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A Service Provision and Financial Performance Approach

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Electrorating

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Content

ABSTRACT

This study identifies and analyzes the evolution of efficiency in providing services and in the financial performance of the LAC electricity distribution companies between 2014-2020. In addition, it examines firms' characteristics that might be related to efficiencies, such as quality of service, corporate governance, firm size, and ownership. This paper uses a two-step procedure. First, it considers the efficiency levels and the total factor productivity (TFP) changes using the Malmquist index and breaks down the total change by relying on a non-parametric data envelopment analysis (DEA) approach. The second stage focuses on the drivers of efficiency obtained in the first stage using the Tobit technique. The main results suggest that there is no significant improvement in the levels of efficiency in the period analyzed in the energy distribution firms in LAC. When analyzing the heterogeneity of a company's efficiency, the evidence shows a relation between companies' efficiency and the quality perceived by users, higher efficiency is related to better-perceived quality. Besides, companies' characteristics, such as firm size, corporate governance, and ownership, are related to the heterogeneity of efficiency.

1 INTRODUCTION

1.INTRODUCTION

In recent decades, the energy markets in most countries have witnessed regulatory reforms. In this path, the main aims of the electricity sector reforms are to introduce competition into electricity generation and supply and improve the efficiency of the natural monopoly activities of distribution and transmission through structural and regulatory reforms (Ramos-Real et al., 2009; Çelen, 2013).

Regulatory and structural reforms in the electricity industry would generally be expected to: increase investment, increase the number of customers connected, reduces losses, and cut the number of employees, among others (Vine et al., 2003; Ramos-Real et al., 2009) via the increase of efficiency and productivity.

Although much of the research on electricity market reforms has focused on the evolution of the potentially competitive segments, such as generation and commercialization, the performance of the remaining regulated network segments (namely distribution and transmission) is also of considerable economic importance. First, these regulated segments often represent a significant fraction of the total price paid by final consumers. Second, the performance of the regulated segments can have important effects on the performance of the competitive segments because the regulated segments provide the infrastructure platform upon which the competitive segments rely (Joskow, 2014). And this becomes more important in the context of energy transition, in which the tendencies of the energy sector transformation, such as decentralization and digitalization, depend on transformations of the network segment, both technologically and economically. Improve prices and regulated charges are a must to adequately efficiently energy systems to the energy transition requirements (Pérez-Arriaga and Knittel, 2016; Hallack et al., 2020).

Electricity distribution companies are regulated monopolies[3]. The reshaping of distribution requires changes in the legal framework directed to investments and operation. Regulators should be able to drive distribution companies to increase efficiency, especially to meet innovation requirements for the energy transition. However, information asymmetry is a key challenge to guarantee the correct incentives through legal means. Regulatory designs need to combine stimulus for improving service quality while also enhancing the efficient use of economic resources. These rules should additionally balance incentives for raising efficiency for companies while transferring part of these gains to final consumers through price reductions gaining affordability in the long run. In this context, Pérez-Arriaga & Knittel (2016) underlines the need of advancing distribution companies' regulation to enable the development of more efficient distribution utility business models.

To build better governance models for Latin America and the Caribbean, it is key to understand the current level and evolution of economic efficiency of these companies. This paper contributes by addressing this question through different benchmark methods that capture efficiency and productivity in the LAC electricity distribution companies between 2014-2020. In addition, the paper analyzes how different firms' characteristics relate to electricity companies' efficiency.

The analysis is based on a two-step procedure. First, it assesses the efficiency levels and the changes of the total factor productivity (TFP) using the Malmquist index and a non-parametric data envelopment analysis (DEA) approach. The second stage focuses on the efficiency drivers obtained in the first stage and compares the mean values of efficiency between companies according to the selected characteristics. Next, we direct towards different robustness checks to show similarity in results when different outputs are used.

3 Theory characterizes natural monopolies as the most technically efficient market structure when a single firm can produce a specific output vector at less cost than two firms (subadditivity).

The present work contributes to the empirical literature in several ways. First, it analyzes the evolution of energy distribution firms' efficiency regionally, in 9 LAC countries, using a novel survey dataset collected by the Inter-American Development Bank (IDB). Second, it looks at the impact of electricity distribution firms' characteristics on efficiency. Finally, it compares different models and dataset samples to get evidence of the robustness of the results.

For such a task, we have organized the present work as follows: Section 2 discusses the literature review on efficiency related to energy distribution firms and the ways firms' characteristics may relate to efficiency. Section 3 explains the methodology of the two-stage procedure. Section 4 presents the data used. Section 5 discusses the results and offers a robustness check by using a restricted sample. And, lastly, Section 6 concludes the analysis.

2 EFFICIENCY OF ENERGY DISTRIBUTION COMPANIES

2.EFFICIENCY OF ENERGY DISTRIBUTION COMPANIES

The measurement of efficiency in various sectors of the economy is not a new topic. However, advances in statistical methodology, an increase in data availability, and high-quality software have all contributed to the increasing interest in this task (Smith & Street, 2005). In particular, the measurement of efficiency heterogeneity and its changes have become ascending topics for research in recent years.

Regulators are not aware if firms are efficient when they declare their costs in the tariff's revision process. However, the evolution of regulatory practices in many countries strives to mitigate the information asymmetry faced by the regulators by making this information available to them and the public. The electricity markets in most countries have become good candidates to apply the efficiency measurement methods (Çelen 2013)[4]. However, there is still scarce literature on this topic in developing countries, especially at a regional level.

Ramos-Real et al. (2009) estimated changes in the productivity of the Brazilian electricity distribution sector using DEA on a panel of 18 firms from 1998 to 2005 and found that the incentives generated in the reform process did not lead to firms behaving more efficiently. Still among developing countries, Pérez-Reyes & Tovar (2009) analyzed the evolution of productivity between electricity distribution companies in Peru and found a positive relationship between the restructuring of the energy sector and improvements in efficiency and productivity of electricity distribution. Furthermore, Jamasb et al. (2021) examined the performance of electricity distribution utilities in 24 Indian states and found that economic development and institutional quality positively affected the performance of electricity distribution utilities.

It has been hypothesized that certain characteristics may affect the efficiency of energy distribution firms. Regulators should be aware of this when planning efficiency performance. Some of these characteristics can be incentivized through regulations and policies, such as governance transparency. Others can be a consequence of other choices and regional specificities, such as size and consumer perception. Even if these attributes are not considered normative variables s, they should still be accounted for when defining adequate efficiency benchmarks and goals.

In studies that focus on efficiency performance between public and private firms, the main findings suggest that private firms tend to outperform public ones (see, for example, Çelen, 2013; Zelenyuk & Zheka, 2006; Cullmann & von Hirschhausen, 2008). However, it is important to be aware that other characteristics of energy distribution firms could impact efficiency, like consumers' perception and mechanism of governance, and both have been scarcely explored. These less highlighted variables can contribute to deepen the public/private firm discussion on efficiency. For instance, independently of the type of ownership, it is expected a positive relationship between the levels of corporate governance and the relative firms' efficiency (see, for example, Zelenyuk & Zheka, 2006). However, evidence for this is deficient. Yet, it is important to mention that these firms serve final consumers, so the perception of service quality is important and can in fact lead to different levels of efficiency.

There is an ongoing debate whether larger companies are more efficient than smaller ones in their inputs (Mousavi-Avval et al., 2011; von Hirschhausen et al., 2006). The general answer points to how easily the company can expand its production given its capacity. Under this assumption, larger companies that invest their profits well can be more efficient than smaller companies.

4 Arcos-Vargas et al. (2017), Çelen (2013), Ramos-Real et al. (2009), and Pérez-Reyes & Tovar (2009) review the empirical literature which has applied DEA methodology and the analysis of efficiency to the energy distribution industry (firms). In the literature review, the authors identified that most of the DEA analysis was focused on distribution companies in a single country; however, few studies analyze firms from several countries (see, for example, Jamasb & Pollitt, 2003). Moreover, some papers concentrated on unbundled distribution companies and others on vertically integrated companies (including power generation with energy distribution companies). This is a caveat in some studies as it can raise challenges when studying efficiency since the outputs of generation and distribution companies are different.

Nevertheless, if small companies invest in expanding their production and if the large firms do not renew their capital stock, then they will be less efficient than the small ones (Arcos-Vargas et al., 2017). As a regulated natural monopoly, power distribution companies' size has another perspective, especially in a region where most of the population have electricity access (97% in LAC). The distribution companies' size is currently mostly related to institutional choices (such as concession choices) and geographical/demographic specificities. However, in the future, with more distributed energy and batteries, companies will be able/ or be forced to contemplate other business models and possibly plan more autonomously strategic decisions about size, since the firm's size may come to play a key role in how well they are placed among other firms.

3 METHODOLOGY: TWO-STEP APPROACHES FOR ENERGY DISTRIBUTION FIRMS' EFFICIENCY ANALYSIS

3. METHODOLOGY: TWO-STEP APPROACHES FOR ENERGY DISTRIBUTION FIRMS' EFFICIENCY ANALYSIS

This research employs the data envelopment analysis (DEA) models which incorporate only variables whose values can be changed in a reasonable period by decision-making units (Çelen, 2013). The DEA model is a fractional linear program that assesses the comparative efficiency of decision-making units (DMUs) in a scenario with multiple possible inputs and outputs. The DEA model (CCR) was developed by Charnes et al. (1984) as a generalization of the framework of Farrell (1957) on the measurement of productive efficiency which assumes constants return to scale. Next, a study proposed by Banker et al. (1984) analyzed a new scenario in which they assumed variable returns to scale (DEA VRS). The DEA analysis, as mentioned by Fall et al. (2018) does not need previously estimated parameters[5].

Like Çelen (2013), the present study departs from the linear programming problem corresponding to the basic input-oriented DEA specification of Charnes et al. (1978) under the CRS assumption (which is known as the CCR model) to expand the model to incorporate the case of VRS (which is known as the BCC model)[6].

Concerning productivity changes; Pérez-Reyes and Tovar (2009) rely on other measures like productivity and mention that productivity and efficiency are indeed different yet related concepts. Productivity is the ratio between the products obtained and the factors used in their production. While technical efficiency is the capacity of obtaining the maximum amount of output from certain inputs (output orientation). Technical efficiency can also be seen as the capacity of obtaining a given output level using the minimum number of inputs (input orientation). In addition, with technical efficiency one can also measure the existence of economies of scale, when a company reaches maximum productivity with its current technology. With the previous definitions, it is deduced that technical efficiency is only one of the factors that determine productivity (Pérez-Reyes & Tovar, 2009).

Overall, productivity is efficiency in production, that is: how much output is obtained from a given set of inputs (and is typically expressed as an output-input ratio) (Syverson, 2011). So, the measuring of productivity must be achieved using the total factor productivity (TFP) measurement. TFP being a generalization of single-factor productivity measurement, and TFP growth refer to the change in productivity over a period (Pérez-Reyes & Tovar, 2009). Important to mention that there are several approaches to measuring productivity[7]. This study uses a non-parametric frontier approach such as the Malmquist index. In the Annex, subsection 7.2, the Malmquist index (MI) methodology is presented.

According to the decomposition proposal by Färe et al. (1994), four distance functions defined under constant returns to scale (CRS) and two under variable returns to scale (VRS) are required to calculate the MI (Pérez-Reyes & Tovar, 2009).

5 Contrary to the Stochastic Frontier Analysis (SFA) which requires specification of functional form and assumptions regarding the distribution of the error term.

6 CRS refers to the Constant Returns to Scale, and VRS refers to the Variable Returns to Scale.

7 Van Biesebroeck (2007) and Van Beveren (2012) provide an excellent review of several non-parametric methods (specifically, index numbers and DEA).

The current study employs the non-parametric input-oriented DEA model with constant returns to scale (CRS) and variable returns to scale (VRS), having the objective of the DMUs to minimize the inputs given a level of outputs. For this, we use an input-oriented approach since electricity distribution companies usually tend to have more control over the minimization of costs (inputs) rather than the maximization of profits (outputs) which typically depend on the market demand. To perform the efficiency analysis with the DEA model, this document solves the following linear program:

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

$$s.t.: \theta x_j - X\lambda \geq 0$$

$$Y\lambda \geq y_j$$

$$\lambda \geq 0$$

where λ is a semi-positive vector in R^k and θ is a real variable that represents the efficiency score of as given firm and has values from 0 to 1; x_j is a vector of the firms' inputs, and y_j is a vector that contains the outputs. The minimization problem is subject to the constraint that no DMU can function beyond the production possibility curve and weights cannot be negative. Furthermore, DEA uses the VRS technical efficiency score for X-efficiency and scale efficiency for the division of the constant returns to scale (CRS) efficiency score by the VRS efficiency score (SE=CRS/VRS)[8].

