itself* and has a truncated normal distribution: $u_i \sim N^+(\mu, \sigma_u^2)$ and it accounts for unobserved factors which are in control of the firm, such as those coming from the will and effort of the producer and his employees. Both u_i and v_{it} are independently distributed with from each other and the model's covariances.

With regards to the inefficiency term, two especifications were estimated: (i) a time-invariant (TI) inefficiency and (ii) a time-varying-decay (TVD) version, where inefficiency is allowed to change. Theses models were proposed by Battese and Coelli (1988) and (1992), respectively. In the TI model $u_{it} = u_i$ and in the time-varying-decay (TVD) version,

$$u_{it} = \exp\{-\eta(t - T_i\} u_i \tag{6}$$

where T_i is the last period in the panel i, η is the time decay parameter of inefficiency. We test TI by constraining $\eta = 0$ in the TVD model.

Although the efficiency levels change over time in the TVD models, it is worth noting that they do so in the same proportion for every firm, thus preventing changes in efficiency rankings on a year-to-year basis.

Since Feigenbaum and Teeples (1983) public utility have been considered not as producers of water from factors such as labor and capital but instead as transformers of "the location (in space and time) and quality of water given the inputs". This means that each firm is characterised by a different typology as far as the inputs and output of water and the service provided are concerned. Therefore, the inclusion of environmental variables in the costs function makes it possible to "homogenize" firms which, though equal in terms of the volume supplied, operate in different environmental conditions and produce different services.

The flexibility of the translog function allows the environmental variables to interact with the output, the productive factors and themselves in the costs structure, in contrast to the Cobb–Douglas representation in which environmental variables have a linear impact on costs (See Faria et al. (2005, 2008) and Sabbioni (2007)). We test the Cobb-Doulgas as a special case.

Along the review of the efficiency studies for Brasil (Table 1), it emerges a trade-off between flexibility in the cost function vis a vis determinants of inefficiency. Papers that assigned efficiency levels to exogenous factors had estimated Cobb–Douglas functions (Souza et al., 2005, 2008); in contrast Campos (2011) chose a flexible functional form at the expense of not explaining the observed efficiency through exogenous factors.

A final remark with regards to the model selected is that although we ended up favoring the flexible functional approach, we tried to apply Greene (2005a,b)'s true fixed and random effects (TFE and TRE) in order to disentangle unobserved heterogeneity from inefficiency, but we found that the TRE did not converge and the TFE is not recommended for short panels ($T < 10$) because of the so-called incidental parameter problem. Belotti and Ilardi (2012) argue that as long as TFE is a Maximum Likelihood Dummy Variable (MLDV) estimation, the fixed effects α_i are estimated inconsistently as $N \to \infty$ and this inconsistency contaminates mostly the variance parameters, which represent the key ingredients in the post-estimation of inefficiencies.

Given this, in order to account for heterogeneity instead of fixed effects we included several dummies to account for differences in the operational and institutional environment, services supplied, and regional characteristics. We try to be comprehensive and capture all heterogeneity. If some heterogeneity remains, then it is going to be captured by the efficiency term. So, this model should be considered an upper bound in efficiency.

3.2. Data

The data comes from the National System of Sanitation Statistics (SNIS) and comprises a strictly balanced panel of 127 service providers resulting in a sample of 1016 annual observations for the period 2003–2010 (8 years). It accounts for approximately 72 percent of Brazil's urban population.

Table 2 presents a synthesis of the selected variables to fit Equation (5), coupled with the SNIS codification (Table 3).

Total operating costs[2] is the dependent variable while the following are the selected explanatory variables:

- Outputs: the number of customers served with water, and total sanitation coverage.

[2] Every nominal variable was deflated using the IBGE/OPCA index with base year 2010.

Table 2
Variables used for estimations.

