The most efficient clusters of Brazilian water companies

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Abstract

Usually water utilities provide their services under natural monopoly, with few incentives to become efficient, therefore affecting customers in the form of expensive tariffs. Hence, it is extremely important to find out the sources of inefficiency. The present study aims to identify the most efficient water utility groups in Brazil. For this purpose, a robust non-parametric method was applied. The results show that the utilities that provide both drinking water and wastewater services, the local utilities, and the utilities with private participation are more efficient. Furthermore, this study proved that the utilities were more efficient before the regulatory framework had been implemented.

Keywords: Brazil; DEA; Efficiency; Statistical tests; Water and wastewater utilities

1. Introduction

Water is a unique and scarce natural resource, essential for the life of all living beings. Given its environmental, social, and economic value, water is critical for the survival of humankind. Access to water, in appropriate quantity and quality, has direct implications for public health, for the population’s productivity and economic growth (UN-Water, 2013). However, water utilities provide essential services under natural monopoly, with few incentives to become efficient, wasting resources and affecting customers in the form of expensive tariffs, subsidized prices or lower quality of service (De Witte & Marques, 2010). Measuring the performance of water utilities is an important issue not only for the companies to identify their weaknesses and set improvement targets for the future, but also for government and regulators to set prices and tariffs and to supervise the quality of service (Araral, doi: 10.2166/wp.2015.148

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This paper estimates the performance of water utilities in Brazil and, in particular, determines whether the different clusters of utilities emphasize different performances. Although Brazil was ranked the seventh biggest economy in 2013, it is a country where a significant part of the population has no piped water or sanitation. The problems with sanitation are even more critical. According to the National Information System on Water and Wastewater (SNIS), for the year 2012, in urban areas 93.2% of the Brazilian municipalities had access to piped water and 56.1% to a sewerage system, but in the peri-urban and rural areas the figures were much worse (SNIS, 2014).

Despite government efforts and the meaningful investments carried out in the country, the water sector is still characterized by strong differences in the access to services between the urban (and peri-urban) and rural regions. This sector is also characterized by a significant heterogeneity in the service providers as regards their size, scope, and ownership and quality of service provided (Ferro et al., 2014). In 2012, there were in total 27 regional, six micro-regional, and 1,422 local water utilities and from these only 66 were private companies.

The main objective of this paper is to investigate which groups of water utilities operating in the water sector in Brazil are the most efficient. For this purpose, one of the most powerful methods found in the literature to compare the efficiencies of different groups of decision-making units (DMUs) is applied. This method was proposed by Simar & Zelenyuk (2006) and consists of a statistical test that is not limited to assessing the equality of location parameters of the efficiency scores’ distributions (such as the mean and the median) of various groups (as is typically done in most studies in the literature), but which also assesses the equality of the entire efficiency distributions. In this context, this study analyzes four major topics, namely: (1) the scope of the services provided by utilities, with the aim of assessing whether there are savings if the water supply service is provided together with the wastewater service; (2) the enactment of the new regulatory framework (Law no. 11.445 in 2007) with the purpose of assessing the impact of this important law (which imposes explicit regulation for the whole sector) on the efficiency of the utilities; (3) the extent of utilities in terms of the territory (regional or local); and (4) the ownership of the utilities (with or without private participation).

From these four topics, in the efficiency analysis literature of the Brazilian water sector, as in the literature worldwide (see Abbott & Cohen (2009) and Berg & Marques (2011) for a complete survey), ownership has been one the most discussed matters. However, most studies do not provide definitive conclusions concerning the superiority of private water utilities over public ones or vice versa, although they recognize the importance of private participation in the sector. For example, Clarke et al. (2004), Motta & Moreira (2006), and Souza et al. (2007) found no evidence that private and public Brazilian utilities are significantly different in terms of efficiency. Souza et al. (2008) found evidence that public firms are more efficient, although the difference in efficiency identified is declining over time. Ferro et al. (2014) inferred that although the costs of private companies are higher than those of public ones, private companies are more efficient. Finally, Faria et al. (2005) concluded that private companies are only marginally more efficient than public companies.