The selection of input and output variables is crucial in DEA applications aiming to measure the efficiencies of DMUs (Çelen, 2013). This work is built on the empirical models developed by Çelen (2013) and Pérez-Reyes and Tovar (2009) In model 1, two outputs are considered: Total Billed Electricity (TBE) in MWh, and the number of costumers (NC), respectively y_1 and y_2. Regarding the inputs, the number of employees, x_1, and total assets, x_2 (in logarithms) are used. Seen the current characteristics of distribution companies as regulated monopolies, both variables are exogenous[9].

Moreover, the current study uses financial measures as outputs (model 2), to show how efficiency in service provision can trade off with financial efficiency. It is hypothesized that firms with the greatest efficiency in service provision are also the most efficient financially[10]. In this sense, two different outputs are considered: Total sales (sales), and net profit (NP) (also in logarithms and with similar inputs as mentioned earlier)[11].

Here we analyze several firms' characteristics and their relationship to efficiency. More specifically, a focus is given to the consumer satisfaction index since it is believed that higher customer satisfaction can lead toa stronger competitive position resulting in higher market share, profitability (Fornell, 1992) production, and efficiency (Bayraktar et al., 2012). We also take into consideration in the present analysis if the firm has (or not) an internal audit, an administrative council, or other councils. Stiglitz (1999) argues that the establishment and enforcement of proper corporate governance principles significantly enhance the development of individual firms and economies as a whole – at least due to increasing efficiency of resource utilization. In addition, Zelenyuk & Zheka (2006) find empirical support to suggest a positive relationship between the levels of corporate governance quality across firms and the relative efficiency levels between them. Firm's size is analyzed based on the assumption that the bigger the firm is, the more

8 To obtain the result the command in Stata developed by Ji and Lee (2010) is used.

9 The measuring of efficiency in energy distribution firms has no clear consensus in the literature related to which combination of input and output variables best describes the performance of these firms (Arcos-Vargas et al., 2017). However, the analysis uses an input-oriented model specification that is less controversial once these companies have been responsible for serving all customers, making the outputs exogenous (Çelen, 2013).

10 ng Similar work was developed by Zheng, Lam, Hsu, and Ren (2018).

11 Total sales are an exogenous variable because it depends on a variety of external factors; furthermore, net profit in several models is treated as an exogenous variable. Nevertheless, net profit would be an endogenous variable because it could be affected by other variables in the model, and also the firm might decide the level of net profit. Banker and Morey (1986) argue that unlike most of the traditional econometric approaches, DEA does not require any restrictions on the underlying production technology, or an exogenous specification of the parametric form of the production correspondences.

control it has over capital and labor, thus, improving general efficiency in energy management (Moon & Min, 2017). In the final section of the paper, we analyze efficiency changes according to ownership. Some authors have found a negative association between state and firm's efficiency (see, for example, Zelenyuk & Zheka, 2006; Cullmann & von Hirschhausen, 2008).

Like several authors who analyzed the efficiency drivers (see, for example, Pérez-Reyes & Tovar, 2009; Çelen, 2013; Lee et al., 2021), we obtained the efficiency scores generated from DEA in the first step. Next, we used the score as the dependent variable in a Tobit regression parametric model. Afterward, we used a censored approach since the efficiency score is truncated from zero to one. In this path, we estimated the following censored regression model:

$$y_{i,t} = \{x'_{i,t}\beta + \varepsilon_{i,t}, \quad when\ 0 < y_{i,t} < 1\ 0, \quad for\ others\ values\ of\ y_{i,t} \}$$

where $x'_{i,t}$ is a set of covariates that might affect firm efficiency. In this case, it includes four covariates: Consumer satisfaction index, firm size, a dummy for having a council, and a dummy for ownership. This model also included year and country fixed effects to control for possible macroeconomic shocks. In the second stage, efficiency dimensions are used endogenously, to analyze which variables explain these measurements (Pérez-Reyes & Tovar, 2009).

Overall, this paper uses the DEA analysis to study the evolution of efficiency of electricity distribution companies in 9 LAC countries. Also, we present mean differences in efficiency between four firm characteristics in section 4. In this line, a Tobit approach tested the robustness of the results is showed in the Annex section. Additionally, an efficiency analysis using final services measures (model 1) and financial measures (model 2) as outputs to test the robustness of the results are presented. Finally, in the Annexes the results are tested using a restricted sample of companies which held information during the entire period of analysis while other which did not hold information were eliminated.

4 DATA FROM ELECTRICITY DISTRIBUTION COMPANIES

4. DATA FROM ELECTRICITY DISTRIBUTION COMPANIES

The data source utilized in the analysis was obtained from the Electrorating database (Weiss et al., 2022) which can be considered a novel effort implemented by the Inter-American Development Bank (IDB) to increase and strengthen knowledge distribution between LAC companies. IDB collected publicly available[12] data from energy regulatory bodies and utilities' webpages. The data includes more than 60 financial and non-financial indicators from a sample of electricity distribution companies from 19 countries of LAC. The database is integrated by annual data for 316 companies distributed among Argentina (51), Belize (1), Bolivia (6), Brazil (153), Chile (15), Colombia (21), Costa Rica (8), Ecuador (25), El Salvador (9), Guatemala (1), Guyana (1), Jamaica (1), Mexico (1), Panama (3), Paraguay (1), Peru (13), Dominican Republic (4), Trinidad and Tobago (1), and Uruguay (1), covering the years from 2000 to 2020. The definition of the variables used for this analysis is described in table 3 in the Annexes section.

The financial information collected consists of a wide range of components of the companies' income statements and balance sheets. The former includes net profit, gross profit, financial result, EBIT[13], EBITDA[14], sales, total cost, total expenses, income taxes, energy purchase cost, OPEX[15], depreciation and amortization costs, and employee cost, among others. The latter contains total assets, current assets, own power plants and equipment, non-current assets, cash and equivalents, net assets, total liabilities, current liabilities, non-current liabilities, and so forth.

Additionally, Electrorating presents non-financial indicators related to the market, such as: energy losses, technical service quality, governance and capital, employees, diversity and workplace, and quality of customer service. The market indicator includes clients, total electricity billed, and the length of the distribution network. The technical service quality is measured by System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). The governance and capital indicators contain variables that capture if the company has a board of directors, independent audit, internal audit, the participation of the main shareholder, and the number of shares. The employees, diversity, and workplace indicators include variables related to the number of employees, female labor participation, and frequency of accidents. Finally, customer service quality incorporates the number of claims and the customer satisfaction index.

The sample taken from the database for the purpose of investigation included companies with enough financial and non-financial data which allowed us s to construct the variables in accordance with the literature on efficiency. So, the current study uses unbalanced panel data from 80 electricity distribution firms over the period from 2014 to 2020[16].

As mentioned earlier, the sample contains information from firms based in Argentina, Bolivia, Brazil, Chile, Colombia, El Salvador, Jamaica, Peru, and Uruguay. Table 1 shows the descriptive statistics of the inputs and outputs used in the two different models. Moreover, it presents several firms' characteristics of the market. Specifically, it shows that the mean value of the consumer satisfaction index in this market is 0.672 which suggests that consumers are relatively satisfied with the provision of the services of these companies. Table 1 also shows that 26.1% of firms have an internal audit, 59.5% have an independent audit and 63.7% have an administrative council.

12 The Electrorating database can be consulted on the Energy Hub site of IDB. https://hubenergia.org/en

13 *EBIT* (Earnings before interest and taxes)

14 *EBITDA* (Earnings before interest, taxes, depreciation, and amortization)

15 *OPEX* (Operational expenditures)

16 We use only 80 electricity distribution firms over the period from 2014 to 2020 because it is in this period where a greater number of companies have reported the information corresponding to the inputs and outputs used in this research. Likewise, companies that have not reported one or several inputs have been discarded from the analysis since the DEA does not allow missing values in their programming.

These descriptive are important since the literature works under the assumption that a culture of corporate governance functions towards making companies more efficient.

Table 1. Descriptive statistics

Variable	Observations	Unit	Mean	Std. Dev.	Min	Max
Total Billed Electricity*	527	MWh	5870	7670	13.2	37900
Number of customers*	527	Person	1.359	1.791	0.003	8.724
Total sales*	527	USD	504	631	1.019	3140
Net profit*	527	USD	17.30	67.40	-220	495
Total assets*	527	USD	920	1300	0.753	8910
Number of employees*	527	Person	37.30	57.5	0	346
Consumer satisfaction index	245	Index	0.672	0.217	0.329	1
Internal audit	422	Dummy	0.261	0.439	0	1
Administrative council	422	Dummy	0 .637	0 .481	0	1
Independent audit	422	Dummy	0 .595	0 .491	0	1

Notes: * measured in millions.
Source: Authors

Due to the high volatility of the variables used as inputs and outputs and the changes in scale between certain variables, it was decided to use the variables in logarithms when calculating the DEA and MI. In this sense, Table 2 shows the correlations between the variables used in the empirical analysis. It shows that all variables are statistically significant at a 5% level and are highly correlated. In this sense, it is shown that the Total Billed Electricity is associated with the number of customers and total sales at 98%, net profit at 84%, total assets at 90%, and with the number of employees at 94%.

Table 2. Correlation matrix

Variable	Total Billed Electricity	Number of costumers	Total sales	Net profit	Total assets	Number of employees
Total Billed Electricity	1.00					
Number of customers	0.98*	1.00				
Total sales	0.98*	0.98*	1.00			
Net profit	0.84*	0.84*	0.87*	1.00		
Total assets	0.90*	0.90*	0.89*	0.77*	1.00	
Number of employees	0.94*	0.91*	0.93*	0.79*	0.84*	1.00

Notes: All variables are measured in logarithms. * Significance at 95% confidence level.
Source: Authors

In sum, we concluded that the variables selected as inputs are highly correlated with the outputs conferring validity to our empirical strategy. The high correlation found also confirms the association between the selected inputs and outputs as statistically significant (at 5%), which informs us that in an input-oriented model the outputs can be affected by the selected inputs.

5 RESULTS

5. RESULTS

This section presents the main results, more specifically, the estimation of technical efficiencies measures.

As mentioned in previous sections, an input-oriented DEA model was used to measure the efficiency of the electricity distribution firms from 2014 to 2020 in different LAC countries. In the results section, we also show the evolution of technical efficiency (CRS) and variable returns to scale (VRS) efficiency scores. In addition, several firms' characteristics that might be related to efficiency are analyzed, such as quality of service, mechanism of governance, firm size, and ownership. The results suggest that in the mean, firms exhibit increasing returns to scale during the period of analysis. However, there is no significant improvement in efficiency compared year after year during the period of analysis in the energy distribution firms in LAC. Finally, firms with better corporate governance practices tend to be more efficient than their counterparts.

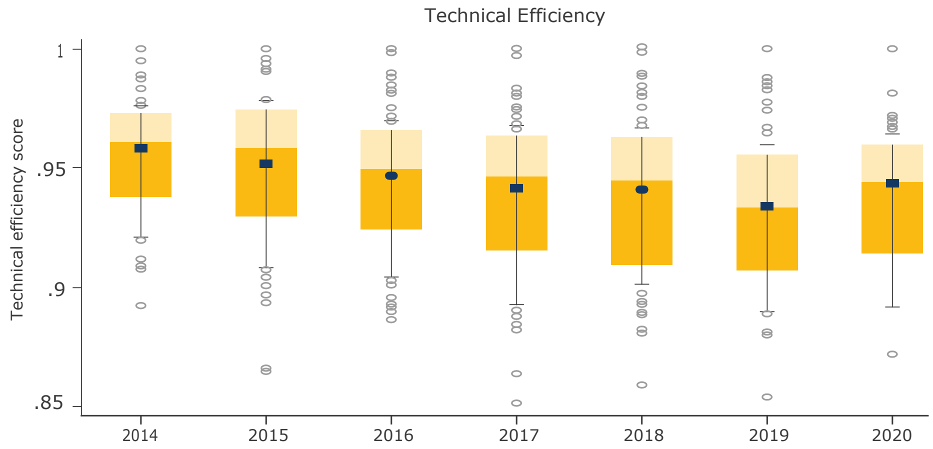
The evolution of efficiency of electricity distribution companies in LAC

Figure 1 presents the constant returns to scale technical efficiency (CRS) mean scores by year using Model 1 which uses the Total Billed Electricity (TBE) in MWh, and the number of costumers (NC). Moreover, the results of Model 2 use Total sales (sales), and net profit (NP) in logarithms as outputs presented in Figure 2[17].

The main results of efficiency by year are shown in figure 1. According to the CRS scores, it is found that, in the mean, the efficiency of these firms is high and above 0.93; nevertheless, **the efficiency levels have been decreasing from 2014 to 2019, with a small recovery in 2020**. It can be an outlier in the tendency because of the COVID pandemic impact; however, this needs to be further explored. Çelen (2013) mentions that relying on constant rates of return assumption implies that the electricity distribution companies are operating at their optimal scale.