Variables	Meaning	Variable type	Formulas (SNIS codification)
TC	Total operating cost	Dependent	Fn017
Cust	Water customers	Output	Ag002
Sewerage	Percent of the population served/Urban population of the served municipalities	Output	Es026/ge06b
P_l	Total wage cost/Number of full times employees	Input price	Fn010/fn026
P_e	Price per kwh consumed (numerary)	Input price	Fn013/ag028
P_o	Other unit costs (costs excluding wages and electricity apportioned to kilometers of the water and sewerage network)	Input price	(Fn017-fn010-fn013)/(ag005 + es004)
Dens	Water connections/kilometers of the water network	Environment	Ag002/ag005
Micro	Proportion of micrometered customers	Environment	Ag004/ag002
Loss	Unaccounted For Water	Environment	IN013
Independent	Dummy: 0 = direct public administration and public law; 1 = autarchy, private law with public administration, social organization, government owned company	Institutional	
Private	Dummy, 0 = company with government participation, 1 = private firm	Institutional	
Local	Dummy, 0 = regional and microregional, 1 = local	Institutional	
W&S	Dummy, 0 = wáter provision only, 1 = joint provision of wáter and sanitation	Multi-product	
Treatment	Dummy, 0 = treated sewage is under 20%, 1 = treated sewage is over 20%	Sewage treatment dummy	(es006 + es014 + es015)/(es005 + es013)
NO	Dummy, 1 = North, 0 = other regions	Regional	
NE	Dummy, 1 = Northeast, 0 = other regions	Regional	
SE	Dummy, 1 = Southeast, 0 = other regions	Regional	
SO	Dummy, 1 = South, 0 = other regions	Regional	
MI	Dummy, 1 = Midwest, 0 = other regions	Regional	

Source: Elaboration by the authors, based on data provided by SNIS.

- Input prices: average labor cost, unit electricity cost and other unit costs. The three prices were constructed adjusting data from the firms' financial statements by the physical quantities.
- Environmental and institutional variables: which are useful for testing specific aspects related to the provision of service, and not under control of the providers.

As to outputs, the adoption of the number of served customers of water services (instead of volumes) helps to better reflect the fact that firms deliver not only drinking water and conduct sewage, but they produce retail and administrative services as well. One argument supporting this view is that significant losses of drinking water occur throughout the piping network (averaging a loss of 35 percent for the full sample) and that sewerage is a multiple of the amount of water delivered. A second argument supporting this paper's definition of output is the presence of a strong correlation between customer based variables and volume variables.

With regard to the construction of input prices, this paper is in line with most of the literature. The price of electricity stems from apportioning the expenses incurred in that input to the total amount of kilowatts consumed. The price of labor was proxied by the average wage and the price of other unit costs was calculated by apportioning the remaining operating costs (i.e. excluding wages and electricity expenses) to units of physical capital as proxied by the extension in kilometers of the piping network.

The cost structure is usually influenced by environmental factors which go beyond the firms' control. In order to account for these circumstances, the following control variables were included:

- Customer density since higher levels of concentration results in lower costs.
- The proportion of metered customers. As individual metering demands both minimum water pressure levels and regularity, and specifically assigned personnel, this is usually considered a proxy for quality.
- Network transmission losses. These arise from technical issues (the poor condition of the pipes) as well as from illegal connections to the system.

The institutional operation framework was taken into account via the adoption of three dummy variables:

- Whether decisions regarding the firm's management and financing policies are autonomous (in contrast to an administrative dependence on the municipality).
- Whether the firm is state-owned or private-owned.
- Whether the firm has only local coverage (one municipality is served).

Finally, the following set of variables was included in the estimations as well:

- Dummy variable for the joint provision of water and sanitation services by the same firm (the rationale being its significant impact on fixed costs).
- Dummy variable for the treatment or non-treatment of waste water (which impacts costs).
- A set of dummy variables considering geographical differences (Brazil is often divided into five regions with significant differences in each region's development).