Another topic also frequently addressed in the literature is the territorial scope or, in other words, the scale of operations of water utilities (see Carvalho et al. (2012) for a complete survey). The literature points to large water utilities worldwide exhibiting diseconomies of scale, while small utilities usually present significant economies of scale, conveying the idea that if small utilities increase their scale of intervention (translated as an increase in land area of intervention), they tend to have advantages in terms of cost savings and, consequently, efficiency earnings, while larger utilities tend to have advantages if they reduce their scale of intervention (Saal et al., 2013).
Concerning the literature on the water sector in Brazil, some studies point to a greater efficiency of local operators compared with regional operators, even though the regional operators benefit from economies of scale and have higher scale efficiencies (Motta & Moreira, 2006). The regional operators (state-owned operators) provide a group of municipalities within a state and the local operators are municipal-based and provide one or more municipalities (inter-municipal), which can be either directly managed by the municipality or by a private operator. The recent study carried out by Ferro et al. (2014) underlines previous findings, stating that the local companies are more cost efficient, although they have, on average, costs 10% higher than regional and micro-regional companies. Motta & Moreira (2006) attribute these results to the fact that local providers face stricter political pressures. Nevertheless, Faria et al. (2005) found the opposite, suggesting that the regional companies are more efficient.

Motta & Moreira (2006) reported that the low efficiency levels of regional operators may be due to higher wages (as mentioned by Yepes (1990)) and to higher water losses in distribution compared with local operators. Moreover, they do not have any tax advantages from which local operators benefit. The authors emphasize, however, that the regional companies are investing and expanding their infrastructure at a more pronounced rhythm than are municipal services. In contrast, Sabbioni (2008) reached the conclusion that the regional providers have the lowest firm-specific costs and that regional companies are more scale efficient than the local ones. Sabbioni’s findings also indicate that the economies of scale are so significant that it is enough to claim that the provision of these water services at the state level is more efficient than their provision at the municipal level.

The scale efficiencies of regional operators are also underlined by Nauges & Van Den Berg (2008) and Campos (2011). Nauges & Van Den Berg (2008) investigated density, scale, and scope economies in Brazil, Moldova, Romania, and Vietnam and found evidence of economies of scale in Moldova, Romania, and Vietnam for average-sized water operators, but in Brazil they found evidence of constant returns to scale (CRS) for the regional utilities, which produce, on average, 425 million cubic meters per year and serve, on average, more than 900,000 connections, showing that regional operators have already reached the optimum size. Campos (2011) also noted that the state companies benefit from economies of scale, despite the fact that smaller companies have a higher earning potential.

Concerning the amount of services provided by the utilities, this is also a topic quite frequently addressed in the worldwide literature – in other words, the search for economies of scope – although less discussed than the previous economies of scale (Carvalho et al., 2012). Regarding the studies that examine this topic in the Brazilian water sector, they do not provide consistent results. Nauges & Van Den Berg (2008), for instance, when studying the water sector in Brazil, Moldova, Romania, and Vietnam, found evidence of economies of scope in all countries where utilities provide both water supply and wastewater services (which includes Brazil), showing that it is more advantageous to integrate these two services. In contrast, the recent study carried out by Ferro et al. (2014) shows that the joint provision of water and wastewater services raises the total costs by 6% relative to the companies that provide only water, which suggests that water-only companies are more efficient.

Finally, regarding the impact of the new regulatory framework, there are no studies investigating its consequences in terms of water utilities efficiency. This law was very important because it imposed and universalized the regulation of all water utilities, and established a set of rules and practices that the operators should follow, thus contributing to the improvement of the quality of service provided and to the modernization of the sector (Junior & Paganini, 2009).

The paper is organized into six main sections. After this brief introduction, the second section reviews the panorama of the water sector in Brazil and the third section provides the methodology applied.
fourth section describes the sample and model specifications. The results obtained from this analysis are presented and discussed in the fifth section. The paper ends with some concluding remarks.

2. Water sector in Brazil

Up to the first two decades of the 20th century, the participation of the federal government in the water sector was limited to the adoption of actions to attract private investment. This objective was partly achieved with the concession of water services to private companies by some municipalities. However, in most cases, the provision of the service was dependent on local solutions supported by the respective state (Saiani et al., 2009).

In 1971, due to a global economic crisis that reduced the appeal to private companies in this sector, as well as the industrial and urban expansion, and the low coverage of services and the poor service provided, in general, in the country, the federal government implemented its first reform in the water sector with the introduction of the Water National Plan (PLANASA). This plan led to the creation, in each Brazilian state, of a State Water Company (CESB). The motivation for the development of PLANASA, which still has a central role in the Brazilian water sector, was associated with the achievement of economies of scale regarding the regional organization of the service providers, in order to ensure the access of small municipalities to these services.