Also, the results considering this assumption and firms' variable returns to scale technical efficiency (VRS) is presented in the Annexes section 7.1, Figure 7. It is shown that the mean variable returns to scale technical efficiency score by year is higher than the technical efficiency score (CRS) and above 0.95.

Figure 1. Efficiency of electricity distribution firms by year: final services output (model 1).

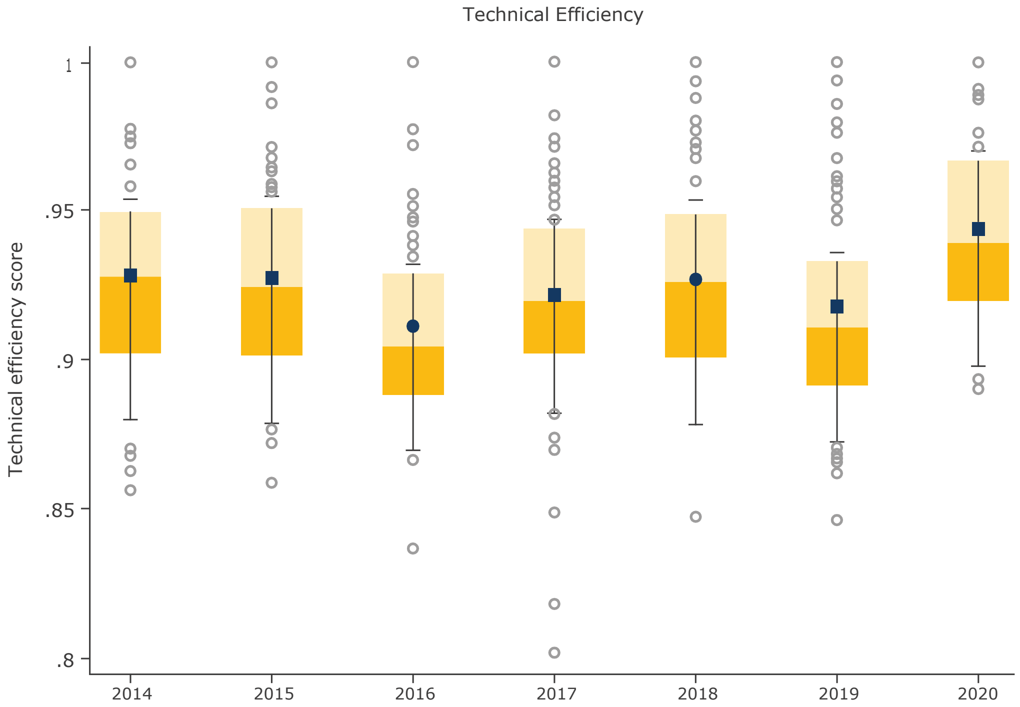


Note: The blue point separating the two small boxes represents the mean, while the white line separating the two small boxes represents the median, and the box represents the dispersion. The dot points are the companies' considered outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

17 The variable returns to scale technical efficiency (VRS) mean scores by year are presented in the Annexes section 7.1, in Figure 7.

Figure 2 presents the results by using financial measures as outputs (model 2): Total sales (sales), and net profit (NP) in logarithms, to show how efficiency in service provision can trade off with financial efficiency. Model 2 demonstrates the constant returns to scale technical efficiency (CRS) mean scores by year. Furthermore, the variable returns to scale technical efficiency (VRS) mean scores by year using Model 2 is presented in Annex section 7.1, Figure 7. Calling attention to Model 2 validating the results of model 1, **where no significant improvement in efficiency was found during the years of analysis.**

Figure 2. Efficiency of electricity distribution firms by year: financial measures output (model 2)



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

The results of the evolution of the distribution companies' efficiency showed that:

1) In the mean, **firms exhibit increasing returns to scale during the period of analysis.** This finding implies that these firms were increasing their operations to become scale efficient. This is an expected result in a monopoly and is compatible to Çelen (2013) and Pérez-Reyes and Tovar (2009). This means that it is possible to distribute the same amount of electricity to the same number of customers with about 3–4% fewer inputs if the technical efficiency performances of the scale-inefficient firms increase[18].

2) **Firms with the greatest efficiency in the provision of services were also the most efficient financially.** Considering that the efficiency scores in Model 1 are like Model 2, it is found that, in the mean, the CRS efficiency of these firms is high and above 0.92; furthermore, it exhibits again that the VRS score by year is higher than the technical efficiency score and above 0.95, as is displayed in the Annex section 7.1, Figure 7. In other words, the results are robust by using financial measures or provision of services measures, demonstrating that production efficiency is related to financial efficiency, which can be reassociated with lower costs. In this context, results found suggest that regardless of which outcome measure is used, on average, efficient use of inputs will lead to increased output and better performance indicators.

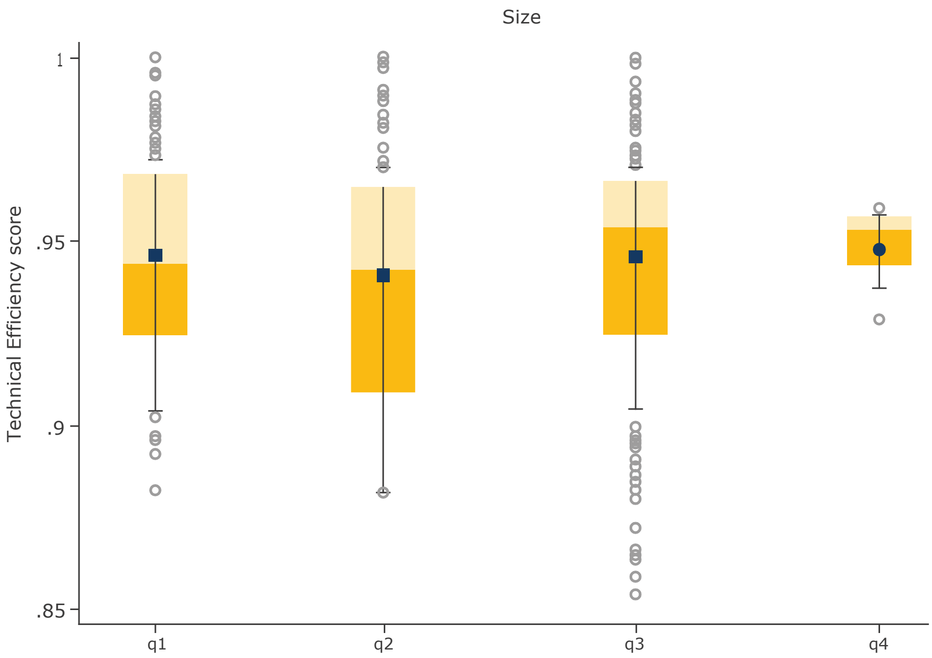
18 To brief, this study only reports meaning efficiency scores. Annual results by each firm are available from the authors upon request.

3) **Overall, this research finds that there are no significant (important) changes in efficiency in a year-by-year analysis during the investigated period the energy distribution firms in LAC[19].** Even though further investigation is recommended, the results suggest a period of certain stability in efficiency levels of the sector. Consequentially, one could argue that no substantial improvement in efficiency of energy distribution companies in the region is feasible, without an improvement in regulation and corporate governance. These two variables are important since developed countries have shown significant effects on efficiency changes in companies of the sector (see, for example, Borghi et al., 2016) which can be potentially related to higher adoption of innovation (a gap in LAC) (Gavin et al., 2020).

5.1 The efficiency of electricity distribution companies in LAC by companies' size

The following section discusses the relationship between firms' size and the efficiency of electricity distribution companies in LAC. In Figure 3 differences in efficiency by firm size are analyzed. Firm sizes are divided by quartiles (q1 – q4) of sales and the results suggest that efficiency is 2 percentage points higher between the highest quartile (q4) and the lowest quartile (q1) when model 1 is used. Nevertheless, when model 2 (Figure 12 in Annexes) is utilized, again it shows that firms in the highest quartile have higher VRS efficiency than firms in the lowest quartile even though the result using CRS efficiency is not statistically significant (see Figure 8 in Annex section 7.1). In general, the evidence could denote a challenge for small to medium-sized firms to control overall efficiency due to a lack of financial investment by third parties when compared to larger firms (Mousavi-Avval et al., 2011). Yet we recommend further studies utilizing detailed financial information.

Figure 3. Mean efficiency of electricity distribution firms by firm size.



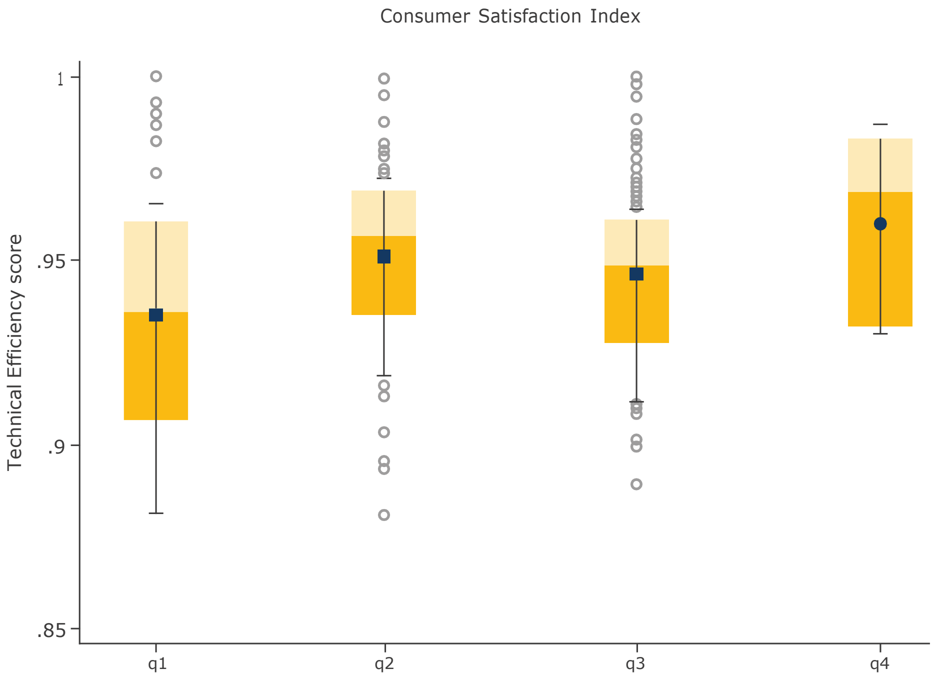
Note: The blue point separating the two small boxes represents the mean. The white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

19 In the Annexes, in subsection 7.3 the results by using the Malmquist index are presented. The evidence is very similar and the conclusion of this is robust.

5.2 The relation between the efficiency of electricity distribution companies and consumer satisfaction in LAC

The present section analyzes the differences in efficiency using a consumer satisfaction index. Figure 4 indicates the differences in CRS efficiency in model 1. The consumer satisfaction index is divided by quartiles (q1 – q4) and the results point to **a positive relationship between the consumer satisfaction index and efficiency**[20].

Figure 4. Efficiency of electricity distribution firms by consumer satisfaction index.



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

According to the graph, there are 3 percentage points higher efficiency between the highest quartile (q4) with the lowest quartile (q1)[21] which suggests that firms with a higher consumer satisfaction index operate with higher efficiency levels. In regulated monopolies, usually the question refers to how much companies should increase service quality without impacting costs and firms' economic efficiency. The outcome indicates that there is no trade-off between efficiency (technical and financial) and quality perceived by consumers.in LAC distribution companies. Firms with better consumer appraisals tend to be most economically efficient[22].

20 In the Annex section 7.1, Figure 9 shows the VRS efficiency of model 1.

21 These results are robust when using model 2, for the result details see Figure 13 in Annexes.

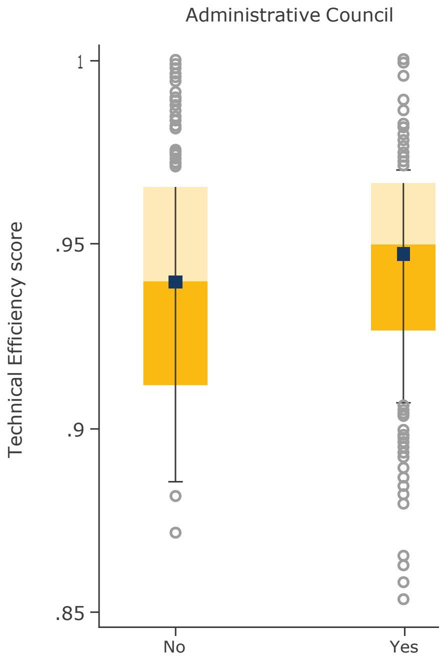
22 It is important to mention that most of the observations of this analysis are from Brazilian companies. Furthermore, we refer to economically efficient as having technical and financial efficiency. The results are presented in the Annex section.