All the variables with the exception of those for ratios and dummies were transformed logarithmically and then we normalized all the variables around their mean to enable the direct effects to be interpreted as elasticities for that mean. The estimated cost functions are nondecreasing, linearly homogeneous and concave in inputs (provided that the estimated β is nonnegative) and are subject to the sum of the β adding up to 1. The price of electricity was adopted as numerary by taking quotients over costs and every other price, thus enforcing the fulfillment of the imposed properties for the cost functions.

As long as the error term (e) is the sum of has two independent variables u_i and v_{it}. The variance of the error term is $\text{Var}(e) = \sigma^2 = \sigma_u^2 + \sigma_v^2$ and we can test whether the error term is explained by efficiency or pure randomness. Specifically, given that $\gamma = \frac{\sigma_u^2}{\sigma^2}$; $\gamma \in (0;1)$ if $\gamma = 0$, then the variability of the residuals is entirely explained by the random component v.

Table 3
Descriptive statistics for the entire sample, and subsamples (2003–2010).

Variable	N whole sample	Mean	Standard deviation	Minimum	Maximum	N North region	N Northeast region	N Southeast region	N South region	N Midwest region
TC	1016	160	656	0.07	8190	40	184	456	208	128
Cust	1016	194,596	635,130	306	6,558,559	40	184	456	208	128
Sewerage	1016	0.50	0.40	0.00	1.07	40	184	456	208	128
P_l	1016	35,344	19,440	7023	134,021	40	184	456	208	128
p_e	1016	328	139	5.01	1375	40	184	456	208	128
p_o	1016	13,810	15,256	182	115,383	40	184	456	208	128
Dens	1016	75.18	26.88	15.96	179.39	40	184	456	208	128
Micro	1016	0.88	0.22	0.00	1.36	40	184	456	208	128
Loss	1016	0.35	0.17	0.00	0.79	40	184	456	208	128

	Whole sample	State-owned	Private	Dependent	Independent	Regional and micro-regional	Municipal	Water only	W&S	Regions
N	1016	934	82	484	532	160	856	194	822	5

Variable	N companies with government participation	Mean	Standard deviation	Minimum	Maximum	N private companies	Mean	Standard deviation	Minimum	Maximum
TC	934	166	684	0.07	8190	82	90	68	–	269
Cust	934	201,973	661,440	306	6,558,559	82	110,563	87,554	1845	326,214
Sewerage	934	0.50	0.41	0.00	1.07	82	0.49	0.31	0.00	0.99
P_l	934	35,005	20,029	7023	134,021	82	39,212	9,921,583	21,323	68,205
p_e	934	325	134	5.01	1375	82	367,083	178	178	912
p_o	934	12,085	13,351	182	115,383	82	33,454	20,932	2922	93,637
Dens	934	75.58	27.68	15.96	179.00	82	70.55	14.41	45.89	103.64
Micro	934	0.88	0.23	0.00		82	0.93	0.11	0.60	1.00
Loss	934	0.35	0.17	0.00	0.79	82	0.39	0.14	0.13	0.71

Variable	N non-independent companies	Mean	Standard deviation	Minimum	Maximum	N independent companies	Mean	Standard deviation	Minimum	Maximum
TC	484	28	50	0.07	269	532	280	889	1.07	8190
Cust	484	44,615	62,761	306	326,214	532	331,044	853,426	522	6,558,559
Sewerage	484	0.49	0.42	0.00	1.07	532	0.51	0.39	0.00	1.01
P_l	484	27,771	12,846	7023	78,114	532	42,234	21,736	12,084	134,021
p_e	484	345.03	165.67	31.63	1374.73	532	313.41	106.61	5.01	959
p_o	484	11,788	14,516	182	93,637	532	15,648	15,687	419	115,383
Dens	484	71.60	25.31	15.96	162.49	532	78.43	27.86	19.30	179.39
Micro	484	0.88	0.23	0.00	1.36	532	0.88	0.21	0.08	1.00
Loss	484	0.33	0.17	0.00	0.79	532	0.38	0.16	0.00	0.79