Through a funding model of centralized investments, the main objective of PLANASA was to reduce the deficit of access (coverage) to the water supply and wastewater services. To accomplish this, in order to centralize the federal funds for investments in the water sector, the Water Financial System (WFS) was created with the Housing National Bank (BNH) being responsible for its management and for the assessment of the loans made to the CESBs. With the introduction of this plan, strategic decisions were transferred to the federal level, forcing the municipalities to give away their services to the state-owned utilities that had been created. The municipalities that refused to sign the concession agreement with the state-owned utilities would be excluded from the WFS, having no access to funds to develop their infrastructure.

Before the introduction of PLANASA in 1971, 50% of the urban population had access to drinking water and 20% to a wastewater service. In 1985, 15 years after PLANASA was created, a study provided by the Brazilian Institute of Geography and Statistics concluded that 87% of the population had access to potable water. Despite its satisfactory results, this model ended in 1992 after the BNH entered into bankruptcy due to the high indebtedness of some water companies. With the failure of PLANASA and its funding programs, deregulation of services occurred, causing an increase in private sector participation in the industry, with an increase in the number of municipal contracts with the private sector, in order to ensure an expansion of their services (Salles, 2009).

Although responsible for a notorious expansion of the Brazilian water services, investments from PLANASA prioritized the construction of water supply systems, rather than projects that would reduce losses and improve the overall efficiency of service providers. This situation led to excessive losses and inefficiencies in the sector. The Brazilian water sector became self-regulated in the absence of minimum standards between the providers and customers, resulting in a lack of investment in the expansion and updating of services, and access to a piped water system was denied to a great part of the population. The wastewater service was not a priority and the coverage level was very low (even in South America it was one of the lowest). The first full concession contract under private initiative,
like the first partial concession contract, occurred in 1995 after the enactment of the Concessions Law (Law no. 8.987).

In 2007, the enactment of Law no. 11.445 established national guidelines for the water sector that included the following four components: water supply, wastewater collection and treatment, solid waste management, and storm water management. This law determines that all water services should be regulated, otherwise the water utilities can be penalized, such as having their contracts canceled or ceasing to have access to the financial resources of the Central Government. Besides the modernization of the water sector rules, among other relevant issues, the law also imposed the need to develop a plan for the water sector in each municipality. Owing to its importance, this legislation is known as the regulatory framework of the water sector.

In 2000, a regulatory agency for the water sector (Agência Nacional de Águas (ANA)) was established as an independent agency (yet formally associated with the Environment Ministry). The agency is essentially responsible for the management of the water basins in terms of the implementation and coordination of a national system for water resources (Sistema Nacional de Gerenciamento de Recursos Hídricos). The main function of the ANA is to monitor the utilization of water resources and the discharge of sewage in water basins (Tupper & Resende, 2004). Following this, and, in particular, the regulatory framework, tens of regulatory agencies were created. Some of them are focused only on the water sector, but others are multi-sector and also involve additional sectors, such as transportation and electricity. However, they are normally like a branch of their level of government (municipal, inter-municipal or state).

Two other laws were very important for the water sector: Law no. 11.079, of 2004, concerning the setting of rules for the public–private partnerships arrangements and Law no. 11.007 with respect to consortia formation to provide public services, including those related to the water sector.

By the end of 2012, the coverage of water supply in Brazil was 84.36%. This value is not homogenous in the country, with percentages quite low in the North and Northeastern and greater in the South, Southeastern, and Central-Western Brazilian regions. The wastewater collection coverage was 57.06% in that year. There is no credible information about the coverage of wastewater treatment. The same heterogeneity is observed in the water supply coverage across the different states and regions in Brazil. As stated before, the coverage levels do not correspond to the connected population since this value is much lower.

In December of 2013, a National Plan for Water and Wastewater (Plano Nacional de Saneamento Básico (PLAN SAB)) was published. The PLAN SAB offers an integrated approach to the Brazilian water sector in its four components. PLAN SAB predicts achieving in the next 20 years 99% of drinking water coverage – 100% in urban areas – and 92% in wastewater with 93% in urban areas, investing more than 262 \times 10^9 R$ in the Brazilian water sector.