5.3 The relation between governance and efficiency of electricity distribution companies in LAC

The following part studies the differences in efficiency among energy distribution firms in LAC with a focus on corporate governance. Lin et al. (2009) has argued that corporate boards play a critical role in limiting the power of controlling shareholders and thus protecting the interest of minority shareholders. As a result, board's independence is related positively to firm efficiency. Therefore, it is recommended a stringent set of rules to ensure that directors are committed to good corporate governance practices. So, firms with more independent boards tend to be more efficient (Su & He, 2012). Following, we analyze how corporate governance is related to efficiency, more precisely, s the relationship between companies and an administrative council or board of directors.

The administrative council or board of directors is the highest administration body responsible for organizing, controlling, and evaluating companies' activities. Its attributions often include the establishment or approval of policies, master plans, annual and/or multi-annual work programmers, etc. Figure 5 compares the mean efficiency of electricity distribution between firms that have administrative councils and those that do not.

Figure 5. Efficiency of electricity distribution firms by administrative council.



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies' considered outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 5 analyzes the topic from the perspective of model 1, in which the output is final services[23]. Also presents the difference in the mean of electricity distribution regarding companies' efficiency between corporations with a mechanism of governance (yes) and those without (no). The firms with an administrative council have shown have higher efficiency mean[24].

23 In addition, in Annex section 7.1 in Figure 10 the results of using the VRS approach are presented. Moreover, the results of model 2, financial measures output, corroborating the results can be found in the annexes (see Figure 14).

24 The relation between corporate governance and efficiency is positive in both considering technical efficiency and

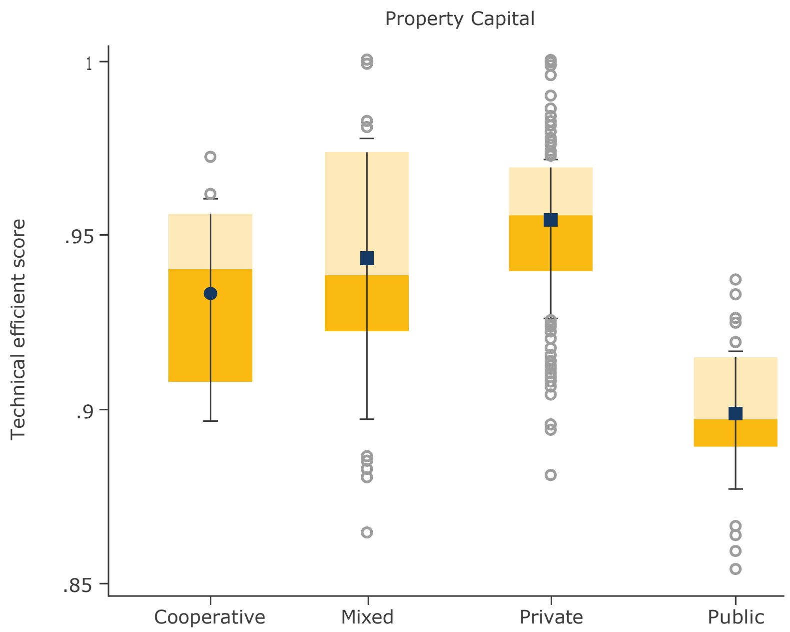
Altogether, the analysis of the relationship between governance and efficiency is aligned with the literature; **there is a positive relationship between corporate governance and efficiency levels across firms.**

5.4 The relation between governance and electricity distribution companies' ownership in LAC

This next section analyzes differences in efficiency between firms according to ownership. For such task, we classify the type of ownership into four categories (dummies): public, private, mixed, and cooperative. Last two categories have private participation. The empirical evidence points to public firms being less efficient than firms with private capital (see, for example, Zelenyuk & Zheka, 2006; Cullmann & von Hirschhausen, 2008).

Figure 6 presents the differences in the efficiency of electricity distribution firms by type of ownership (using model 1). The results are in concordance with the empirical evidence, in which private companies' efficiency is firstly rated, followed by mixed, cooperatives and public companies[25].

Figure 6. Efficiency of electricity distribution firms by type of ownership.



Note: The blue point separating the two small boxes represents the mean, and the white line separating the two small boxes represents the median, and the box represents the dispersion. The dot points are the companies' considered outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Private participation in the ownership tends to mean higher levels of economic efficiency when considering total billed electricity, the number of customers, total sales, and net profit. Further exploration is recommended though.

variable returns to scale efficiency. The results are also robust when using model 2, for more detail in model 2, see Annexes. When testing other variables of governance, such as auditing, the results suggest the more mechanisms of corporate governance the firm has, the higher its level of efficiency when model 1 is used. However, when model 2 (Figure 14 in Annexes) is utilized, no statistical difference between the three categories is found. This difference should be further explored yet it can be a result of the restricted companies's database regarding the three different mechanisms.

25 Furthermore, Annex section 7.1, Figure 11, presents the mean VRS efficiency of electricity distribution by type of ownership.. And the results of model 2, Figure 15, are also shown in the Annexes.

Conjecturing from the corporate governance results of the figures above: companies with better corporate governance practices tend to be more efficient. The reasons can be: (a) private companies tend to have better levels of control and corporate governance, which allows them to be more efficient; (b) private companies are more concerned with achieving profitability, so the supervision of production objectives, profit maximization, and cost minimization is prioritized; (c) the above leads to worry about the quality of the service, for more discussion about the relation of ownership and services quality in LAC (see, Bonzi et al., 2021)

5.5 Robustness checks

To display s the robustness of these findings, we present in the Annexes, subsection 7.4, the results by using a restricted sample of firms found in the years of analysis. Overall, we identified similar results using a restricted and unrestricted sample which, overall, validates the specification used in the baseline results and shows that the efficiency score obtained is robust to changes in the number of observations and firms.

In the Annexes, subsection 7.5, the paper delineates the findings achieved by -using an econometric approach to capture the relationship between the different observable characteristics of the energy distribution firms in LAC and the level of efficiency. wo different Tobit models were estimated equation (7). the results received reinforced the assumption that there are important firm characteristics that drive efficiency. Failure to consider these contextual variables could lead to inaccurate conclusions.

6 CONCLUSION

6. CONCLUSION

The distribution companies are key in the electricity services provision and have an important role in guaranteeing the quality of services, affordability, innovation, and in some cases, universal access. The technological changes associated with energy transition require a modernization of the distribution companies, their regulation, and their business models. This study gives an overview of the distribution companies' efficiency in LAC focusing on four aspects: size, consumer perception, governance, and ownership. With this objective, 80 electricity distribution firms are analyzed from 2014 to 2020. The analyzed dataset contains information on corporations from Argentina, Bolivia, Brazil, Chile, Colombia, El Salvador, Jamaica, Peru, and Uruguay.

One of the main results is the **lack of improvement in efficiency among the distribution companies year after year, during the period of analysis.** This needs to be further explored; however, it should raise a red flag about the need to incentivize distribution companies towards improving their performance, especially in times of innovation, digitalization, and decentralization.

As expected, the analysis shows evidence that distribution **firms exhibit increasing returns to scale during the same period.** Yet, it is recommended to dig deeper and inquire if it is possible to better design the concessions to improve the efficiency of distribution companies. Moreover, it is also crucial to ask about the necessary protection and support for small distribution companies, and finally what role can size play in the adoption of new technologies and investments in an energy transition scenario.

Additionally, **we found a correlation between firms with the greatest efficiency (both in the provision and financially) and consumer satisfaction.** Even if the causal relationship was not analyzed, the sectorial intuition suggests that it is fair to interpret the results as the actual impact of distribution companies on the services, as perceived by the clients. Improving efficiency is not just about improving affordability but also about more satisfied consumers.

Concerning governance and ownership, it is key to underline the **positive relationship between the mechanisms of corporate governance across firms and the relative efficiency levels of these firms. Also, private participation in the ownership tends to mean higher levels of economic efficiency when considering total billed electricity, the number of customers, total sales, and net profit.** At the center, the relationship between corporate governance and ownership of distribution companies in LAC is highlighted. Exists also a tendency of improving corporate governance when there is private ownership involved, especially among the firms with available public information. Yet, further studies are recommended for a better understanding on how ownership and corporate governance can influence efficiency performance.

Before inquiring about the future of utilities in LAC, one should ask, a priori, which utilities are we talking about. A lot is discussed on how innovation can transform and improve electricity services, and for this, the role of utilities is central. The distribution companies' analysis shows a high heterogeneous sector that requires momentum and further action to improve efficiency. As a controlled and legalized monopoly, regulation is a key element to incentivize and remunerate the adoption of new technologies and the potential gains in efficiency.

7 REFERENCES

7. REFERENCES

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8 ANNEXES

8. ANNEXES

8.1 Definition of the variables usedin this study

Table 3. Definition of the variables used in this study

Variable	Definition
Total Billed Electricity*	Amount of energy billed to all customers for a given year
Number of costumers*	Consumption units or customers connected to the distribution network
Total sales*	Sum of total revenues from sales and services
Net profit*	Sales and administrative expenses tax on profit
Total assets*	Sum of current assets and non-current assets
Number of employees*	Total number of workers, considering permanent and subcontracted workers
Consumer satisfaction index	Percentage of customers satisfied with the service
Internal audit	Existence of confirmed internal audit (tracking organization's operations)
Administrative council	Existence of confirmed administrative council (boardroom)
Independent audit	Existence of confirmed independent audit (examination of the financial records, accounts, business transactions, accounting practices, and internal controls)

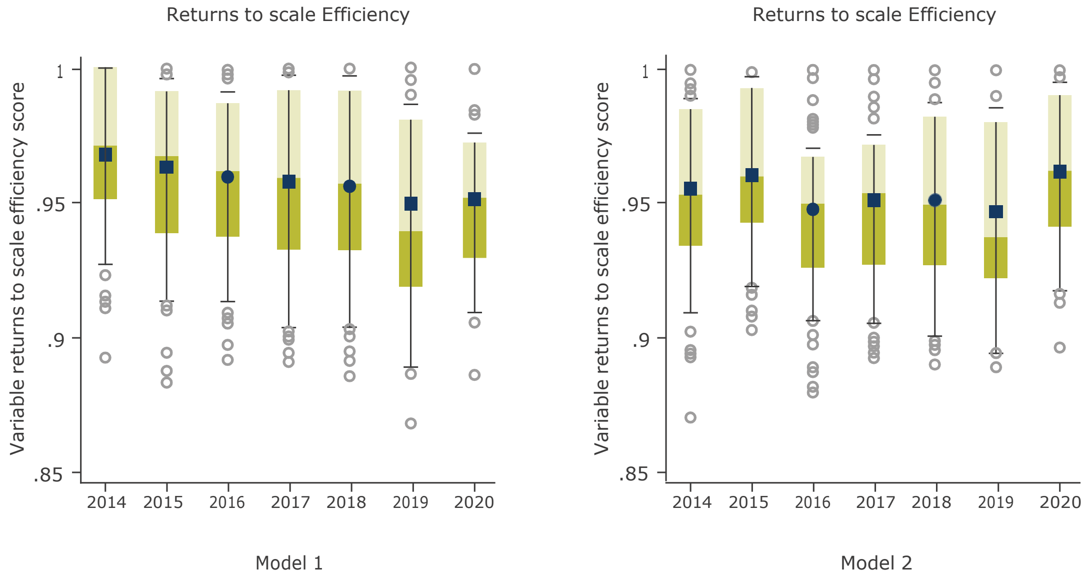
Source: Authors

8.2 Robustness check: Mean efficiency of electricity distribution firms by using the variable returns to scale technical efficiency (VRS) approach

This Annex presents a robustness check of the main results obtained in section 5. Specifically, the mean variable returns to scale (VRS) efficiency scores are obtained by using the DEA methodology and are presented in Figures 7 to 11.

Figure 7 shows the mean VRS efficiency score of electricity distribution firms by year and by models 1 and 2. The results obtained are similar that those obtained in the main results (section 5): there is no significant improvement in efficiency compared year after year during the period of analysis.

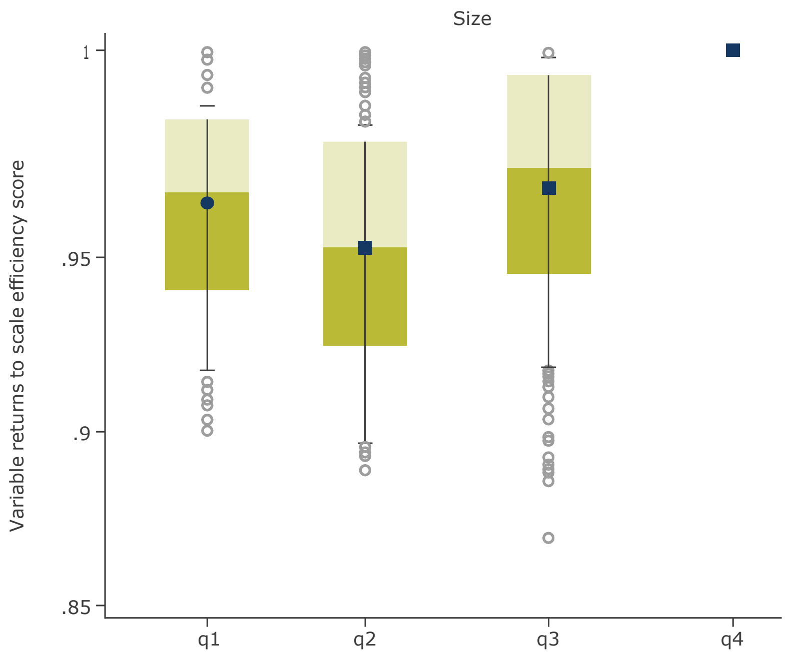
Figure 7. VRS efficiency of electricity distribution firms by year: final services output (model 1) and financial measures (model 2).