Variable	N regional and microregional	Mean	Standard deviation	Minimum	Maximum	N local	Mean	Standard deviation	Minimum	Maximum
TC	160	859	1460	3.8	8190	856	29.4	58	0.07	452
Cust	160	1,000,936	1,334,411	12,259	6,558,559	856	43,878	57,669	306	308,412
Sewerage	160	0.29	0.22	0.02	0.86	856	0.54	0.42	0.00	1.07
P_l	160	59,945	25,405	20,044	134,021	856	30,746	13,936	7023	111,147
p_e	160	281	70.73	175.79	685.95	856	337.39	146.37	5.01	1375
p_o	160	27,817	19,580	2292	115,383	856	11,191	12,705	182.46	93,637
Dens	160	78604.00	26.60	34.52	163.28	856	74.54	26.90	15.96	179.39
Micro	160	0.83	0.21	0.29	1.00	856	0.89	0.22	0.00	1.36
Loss	160	0.43	0.14	0.00	0.70	856	0.34	0.17	0.00	0.79

Variable	N water-only operators	Mean	Standard deviation	Minimum	Maximum	N W&S operators	Mean	Standard deviation	Minimum	Maximum
TC	194	2.14	2.17	0.07	11.9	822	197	724	0.29	8190
Cust	194	7814	6774	306	27,035	822	238,678	698,935	1525	6,558,559
Sewerage	194	0	–	0	0	822	0.62	0.35	0	1.07
P_l	194	22,977	11,599	7023	78,114	822	38,263	19,772	8827	134,021
p_e	194	372	155	32	1019	822	318	133	5.01	1374
p_o	194	6798	6294	251	38,889	822	15,464	16,250	182	115,383
Dens	194	66.74	36.66	15.96	179.39	822	77.17	23.6	26.22	163.28
Micro	194	0.73	0.34	0	1.36	822	0.92	0.16	0.24	1
Loss	194	0.27	0.18	0	0.68	822	0.37	0.15	0	0.79

Source: Authors elaboration on SNIS data.

Four specifications were estimated two Cobb–Douglas models (TI and TVD versions) and two Translog models (TI and TVD versions) using the maximum likelihood method.

4. Results and discussion

Table 4 shows the estimated coefficients.

We test the unconstrained model (Translog TVD) with the rest. The three likelihood ratio tests reject the reduced forms, so we analyze the last one and discard the rest.

In this model the core variables (outputs and input prices) are statistically significant (99%), and have the signs predicted by the theory. Only one of the three environmental variables is statistically significant and has the expected sign (Dens). The quadratic terms

Table 4
Estimations (variables in logarithms).