Table 1 summarizes the Brazilian water market structure, taking into account its scale and ownership. It provides evidence of the trend of private sector participation increase in the water sector. Only regional providers have decreased their private participation because most (24) became mixed companies. This can be explained because regional utilities provide water and wastewater to a higher number of the population and mixed companies combine greater efficiency and investment capacity of private providers with the active role of public providers in ensuring the quality of the wastewater services and the universal access. Furthermore, it is worth noting that most of these companies provide water and wastewater together, corresponding to about 47.2%, and only a small number provide only water (about 28.8%), and others, besides the water and wastewater services, also include waste or other
activities (18.6%). It should be emphasized that many of these companies operate in several municipalities, so a company can encompass a large number of (municipal) water systems.

3. Methodology

The research of the more efficient groups of firms is a subject broadly addressed in the literature (Cook et al., 1998). The comparison between public and private groups of firms in terms of efficiency is a classic example of this kind of research (e.g. Mancebon & Muniz, 2008).

These studies have been very useful in many sectors, since they have identified the most efficient groups and, therefore, the best features of the groups and the corresponding best practices (surprisingly, there are no studies in the water sector on this scope). However, these studies have not always been carried out using the most appropriate methods. The first studies only made the comparison of simple average efficiencies of the different groups of firms (typically the efficiencies obtained from the traditional non-parametric method – data envelopment analysis (DEA) – initially developed by Charnes et al. (1978), by extending the ideas of Farrell (1957) and Debreu (1951)), and only afterward did more robust studies appear using statistical tests to compare the efficiencies between groups. Nevertheless, most of the statistical tests used in the literature have proved, at times, to be lacking power, partly because of the inherent weaknesses of the DEA method (especially concerning the influence of the curse of dimensionality in finite samples) and the corresponding efficiency scores estimation.

Much effort has been made to improve these statistical tests, but without much success. More recently, a statistical test appeared in the literature proposed by Simar & Zelenyuk (2006), which does not only assess the equality of location parameters of the efficiency scores’ distributions (such as the mean and the median) of various groups, but also the equality of the entire efficiency distributions. Therefore, this statistical test has proven to be one of the most powerful tests found in the literature.

Simar & Zelenyuk’s (2006) statistical test aims to determine whether two samples of DEA efficiency scores \( \{\hat{\theta}_1\}_{i=1}^{n_1} \) and \( \{\hat{\theta}_2\}_{i=1}^{n_2} \) (corresponding to the group of DMU 1 and the group of DMU 2, respectively) are drawn from the same distribution and, thus, whether either of the two groups of corresponding DMUs is indeed statistically more efficient than the other. The statistical test consists of testing the following null hypothesis:

\[
H_0: f(x) = g(x) \quad \text{for almost all } x
\]  

where \( f(\cdot) \) is the probability density functions (PDF) of \( \hat{\theta}_1 \) and \( g(\cdot) \) is the PDF of \( \hat{\theta}_2 \).
The statistical test has the following:

\[ T_n^b = \sqrt{n_1n_2}h(T_n^b - C_{n,b})/\hat{\sigma}_b \]  

where \( T_n^b \) is ¹:

\[
I_n^b = \left\{ \frac{1}{(hn_1^2)} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{1i} - \hat{\theta}_{1j})/h] + \frac{1}{(hn_2^2)} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{2i} - \hat{\theta}_{2j})/h] \right. \\
- \frac{2}{(hn_1n_2)} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{1i} - \hat{\theta}_{2j})/h] \right\} 
\]

and \( n_1 \) and \( n_2 \) represent the sample size of the groups 1 and 2, respectively, \( h \) the bandwidth, \( K(\cdot) \) a kernel function and \( \hat{\theta}_1 \) and \( \hat{\theta}_2 \) the estimated DEA efficiency scores of the groups 1 and 2.

And \( C_{n,b} = K(0)/h \times (1/n_1 + 1/n_2) \), where \( K(0) = 1/\sqrt{2\pi} \) in the case of Gaussian kernel, that is, \( K(u) = e^{-u^2}/\sqrt{2\pi} \).