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Furthermore, Figure 8 presents the mean VRS efficiency of electricity distribution firms by firm size- by using model 1. Again, the results are very similar to those obtained in section 5: firms in the highest quartile have higher VRS efficiency than firms in the lowest quartile[26].

Figure 8. VRS efficiency of electricity distribution firms by firm size: final services output (model1).

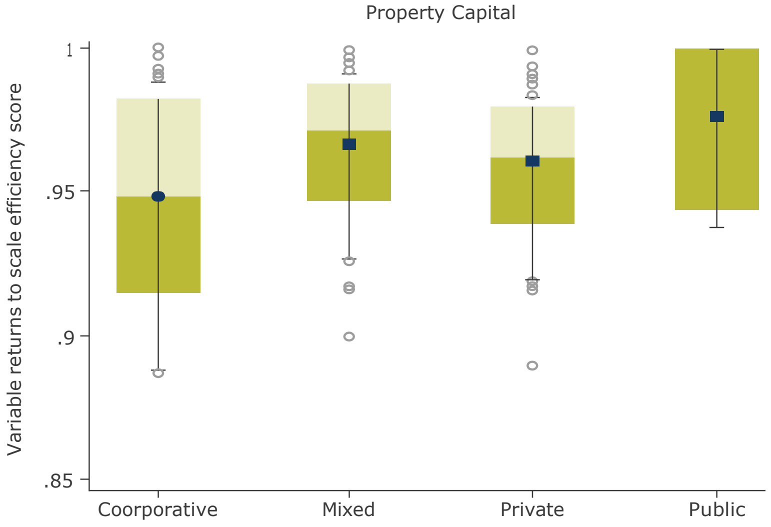


Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

26 Note that when the VRS efficiency score is used, quartile 4 has few observations because large firms might not have variable returns to scale. This is an important characteristic in this sector.

In addition, Figure 9 shows the mean VRS efficiency of electricity distribution firms by consumer satisfaction index by using model 1. This evidence is similar with the main results: there is a positive relationship between the consumer satisfaction index and efficiency[27].

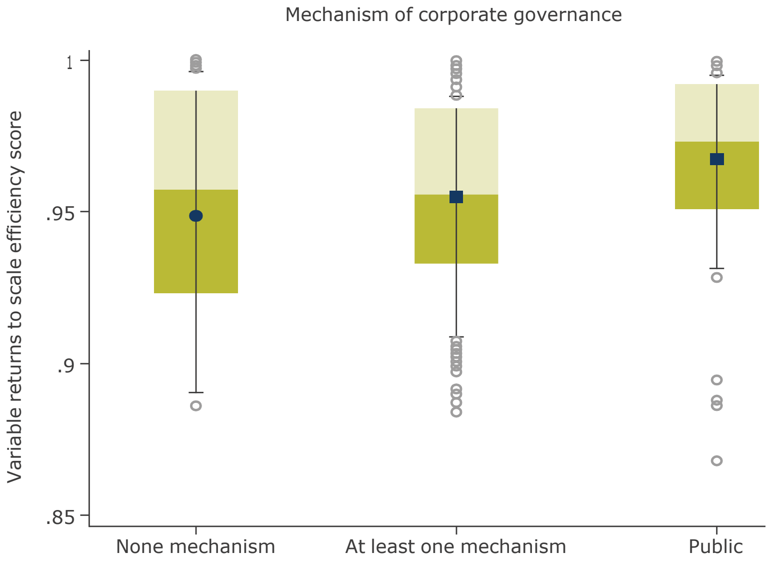
Figure 9. VRS efficiency of electricity distribution firms by consumer satisfaction index: final services output (model 1).



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Moreover, Figure 10 presents the mean VRS efficiency of electricity distribution firms by the three mechanisms of corporate governance by using model 1. The results show that there is a positive relationship between the levels of corporate governance across firms and the relative efficiency levels of these firms.

Figure 10. VRS efficiency of electricity distribution firms by the three mechanisms of corporate governance: final services output (model 1).

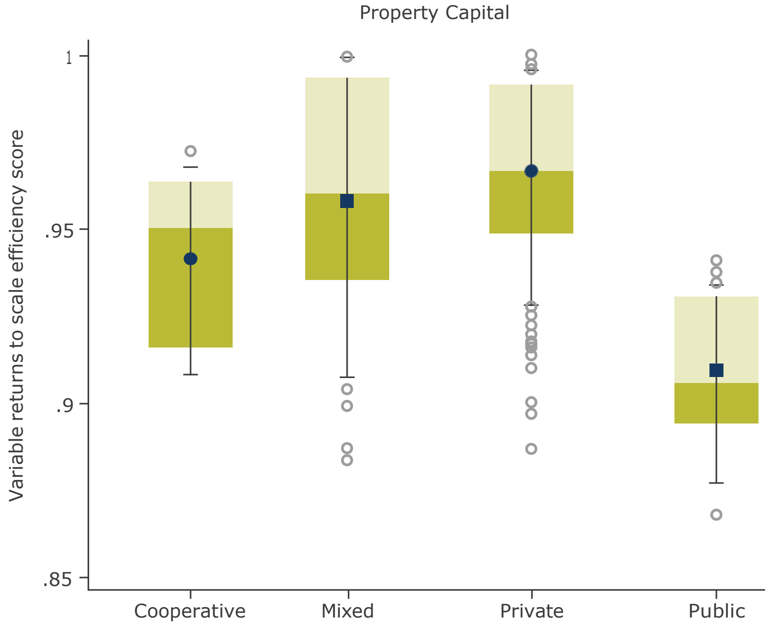


Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

27 In quartile 4 there is only one company; however, it has been decided to keep it in the analysis because eliminating it could bias the results downwards. On the contrary, keeping it does not bias the results upward, since being only one and not so distant from the others does not significantly affect the evidence obtained.

Finally, Figure 11 shows the Mean VRS efficiency of electricity distribution firms by type of ownership by using model 1. Again, this evidence are in concordance with the results by using CRS approach: private participation in the ownership tends to mean higher levels of economic efficiency.

Figure 11. VRS efficiency of electricity distribution firms by type of ownership: final services output (model 1).



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies' considered outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

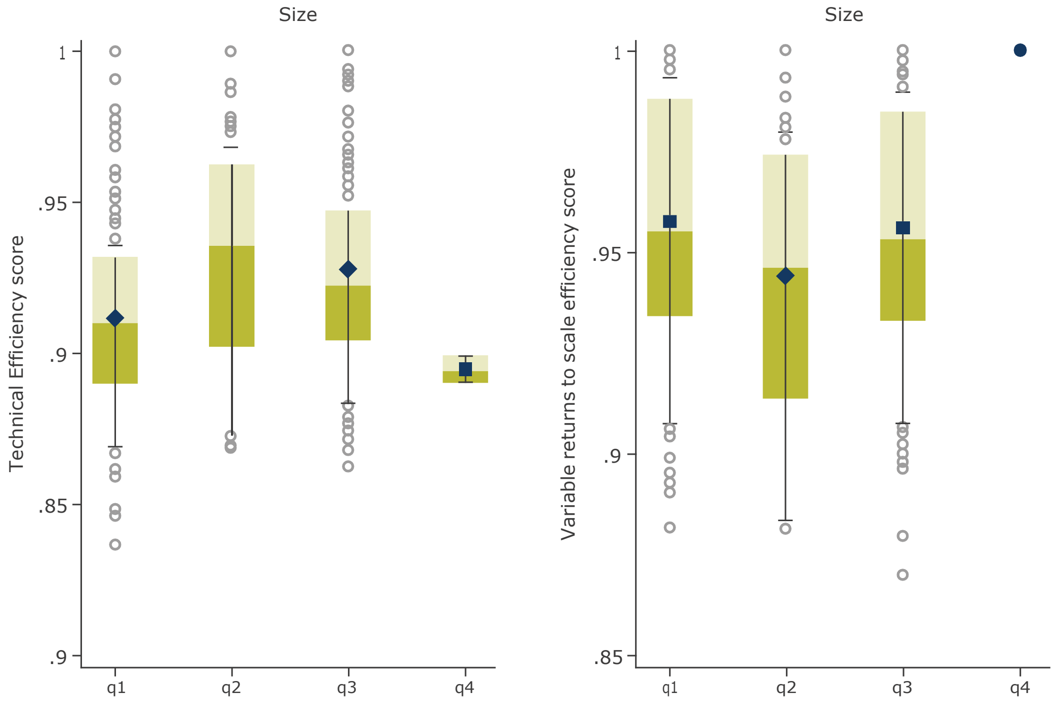
Overall, the results obtained in this section are like those obtained in Section 5. In this sense, this paper shows that using CRS or VRS efficiency scores leads to similar conclusions.

8.3 Robustness check: Mean efficiency of electricity distribution firms by using financial measures output (model 2)

This section presents the robustness of the results obtained in section 5 by using the financial measures as output (model 2). Overall, the results are similar to the output of the final service (model 1). This shows that firms with the greatest efficiency in the provision of services are also the most efficient financially[28].

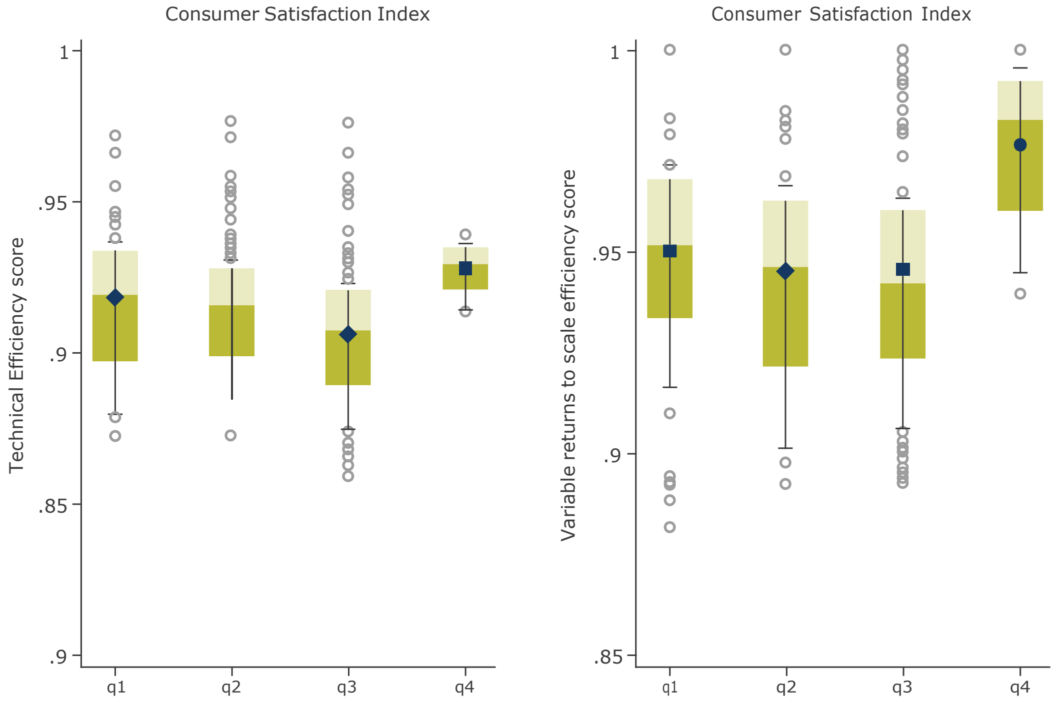
28 In quartile 4 there is only one company; however, it has been decided to keep it in the analysis because eliminating it could bias the results downwards. On the contrary, keeping it does not bias the results upwards, since being only one and not so distant from the others does not significantly affect the evidence obtained.

Figure 12. Efficiency of electricity distribution firms by firm size: financial measures output (model 2).