Variables	Cobb–Douglas time invariant	Cobb–Douglas time varying decay	Trans Log time invariant	Trans Log time varying decay
	T_cost	T_cost	T_cost	T_cost
Cust	1.017***	1.021***	0.997***	1.005***
Sewerage	0.311***	0.287***	0.461***	0.430***
P_l	0.391***	0.391***	0.274***	0.278***
P_o	0.408***	0.407***	0.529***	0.520***
Dens	−0.538***	−0.529***	−0.622***	−0.628***
Micro	0.049	0.019	−0.098	−0.106
Loss	−0.015	−0.011	0.036	0.037
Cust^2			−0.024***	−0.015*
Sewerage^2			0.705***	0.588***
P_l^2			0.084***	0.087***
P_o^2			0.161***	0.159***
Cust*Sewerage			−0.025	−0.012
Cust*P_l			−0.016*	−0.015*
Cust*P_o			0.009	0.008
Sewerage*P_l			0.043	0.040
Sewerage*P_o			−0.001	−0.010
P_l*P_o			−0.076***	−0.075***
Cust*Dens			0.096***	0.075***
Cust*Micro			0.052*	0.038
Cust*Loss			0.039	0.035
Sewerage*Dens			−0.123	−0.120
Sewerage*Micro			−0.678***	−0.569***
Sewerage*Loss			−0.042	−0.043
P_l*Dens			0.009	0.011
P_l*Micro			−0.010	−0.013
P_l*Loss			0.041	0.016
P_o*Dens			−0.189***	−0.191***
P_o*Micro			0.020	0.021
P_o*Loss			−0.018	−0.001
Dens^2			−0.071	−0.148
Dens*Micro			−0.051	−0.076
Dens*Loss			−0.059	−0.028
Micro^2			0.316	0.434**
Micro*Loss			−0.304***	−0.303***
Loss^2			0.002	0.002
Private	0.003	0.012	−0.068	−0.069*
Independent	−0.008	−0.012	−0.001	−0.004
Local	0.072	0.118**	0.022	0.105*
W&S	0.051	0.068*	0.045	0.062
Treatment	−0.025	−0.028	−0.012	−0.019
North	0.088	0.018	0.038	−0.022
Northeast	0.011	−0.005	0.049	0.028
Southeast	0.073	0.033	0.056	−0.004
South	−0.028	−0.044	−0.008	−0.015
Tendency	−0.002	0.016***	0.001	0.024***
Constant	14.608***	−21.730*	8.721***	−37.948***
lnsigma^2	−3.385***	−3.564***	−3.633***	−3.873***
Ilgtgamma	0.846***	0.603***	1.275***	1.009***
Mu (inefficiency parameter)	0.495***	0.401***	0.495***	0.386***
Eta (evolution of the inefficiency in time)		0.038***		0.049***
Sigma^2 (variance of the composed error term)	0.034	0.028	0.027	0.021
Gamma (proportion of the variance of the composed error term due to inefficiency)	0.701	0.638	0.782	0.734
Observations	1.016	1.016	1.016	1.016
Providers	127	127	127	127
Periods	8	8	8	8
LR − Test chi^2 (restrictions)	549.91 (29)	538.26 (28)	27.30 (1)	
Prob > chi^2	0.0000	0.0000	0.0000	

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Source: Own elaboration.

and several interaction terms are statistically significant under the TVD Translog specification. The regional dummy variables were not found to be statistically significant, and the institutional dummies were only statistically significant in specific cases.[3]

[3] We tested the elimination of redundant variables due to collinearity but the *t*-test rejected this.

Neither micrometering nor network transmission losses were found to be statistically significant to be able to explain the differences in a firm's cost structures.

The estimated time trend is statistically significant suggesting that real costs increase 2.4 percent per year. The parameter γ asserts that 78 percent of the variability of the error term is explained by inefficiency. The efficiency parameter μ equals 0.386, increasing at a rate of 4.9 percent a year. Both μ are η are statistically significant at a 99 percent confidence level. Note that this value for η contrast

Table 5
Comparison of means and standard deviations.

Whole sample and sub-samples	*N*	Efficiency level mean	Efficiency level standard error	Efficiency level standard deviation	[Confidence	interval at 95%]	Mean test (*t*)	Variance test (*F*)
Whole simple	1016	0.675	0.003	0.106	0.668	0.681	–	–
Government-owned	934	0.673	0.003	0.107	0.666	0.680	−1.80** (Private more	1.39** (Efficiency among
Private	82	0.695	0.010	0.091	0.675	0.714	efficient)	private more dispersed)
Non-independent	484	0.668	0.005	0.113	0.658	0.678	−1.76** (Independent more	1.29** (Efficiency among
Independent	532	0.680	0.004	0.099	0.672	0.688	efficient)	independent less dispersed)
Regional	160	0.648	0.007	0.083	0.635	0.661	−3.43*** (Local more efficient)	0.58*** (Efficiency among
Local	856	0.679	0.004	0.109	0.672	0.687		local more dispersed)
Water-only	194	0.691	0.007	0.104	0.676	0.706	2.45*** (Water-only more	0.96 (Same dispersion of
Water and sanitation	822	0.671	0.004	0.106	0.663	0.678	efficient)	efficiency levels)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Source: Compiled by the authors.