And finally:

\[
\hat{\sigma}_b^2 = \left\{ \frac{h}{(n_1^2)} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{1i} - \hat{\theta}_{1j})/h]^2 + \frac{h}{(n_2^2)} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{2i} - \hat{\theta}_{2j})/h]^2 \right. \\
+ 2h/(n_1n_2) \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{1i} - \hat{\theta}_{2j})/h]^2 \right\} 
\]

The equality of the efficiency distributions is evaluated by computing the following p-value:

\[
\hat{p} = \sum_{b=1}^{B} I\{T_n^b* > T_n^b\}/B
\]

where \( T_n^b* \) are the bootstrap estimates of the statistic of test and \( T_n^b \) are the original statistic of the test, obtained from the DEA efficiency scores \( \hat{\theta}_{DEA} \) estimated initially (for implementation of the statistical test, see Simar & Zelenyuk (2006)).

The null hypothesis of equality of the efficiency distributions will be rejected if the previous p-value takes values below the significance level (\( \alpha \)), meaning, in this case, that the two groups of DMUs are statistically significantly different in terms of efficiency.

Thus, given its potential, this statistical test was adopted by the present study to assess which groups of water utilities operating in Brazil are more efficient. In this research an input orientation was assumed, since the DMU under study aims to rationalize (reduce) the amount of consumed inputs for a given level

¹ For example, the sum \( \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} K[(\hat{\theta}_{1i} - \hat{\theta}_{1j})/h] \) represents the following sum: \( \sum_{j=1}^{n_2} K[(\hat{\theta}_{11} - \hat{\theta}_{2j})/h] + \sum_{j=1}^{n_2} K[(\hat{\theta}_{12} - \hat{\theta}_{2j})/h] + \cdots + \sum_{j=1}^{n_2} K[(\hat{\theta}_{1n_1} - \hat{\theta}_{2j})/h] \), where a value of \( i (i = 1, 2, \ldots, n_1) \) corresponds to each of the parts.
of outputs. Also, a variable returns to scale (VRS) technology (Banker et al., 1984) was assumed for estimation of the DEA efficiency scores, since it is known that the DMU is not operating at the optimal scale, considering the significant size differences of the various Brazilian water utilities.

Since one of the aims of this study is to evaluate the difference, in terms of efficiency, between utilities that provide a different amount of outputs, namely, between those that provide only the drinking water supply service and utilities that provide both drinking water and wastewater services, we applied the shared input DEA model (Beasley, 1995; Jahanshahloo et al., 2004; Chen et al., 2010; Cruz et al., 2013). This method allows estimation of not only the overall efficiencies of the DMUs, as does the traditional DEA, but also the partial efficiencies associated with each activity provided by the DMU. In addition, this method allows estimation of the cost (input) share allocated to each activity (output). To this end, a maximum and minimum limit for these cost (input) shares are defined and imposed in the application of the method, and it estimates the cost (input) shares associated with each of the activities (outputs) in such a way as to maximize the overall efficiency. In this case study, given the large variety of dimensions of water utilities, for those that provide both drinking water and wastewater services we imposed a lower limit near zero and an upper limit close to one to both activities. However, for utilities that provide only the drinking water supply service, we imposed a maximum cost share close to zero to the wastewater activity.

This shared input DEA model is defined by the following linear programing problem, for an input orientation and assuming VRS technology:

$$\text{max } e_k = \sum_{i=1}^{q} u_i y_{ik} + \varphi$$

s.t.

$$\sum_{l=1}^{p} v_l x_{lk} = 1$$

$$\sum_{i=1}^{q} u_i y_{ji} - \sum_{l=1}^{p} v_l x_{jl} + \varphi \leq 0 \quad j = 1, \ldots, n$$

$$\sum_{i=1}^{r} u_i y_{ji} - \sum_{l=1}^{s} \alpha_i v_l x_{jl} \leq 0 \quad j = 1, \ldots, n; \quad i = 1, \ldots, q$$

$$\sum_{i=1}^{q} \alpha_i = 1 \quad j = 1, \ldots, n$$

$$u_i \text{ and } v_l \geq 0$$

$e_k$ is the overall efficiency score of DMU $k$, $x \in \mathbb{R}_+^p$ are the $p$ inputs used by $n$ DMUs to produce the $q$ outputs $y \in \mathbb{R}_+^q$, $\alpha_i$ is the ratio of inputs associated with activity (output) $i$, $u_i$ and $v_l$ are the weights of the outputs and inputs, respectively, and $\varphi$ is an additional incognita referring to the VRS model.