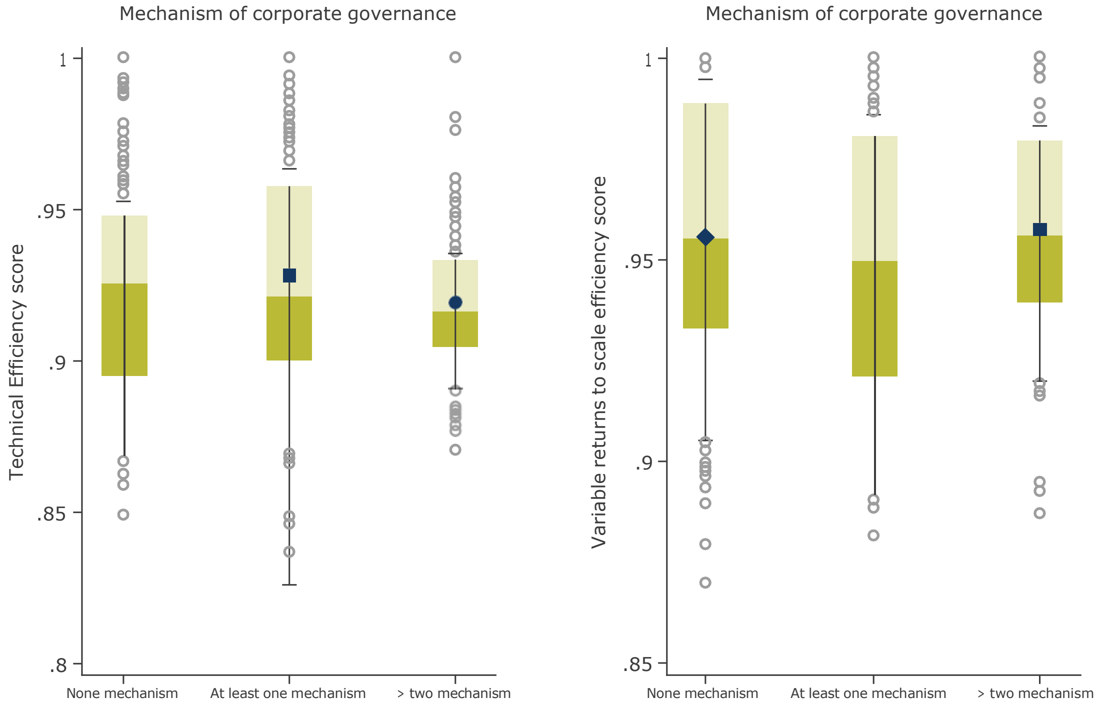
Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 13. Efficiency of electricity distribution firms by consumer satisfaction index: financial measures output (model 2).



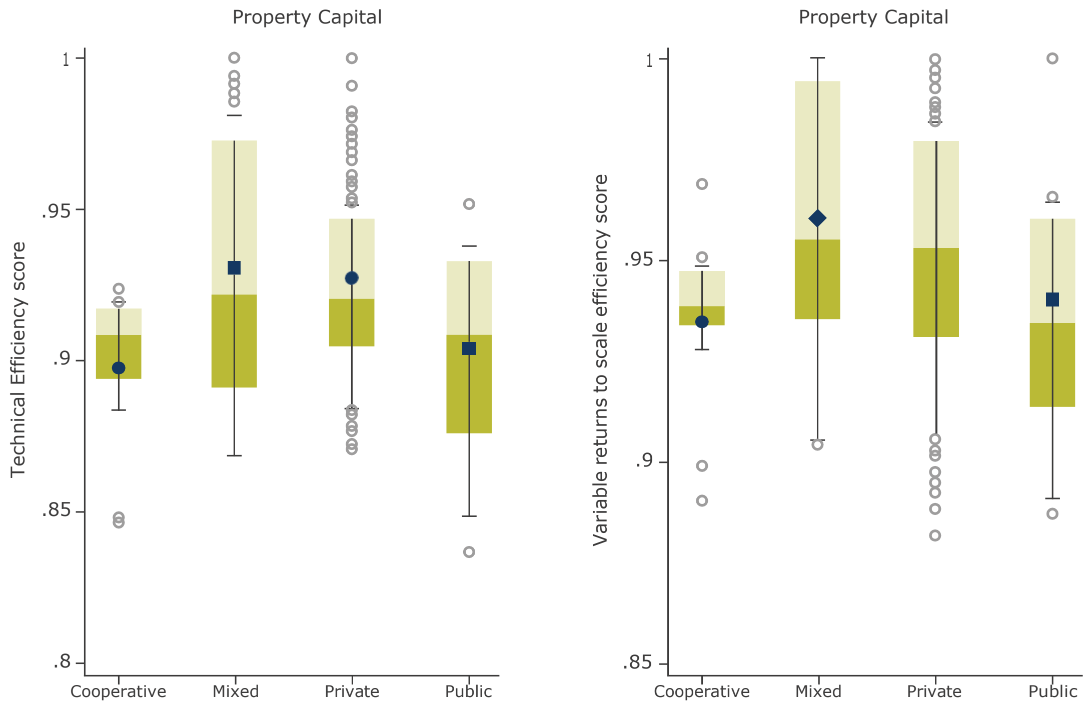
Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 14. Efficiency of electricity distribution firms by the three mechanisms of corporate governance: financial measures output (model 2).



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 15. Efficiency of electricity distribution firms type of ownership: financial measures output (model 2).



Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

8.4 Robustness check: Malmquist index results

The Malmquist index (MI) has the advantage of not requiring input prices or behavioral assumptions. These two characteristics make the MI very suitable for analyzing productivity changes in both public and regulated sectors (Pérez-Reyes & Tovar, 2009). Moreover, the change in productivity measured with the MI can be broken down into the catching-up effect, i.e., the efficacy with which technological knowledge is applied to production, and the frontier shift due to the available technology improvement (Nishimizu & Page, 1982). Finally, the MI can also be used to separate the catching-up effect into technical efficiency and scale efficiency, and this gives a sense of the extent to which the efficiency gains are achieved purely from changes in input mix or better adjustment of the size to the demand (Pérez-Reyes & Tovar, 2009).

To reorder the ideas, the MI can be expressed in terms of distance function (E) as Equation (1) and Equation (2) using the observations at time t and t+1 (Lee et al., 2011):

$$MI_I^t = \frac{E_I^t(x^{t+1}, y^{t+1})}{E_I^t(x^t, y^t)} \qquad (1)$$

$$MI_I^{t+1} = \frac{E_I^{t+1}(x^{t+1}, y^{t+1})}{E_I^{t+1}(x^t, y^t)} \qquad (2)$$

where I denotes the orientation of MI model. In addition, the geometric mean of two MI in Equation (1) and Equation (2) gives the Equation (3):

$$MI_I^G = (MI_I^t MI_I^{t+1})^{\frac{1}{2}} = \left[\left(\frac{E_I^t(x^{t+1}, y^{t+1})}{E_I^t(x^t, y^t)}\right) * \left(\frac{E_I^{t+1}(x^{t+1}, y^{t+1})}{E_I^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \qquad (3)$$

The input oriented geometric mean of MI can be decomposed using the concept of input oriented technical change (TECHCH) and input-oriented efficiency change (EFFCH) as given in Equation (4):

$$\begin{aligned} MI_I^G &= (EFFCH_I) * (TECHCH_I^G) \\ &= \left(\frac{E_I^t(x^{t+1}, y^{t+1})}{E_I^t(x^t, y^t)}\right) * \left[\left(\frac{E_I^t(x^t, y^t)}{E_I^{t+1}(x^t, y^t)}\right) * \left(\frac{E_I^t(x^{t+1}, y^{t+1})}{E_I^{t+1}(x^{t+1}, y^{t+1})}\right)\right]^{\frac{1}{2}} \end{aligned} \qquad (4)$$

The first and second terms represent the efficiency change and the technology change respectively. Lee et al. (2011) argue that the MI given by Equation (3) and Equation (4) can be defined using DEA like distance function; in other words, the components of MI can be derived from the estimation of distance functions defined on frontier technology. Färe et al. (1994), provided the formal derivation of MI and it is the most popular method among the various methods that have been developed to estimate a production technology. The authors, by utilizing both CRS and VRS DEA frontiers to estimate the distance functions in Equation (4), the technical efficiency can be decomposed into scale efficiency and pure technical efficiency components. A scale efficiency change (SECH) is given in (5):

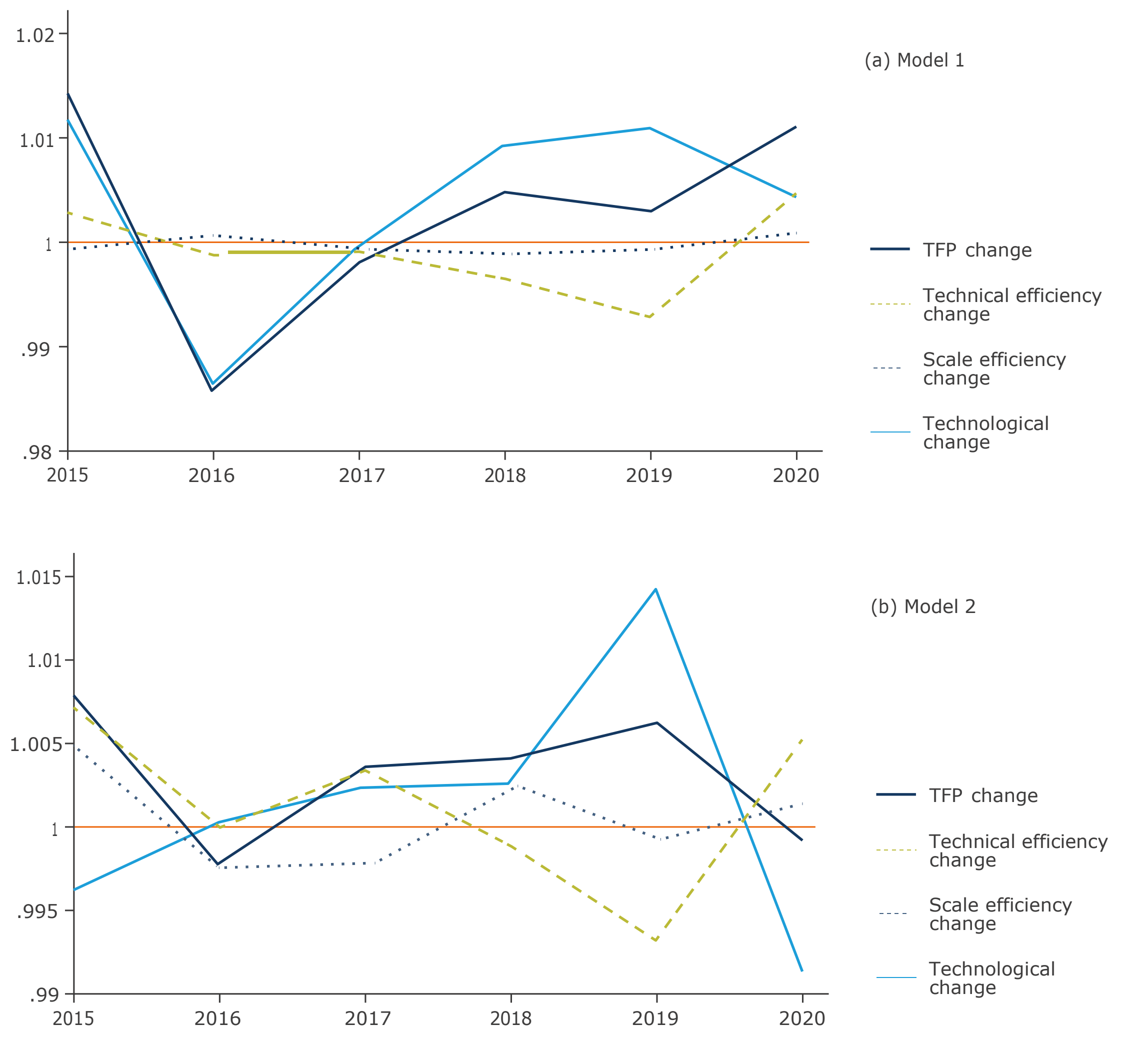
$$SECH = \left[\frac{\frac{E_{vrs}^{t+1}(x^{t+1}, y^{t+1})}{E_{crs}^{t+1}(x^{t+1}, y^{t+1})}}{\frac{E_{vrs}^{t+1}(x^t, y^t)}{E_{crs}^{t+1}(x^t, y^t)}} * \frac{\frac{E_{vrs}^{t}(x^{t+1}, y^{t+1})}{E_{crs}^{t}(x^{t+1}, y^{t+1})}}{\frac{E_{vrs}^{t}(x^t, y^t)}{E_{crs}^{t}(x^t, y^t)}}\right]^{\frac{1}{2}} \qquad (5)$$

This distinction enables us to contemplate those situations where a productive unit can be technically efficient, as the production volume uses the least quantity of factors. Finally, a pure efficiency change (PECH) is given in (6):

$$PECH = \frac{E_{vrs}^{t+1}(x^{t+1}, y^{t+1})}{E_{crs}^{t+1}(x^{t}, y^{t})} \qquad (6)$$

Figure 15 shows the Malmquist index (MI) summary of annual means changes for each year of analysis. The evidence shows that the scale efficiency and technical efficiency did not change significantly through the period of analysis which is similar to the previous conclusion. The electricity distribution market exhibited a 0.65% TFP increase per year over the period 2014-2020. On average, the change in the TFP was determined by technological development (0.90%) rather than a slight efficiency decrease (0.05%). Finally, Figure 15 panel (a) shows the results of model 1, which is similar to model 2 (panel b). More specifically, the TFP increased by around 0.2% per year over the period of analysis[29]. Again, these results are in concordance with Çelen (2013) and Pérez-Reyes and Tovar (2009) who found that the main source of TFP change has been a technological change, which is a particular situation in this sector.