Table 6
Comparison of mean and standard deviation by region.

Region	Region		North		Northeast		Southeast		South		Midwest	
			Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
	Mean	Std dev	0.64	0.05	0.68	0.09	0.66	0.11	0.69	0.11	0.70	0.09
North	0.64	0.05										
Northeast	0.68	0.09	***	***								
Southeast	0.66	0.11	=	***	***	***						
South	0.69	0.11	***	***	=	**	***	=				
Midwest	0.70	0.09	***	***	=	=	***	***	=	***		

***$p > 0.99$, **$p > 0.95$, *$p > 0.90$ means the difference between mean and standard deviations are statistically significant at 99, 95 and 90%, respectably. The sign "=" means that no significant differences can be found between regions.

with the one found by Campos (2011) of −7.8%, this could be explained by the fact that we incorporate a trend variable to distinguish between costs risings and inefficiencies.

The results suggest differences in costs between private and government-owned firms. The costs of private firms is, based on the available data, 6.9 percent lower than the costs of government-owned companies (90% confidence).

We found that the municipal firms' costs (variable "Local") are 10.5 percent higher than regional and micro-regional firms (90% confidence).

The joint provision of service (i.e. companies that provide both water and sanitation services) was found to be statistically significant (89.3% of confidence), explaining differences in costs as well.[4] Joint provision raises total costs by 6 percent relative to the firms that provide only water. Given that joint provision was incorporated into the model via a dummy variable, we can interpret it as the fixed cost of adding sanitation to the firm's product portfolio.

With regards to the location of providers, the dummy variables were not significant, thus suggesting that every region has the same underlying cost structure once we had account for differences in the operational environment. This is consistent with Sabbioni (2007) who finds that there is no evidence that any region affects operating costs in any particular direction. But it could be the case that the differences are not in the underlying efficient technology but on their distance to it. This is dealt with in Table 6.

Before analyzing the distance to the efficient cost frontier by the efficiency scores it should be kept in mind that from Table 4 the frontier of the private operators is 6.9% lower than the public one's and the costs for the local operators are 10,5% higher than the regional or micro-regional ones.

[4] For the purpose of evaluating statistical significance, a *p*-value of 10 percent was set. The *p*-value for W&S was 10.7 percent, and this value was judged sufficient to attach statistical significance to the joint provision of water and sanitation services as an explanatory variable.

Table 5 presents a comparison across the distribution of the efficiency scores with a breakdown by sub-samples.

Results suggest differences in efficiency levels between private and government-owned firms. Private firms appear as more efficient however they exhibit a higher variability in efficiency levels. This results contrast with Faria et al. (2008) cross sectional study.

Efficiency levels are also statistically different when comparing firms operating independently of those that are part of the public administration. We found that independence is not associated with higher or lower costs (the dummy is not significant); however, independence is associated with higher efficiency scores. Independent firms also appear to experience less variability in efficiency scores, a higher concentration around the mean, and are thus both aggregately and individually closer to the cost frontier. The source of this difference could be that dependent firms have comparatively softer budget constraints: they can use other government resources without paying for them, or the other way round, they can buy or contract services that will end up using other part of the government.

Local firms are closer to the efficiency cost frontier and also exhibit less dispersion; thus, although they have costs 10% higher, they are closer to the frontier and less dispersed. Seroa da Motta and Moreira (2006) attribute the fact that local providers face stricter political pressures. This result contrasts to Faria et al. (2008) one, as long as for them regional firms are more efficient. The explanation could be that they assume both regional and local providers are on the same cost frontier, which we prove not to be the case.

Water-only firms seem to be more efficient and exhibit the same variability of efficiency score as the water and sanitation providers.