2 To assume a CRS technology one needs to ignore the variable $\varphi$. 

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Thus, the overall efficiency scores represent the partial efficiency estimates $e_{ki}$ weighted by the respective DEA-estimated cost (input) shares:

$$e_k = \sum_{i=1}^{q} \alpha_i e_{ki} \quad (7)$$

where the partial efficiency scores $e_{ki}$ are defined as a ratio between the weighted sum of the $r$ outputs concerning activity (output) $i$ and the weighted sum of the $s$ inputs consumed by activity (output) $i$:

$$e_{ki} = \frac{\sum_{i=1}^{r} u_{ji} y_{ji}}{\sum_{i=1}^{s} \alpha_i v_{ij} x_{ij}} \quad (8)$$

4. Sample and model specification

The sample comprises a set of about 4,900 utilities that operated in Brazil for 11 years, between 2001 and 2011. The following chart (Figure 1) provides the number of analyzed DMUs corresponding to each of the studied topics, that is, the number of DMUs associated with the utilities that just provide water and those that provide water and wastewater, the number of DMUs recorded before and after the regulatory framework (2007) enactment, the number of DMUs corresponding to regional utilities and local utilities, and, finally, the number of DMUs concerning the utilities with and without private participation.

In the specification of the models, the input adopted was the total costs (in Brazilian Real – R$/year), which includes all operational expenditures and capital expenditures, and the outputs considered were the volume of drinking water billed and the volume of treated wastewater (expressed in m$^3$/year). All costs were updated to the last year (2011), taking into account the Consumer Price Index observed in

Fig. 1. Number of analyzed observations grouped according to the topics studied.
Brazil over the period studied. Figure 2 presents the summary statistics of these input and output variables, for the several years and types of utilities. All data were collected from the SNIS database.

As already mentioned, an input orientation was adopted since the aim of water utilities is to reduce the inputs (minimize costs) for a given level of outputs delivered.

<table>
<thead>
<tr>
<th>Input</th>
<th>Total expenditures (thousands of RS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>79,682</td>
</tr>
<tr>
<td>2002</td>
<td>83,787</td>
</tr>
<tr>
<td>2003</td>
<td>81,728</td>
</tr>
<tr>
<td>2004</td>
<td>80,224</td>
</tr>
<tr>
<td>2005</td>
<td>81,642</td>
</tr>
<tr>
<td>2006</td>
<td>81,716</td>
</tr>
<tr>
<td>2007</td>
<td>82,865</td>
</tr>
<tr>
<td>2008</td>
<td>82,686</td>
</tr>
<tr>
<td>2009</td>
<td>84,986</td>
</tr>
<tr>
<td>2010</td>
<td>86,251</td>
</tr>
<tr>
<td>2011</td>
<td>87,004</td>
</tr>
<tr>
<td>All years</td>
<td>85,144</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output 1</th>
<th>Volume of drinking water billed (thousands of m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>822,831</td>
</tr>
<tr>
<td>2002</td>
<td>842,918</td>
</tr>
<tr>
<td>2003</td>
<td>867,632</td>
</tr>
<tr>
<td>2004</td>
<td>861,318</td>
</tr>
<tr>
<td>2005</td>
<td>853,841</td>
</tr>
<tr>
<td>2006</td>
<td>821,424</td>
</tr>
<tr>
<td>2007</td>
<td>810,400</td>
</tr>
<tr>
<td>2008</td>
<td>848,208</td>
</tr>
<tr>
<td>2009</td>
<td>810,299</td>
</tr>
<tr>
<td>2010</td>
<td>797,387</td>
</tr>
<tr>
<td>2011</td>
<td>756,652</td>
</tr>
<tr>
<td>All years</td>
<td>775,900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output 2</th>
<th>Volume of treated wastewater (thousands of m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1,736,274</td>
</tr>
<tr>
<td>2002</td>
<td>1,951,388</td>
</tr>
<tr>
<td>2003</td>
<td>2,049,825</td>
</tr>
<tr>
<td>2004</td>
<td>2,073,758</td>
</tr>
<tr>
<td>2005</td>
<td>1,950,681</td>
</tr>
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<td>2006</td>
<td>1,882,556</td>
</tr>
<tr>
<td>2007</td>
<td>1,635,736</td>
</tr>
<tr>
<td>2008</td>
<td>2,061,655</td>
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<tr>
<td>2009</td>
<td>1,313,706</td>
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<td>2010</td>
<td>1,567,413</td>
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<tr>
<td>2011</td>
<td>1,510,268</td>
</tr>
<tr>
<td>All years</td>
<td>1,758,672</td>
</tr>
</tbody>
</table>