Figure 16. Malmquist index summary of annual means.



29 To brief, we only report mean efficiency changes. Annual changes by each firm are available from the authors upon request.

8.5 Robustness check: Restricted sample

We present similar results of subsection 5.1. To get robust evidence of our unrestricted sample, we now use a restricted sample, balanced panel data, with 40 electricity distribution firms over the period from 2014 to 2020. The idea behind this exercise is to demonstrate that even when we use firms that exit/enter the sample the results are similar when we use firms that are in all the years of analysis. This exercise helps to validate the results obtained in the previous subsection since our evidence would be robust to using a smaller or larger sample.

Figure 9 shows similar results obtained in the previous subsection. According to the CRS scores, we find that, in the mean, the efficiency of these firms is high and upper than 0.94; furthermore, we show that the mean variable returns to scale efficiency score by year is higher than the technical efficiency score and upper than 0.95 in model 1 and 2. Again, this result shows that, in the mean, firms exhibit increasing returns to scale during our period of analysis. These results using a restricted sample reveal that our specification is robust to changes in the sample and that our main findings do not change. They also show that efficiency in this sector is high but that there is room for improvement.

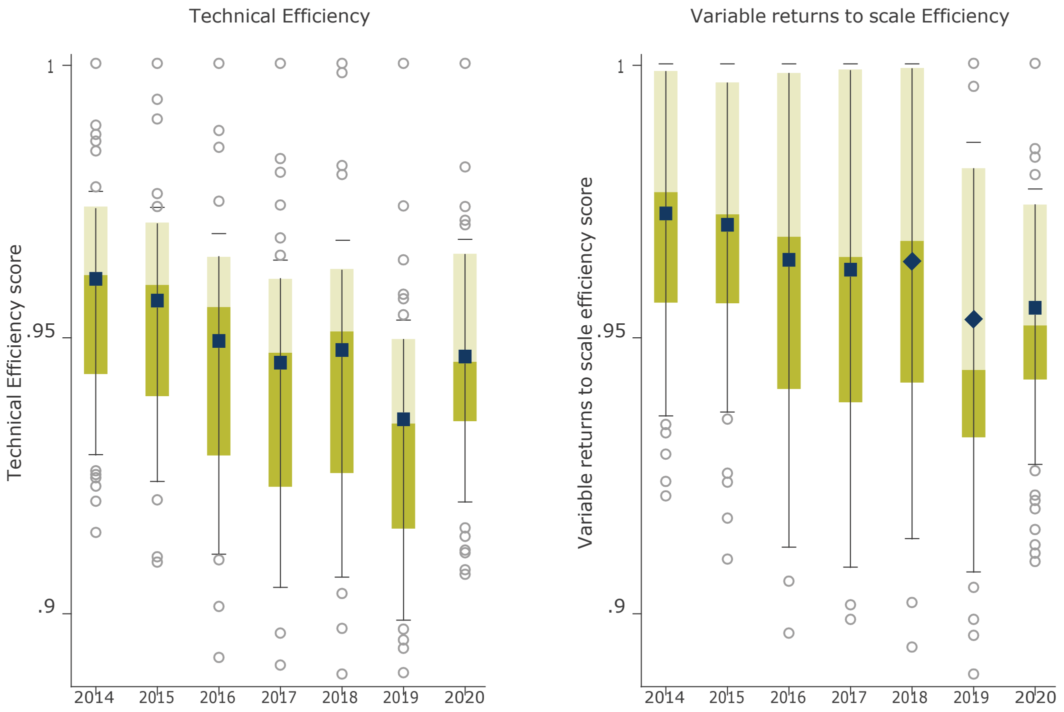
In addition, Figure 10 shows differences in efficiency by consumer satisfaction index. Again, our results suggest that firms with a higher consumer satisfaction index have higher efficiency. Moreover, Figure 11 presents differences in efficiency by firm size. Our evidence suggests that large firms have higher efficiency than their counterparts. Furthermore, Figures 12 to 14 suggest that there is a positive relationship between the levels of corporate governance across firms and the relative efficiency levels of these firms. According to the capital property (ownership), Figure 15 shows that public firms are less efficient than private firms and also with firms that have some private capital property.

Finally, Figure 16 shows the Malmquist index (MI) summary of annual means changes for each year of analysis. Again, we evidence that total factor productivity (TFP) and technological efficiency did change significantly. The electricity distribution market exhibited a 0.52% TFP increase per year over the period 2014-2020. On average, the change in the TFP was determined by technological development (1%)[30].

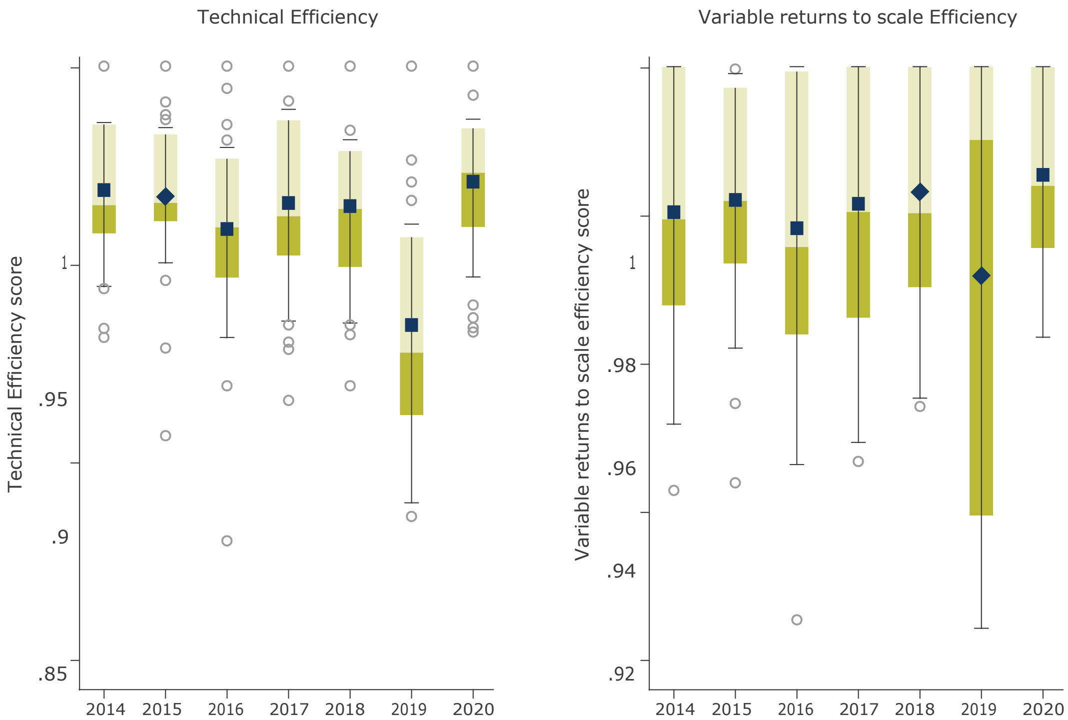
Overall, we find similar results using a restricted and unrestricted sample, this demonstrates the validity of our specification and that the efficiency score obtained is robust to changes in the number of observations and firms.

30 To brief, we only report mean efficiency changes. Annual changes by each firm are available from the authors upon request.

Figure 17. Efficiency of electricity distribution firms by year (Restricted sample).



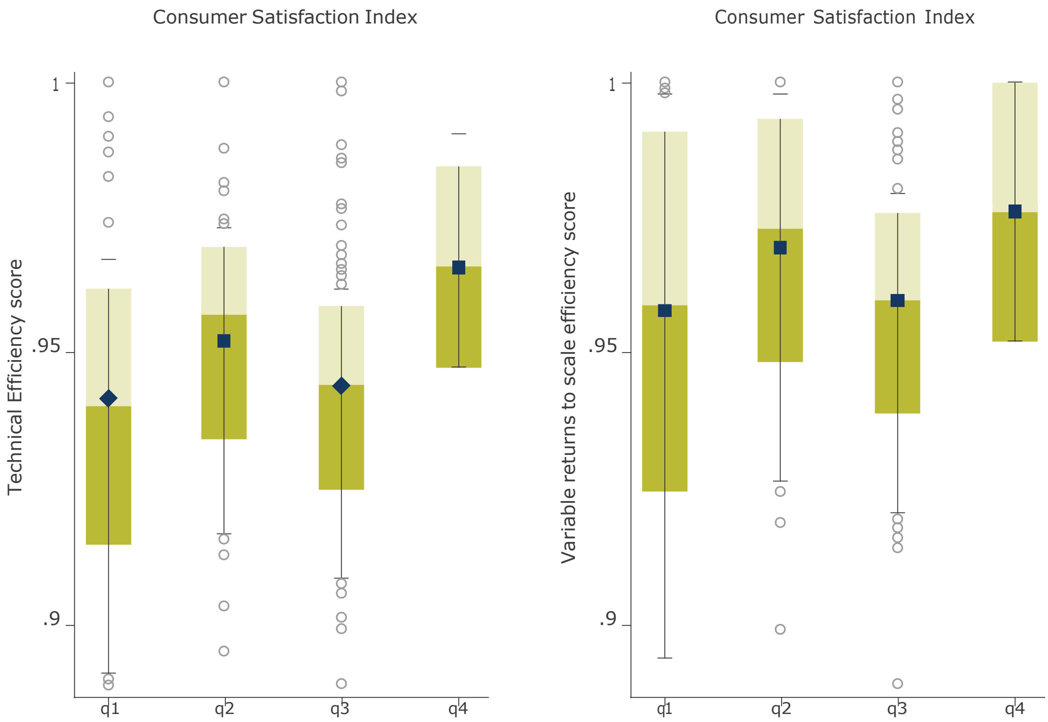
(a) Model 1



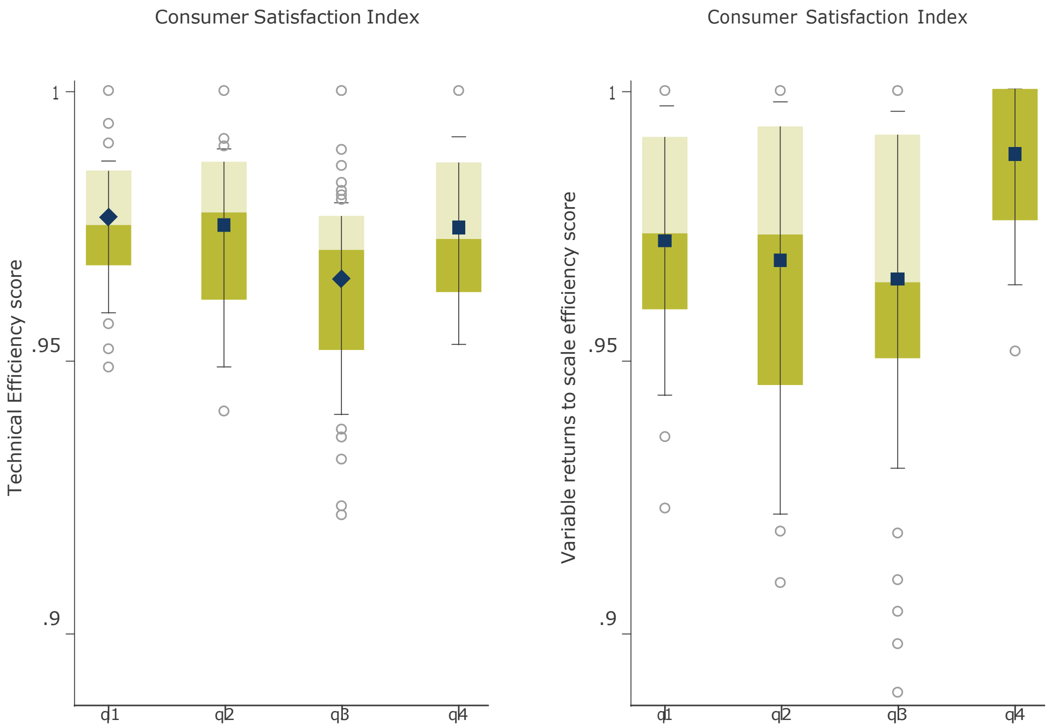
(b) Model 2

Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 18. Mean efficiency of electricity distribution firms by consumer satisfaction index (Restricted sample).