Another topic of interest is the proximity of the efficiency score to the frontier by region. In the first two outer columns and rows of Table 6 we present the mean efficiency score and the standard deviation, and then we evaluate differences in proximity and dispersion by region. For example, providers in the Northeast region are as efficient as the Southeast and Midwest ones, but more efficient than Southeast ones; besides, there are as dispersed as the Midwest ones but less dispersed than the South and Southeast ones.

We see that the most efficient firms – on average – are in the Midwest, compared to the firms from the Northern region that appear to be both the least and the most homogeneous in terms of the dispersion of their levels of efficiency. The Southeast and South show the highest dispersion of efficiency levels, this being statistically different to that of the Northeast and Midwest regions.

The efficiency results by region contrast to Faria et al. (2008). In our paper Midwest operators are as efficient as the South ones and more efficient than that the Southeast ones. While Faria et al. (2008) find that the Southeast region is more efficient, and the South is less efficient than the Center-West region. From this contrast, we could conclude that differences in regional efficiency are sensitive to the specification of the underlying cost structure.

5. Conclusions

The purpose of this paper is to is to estimate the costs frontier of the water and sanitation service providers in Brazil and thus to determine their relative efficiency. In doing so, we seek to answer the following questions:

- Are there significant differences between state-level companies or municipal and micro-regional companies in terms of efficiency or cost structures?
- Does private provision of the service impact on costs or efficiency levels?
- Does independence of service providers from the public administrations ("corporatization") have any impact on costs?

As a by-product we can assess:

- Which is the efficiency level of the industry and its evolution over time?
- How does water-only providers compare with water and sanitation ones in terms of costs?
- The states are grouped in five regions, with marked differences in development, demography, and social indicators. Do cost structures vary in different regions of the country?

For all of the above, an analysis was made using the Stochastic Frontiers Method based on data provided by the National System of Sanitation Statistics (SNIS).

The first finding is that regional and micro-regional firms' cost structure is 10 percent lower than that of municipal firms. The source of this difference appears to originate in their scale rather than in levels of efficiency. This makes a first case for regionalization: by regionalizing municipal and micro-regional firms, cost savings would consequently arise. It may also be interesting to deepen the scale economies' argument and its explanatory power.

The second is that administrative independence – as opposed to the provision of service through a government administrative office – is not relevant when explaining the cost structure, but ownership is. Specifically, private firms have a lower cost structure. Two processes have to do with this but in opposite directions: on the one hand, independent operators are likely to have better cost accounting and a more professional management; on the other hand, this may be offset by implicit subsidies received by the dependent operators in the form of input sharing in many areas (namely billing, administrative and commercial working hours, office space, software systems, and so on). With respect to this second point, it can also happen that dependent providers can subsidize other areas of the municipality with resources, or customers via lower tariffs or delinquency tolerance, and this is possibly the origin of the dispersion in efficiency scores.

Third, the joint provision of water and sanitation results in a 6-percent higher fixed cost compared to water-only operators. Note that sewerage coverage is on average nearly 50 percent (with a standard deviation of 40 percent).

The fourth significant finding concerns differences in cost structures due to regional differences. We find that they are not regional differences in cost structures. However, there are slight variations in the levels of efficiency and in the dispersion of such levels in each region.

Fifth, following the best fitting model, inefficiency is not time-invariant; instead, it decreased at a rate of 4.9 percent per year during the time frame studied.

Finally, a broader research agenda for the Brazilian water and sanitation industry is pending. It would be useful to compare the robustness of the results obtained in this paper with other frontier techniques such as Data Envelopment Analysis (DEA), to test for the presence of significant scale and scope economies, to explore the issue of optimal industrial organization and potential savings arising from the agglomeration of operators, to assess productivity changes over time by means of productivity indexes and indicators (Malmquist, Luenberger) and, lastly, to study the actual agglomeration experiences of municipal operators and how they impacted on cost savings.

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