Fig. 2. Statistics of input and output variables.
5. Results and discussion

In this study, the Brazilian water utilities were analyzed mainly from four perspectives. From the first one, we compared the utilities, in terms of efficiency, as regards the scope of outputs (services) provided, meaning that we tried to find which groups of utilities are more efficient, either the utilities that provide only drinking water supply service or the utilities that provide both drinking water and wastewater services. From the second perspective, we investigated whether all utilities were more efficient before or after the implementation of the regulatory framework in 2007. In a third approach, utilities with regional scope were compared with the utilities with local scope. And, finally, we examined whether the private sector participation has contributed to increase the efficiency of utilities.

The results obtained by the Simar & Zelenyuk (2006) method, regarding the number of services provided, reject the null hypothesis (to confidence level of 95%) (Table 2), which corresponds to the rejection of equality of the efficiency distributions of utilities that only provide the water supply and utilities that provide drinking water and wastewater services together. Thus, it is concluded that the efficiency difference between these two groups of water utilities is statistically significant. As can be seen by observing Figure 3(I), the distribution of the inverse of the overall efficiencies VRS of utilities providing both drinking water and wastewater services is the closest to the axis $yy^*$, which means that in this group of utilities there is a greater number of utilities with higher efficiencies. Therefore, the utilities that provide both drinking water and wastewater services are more efficient compared with those that only provide the drinking water supply service. This result seems to indicate that there are economies of scope in the joint provision of water supply and wastewater services in Brazil, as Nauges & Van Den Berg (2008) also found.

Furthermore, by comparing the partial efficiencies, it was also found that the wastewater service has greater efficiency than the water supply service, since the partial efficiencies corresponding to the wastewater service ($e_{k2}$) are generally greater than the partial efficiencies corresponding to drinking water service ($e_{k1}$) (Figure 4).

Table 2. Results of equality test of efficiency distributions of various groups of Brazilian water utilities.

<table>
<thead>
<tr>
<th>Type of Utilities</th>
<th>VRS overall efficiency scores statistics: Average</th>
<th>Median (standard deviation)</th>
<th>p-value</th>
<th>bandwidth (h)</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only water utilities</td>
<td>0.1610.132 (0.122)</td>
<td></td>
<td>&lt; 0.001</td>
<td>4,525.2</td>
<td>✓</td>
</tr>
<tr>
<td>Water and wastewater utilities</td>
<td>0.24510.211 (0.158)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>They operated before 2007</td>
<td>0.23010.185 (0.154)</td>
<td></td>
<td>&lt; 0.001</td>
<td>3,865.0</td>
<td>✓</td>
</tr>
<tr>
<td>They operated in 2007 and after</td>
<td>0.16910.129 (0.122)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional utilities</td>
<td>0.16410.127 (0.117)</td>
<td></td>
<td>&lt; 0.001</td>
<td>4,905.0</td>
<td>×</td>
</tr>
<tr>
<td>Local utilities</td>
<td>0.23310.188 (0.157)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilities with private participation</td>
<td>0.21310.194 (0.100)</td>
<td></td>
<td>&lt; 0.001</td>
<td>476.2</td>
<td>×</td>
</tr>
<tr>
<td>Utilities without private participation</td>
<td>0.19010.144 (0.140)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

✓ Accept the hypothesis of equal distributions of efficiency to confidence level of 95%.

× Reject the hypothesis of equal distributions of efficiency to confidence level of 95%.
Furthermore, the results reject the hypothesis of equality of the efficiency distributions of the water utilities observed before and after the 2007 regulatory framework (the null hypothesis) (to confidence level of 95%) (Table 2 and Figure 3(II)). According to Table 2, this means that before the regulatory framework the water utilities were more efficient. However, since the regulatory framework is very demanding, it would be expected, at least in the short term, that greater costs would be asked for to comply with the legislation. Obviously, this is counterweighted by a better service provided.

Concerning the size of the water utilities in terms of territory, the results also indicate the rejection of the hypothesis of equality of efficiency distributions of water utilities with regional scope and of utilities with local scope (null hypothesis) (to confidence level of 95%) (Table 2 and Figure 3(III)), indicating that the local utilities are more efficient than regional utilities. This is also in line with the literature (see Section 1: Introduction) and expected for a possible better quality of service provided by the state-owned utilities. This is debatable but an argument frequently given by the state-owned utilities.

Finally, regarding the private sector participation, the results obtained by the Simar & Zelenyuk (2006) method allow the conclusion to be drawn that the private water utilities are more efficient,
because it rejects the hypothesis of equality of the efficiency distributions of water utilities that have private sector participation and those that have no private participation (null hypothesis) (to confidence level of 95%) (Table 2 and Figure 3(IV)). Note that the difference between the efficiency distributions of these two groups of water utilities is the lowest compared with the other cases (Figure 3(IV)). This difference is translated by the much smaller value of the statistic $T^b_n$ of the test (Table 2) compared with the remaining cases. These results are also consistent with what is expected, because although in the literature there is no major evidence that private operators are more efficient, almost all studies refer to the importance of private sector participation and the contribution it can make to the increase of efficiency in the sector (Motta & Moreira, 2006). The results obtained here are also consistent with the results obtained in a recent study by Ferro et al. (2014) for the Brazilian water sector. Indeed, although the operation of a private utility has multiple features, in practice, these operators can usually improve the overall efficiency in broadly three indicators: water losses, bill collection, and labor productivity (Marin, 2009). The reduction of water losses is the most relevant topic. According to recent multi-country studies (Andrés et al., 2008; Gassner et al., 2008), most private operators...
succeeded in reducing water losses notably in developing countries, for instance, in Western Africa, Brazil, Colombia, Morocco, and Eastern Manila in the Philippines, and, in certain cases, even achieving good performance as some of the best-performing utilities in developed countries.

Regarding the optimal scale of water utilities in Brazil, the existence of different optimal sizes for the two types of utilities is observed. Figure 5 shows that the optimal size corresponds to a supply higher than 15/20 million m³ of water/year for water and wastewater utilities, and that the optimal size for water utilities corresponds to a supply higher than 600,000 m³ of water/year, where utilities have the highest scale efficiencies (equal to unity).

6. Concluding remarks

The present study aimed to identify the most efficient water utility groups in Brazil. The identification of the best practice clusters is very useful to understand the performance of Brazilian water utilities and to avoid the comparison between ‘apples and oranges’. For this purpose, one of the most robust methods in the literature was applied. The method used, the statistical test suggested by Simar & Zelenyuk (2006), tests the equality of the efficiency distributions of two different groups of utilities.

The results led to the following conclusions: the utilities that provide both drinking water and wastewater services are more efficient than those that only provide the water supply service; the utilities were more efficient before implementation of the regulatory framework; local utilities are more efficient than regional utilities; and the utilities with private participation are more efficient than those with no intervention of any private entity in their management. This means that the water sector in Brazil should move toward joining the management of both drinking water and wastewater services for the entire sector to become more efficient. The utilities should also try to achieve sizes corresponding to a supply higher than 15/20 million m³ of water/year, which was the minimum optimal size estimated. The results also show that one specific measure should be taken to ensure that the whole regulation process and regulators, despite not having a key role in the sector, are not a kind of obstacle to increasing the efficiency of the utilities, but rather that they contribute to its increase. Furthermore, the results reveal that regulators and entities responsible for the water sector in Brazil should investigate what characteristics of the local utilities make them more efficient than regional utilities. These features...
should be implemented in the regional utilities, since they benefit from economies of scale (Motta & Moreira, 2006). Finally, the importance of the presence of the private entities in the management of these water services should be emphasized and, therefore, water services in Brazil should be encouraged to involve private entities in their management.

The results also demonstrate the existence of different optimal sizes for the two types of utilities: an optimal size corresponding to a supply higher than 15/20 million m$^3$ of water/year for water and wastewater utilities, and an optimal size for water utilities with a supply higher than 600,000 m$^3$ of water/year. As a result of these findings, and as mentioned several times in the literature (Motta & Moreira, 2006; Campos, 2011), it is necessary to create instruments to encourage the efficiency of utilities, taking into account the results obtained, for example, with the help of effective regulation. Only in this way will it be possible to make the sector more efficient and sustainable, and to allow the gains from increased efficiency to be transferred to users through a reduction of tariffs and provision of a better quality of service.

References


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