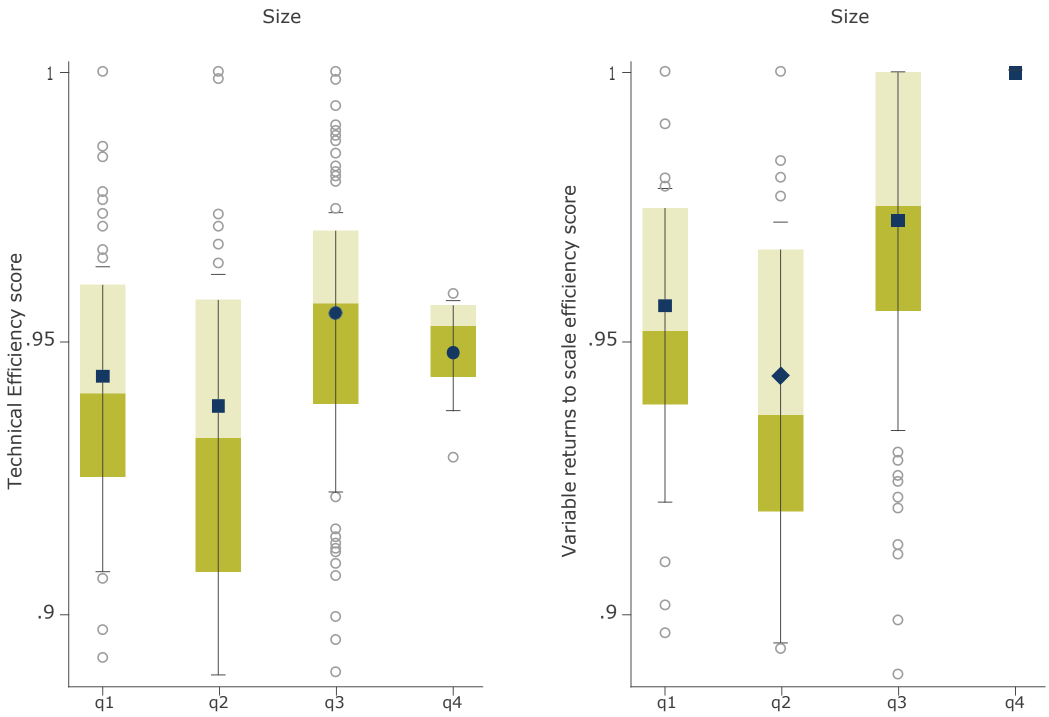
(a) Model 1



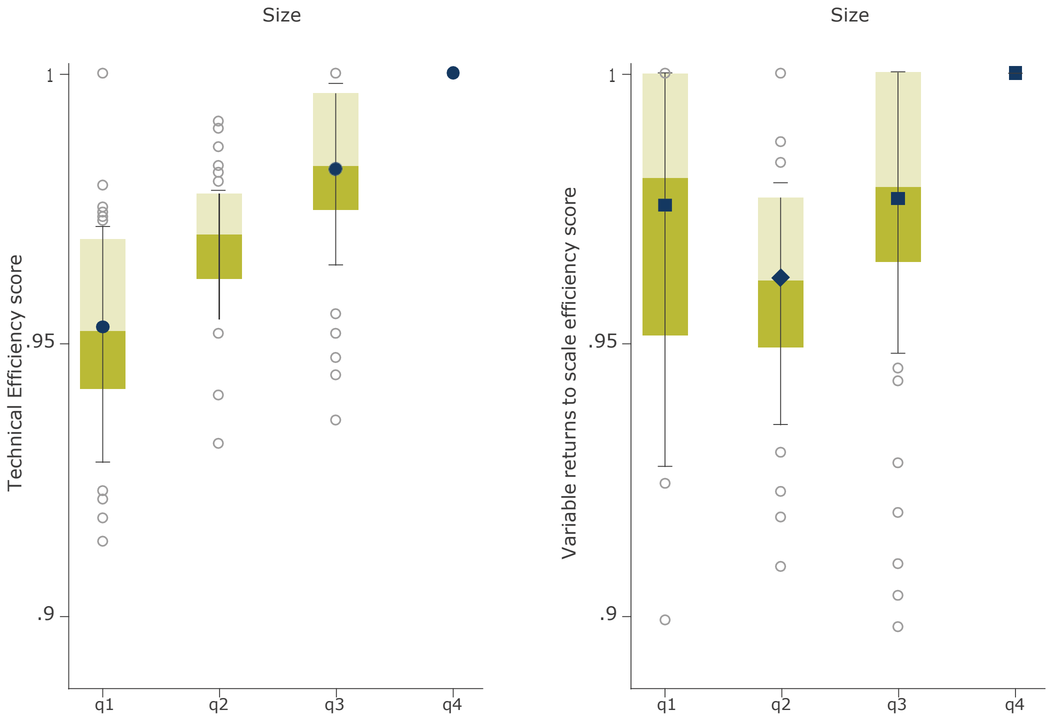
(b) Model 2

Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 19. Efficiency of electricity distribution firms by firm size (Restricted sample).



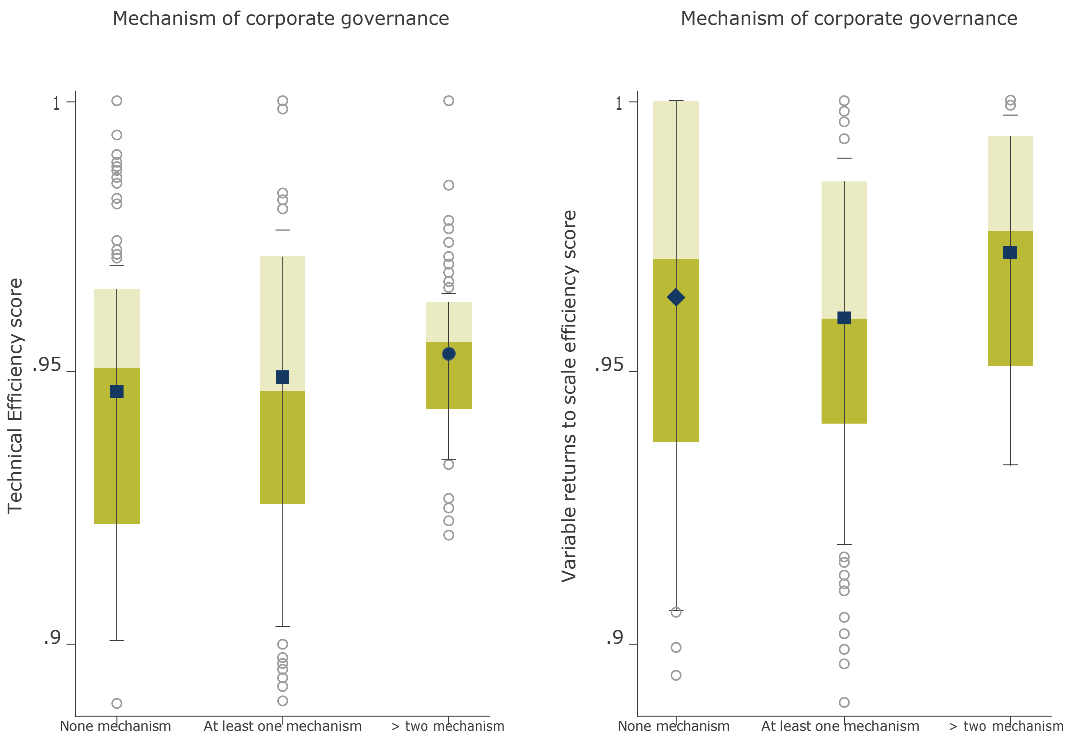
(a) Model 1



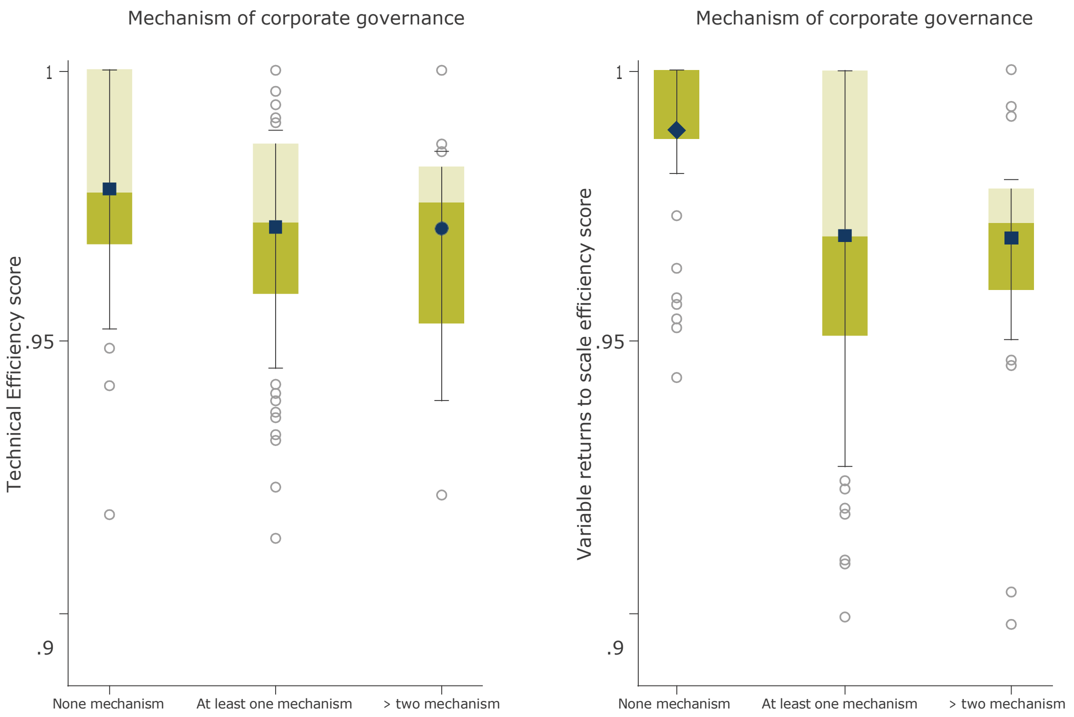
(b) Model 2

Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 20. Efficiency of electricity distribution firms by the three mechanisms of corporate governance (Restricted sample).



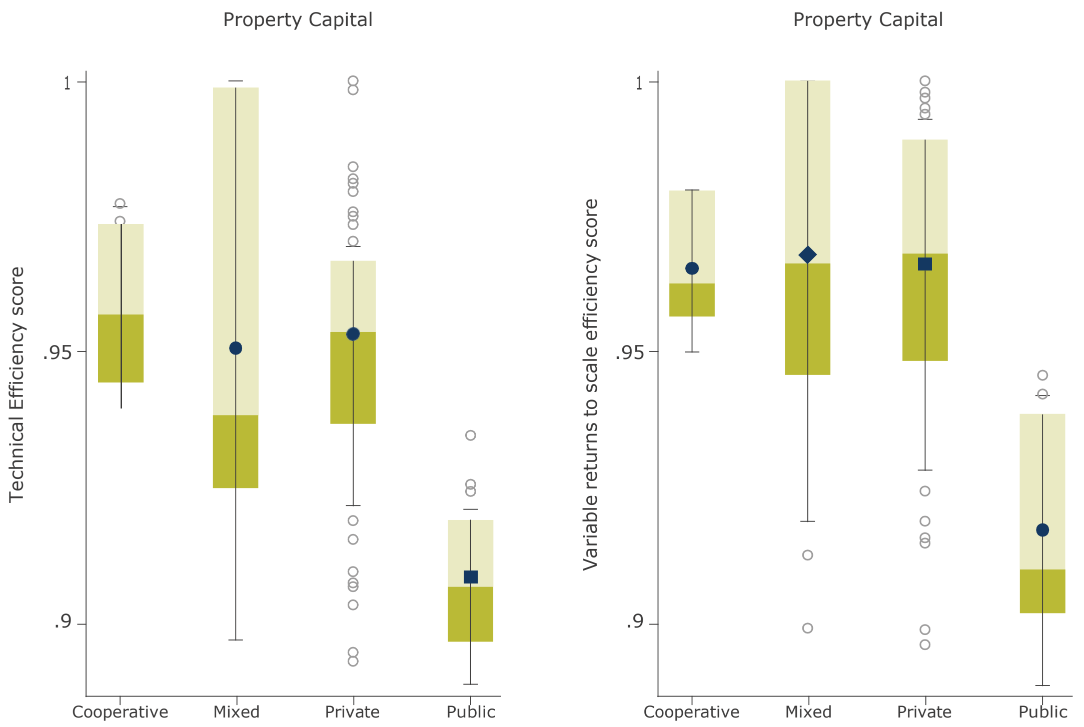
(a) Model 1



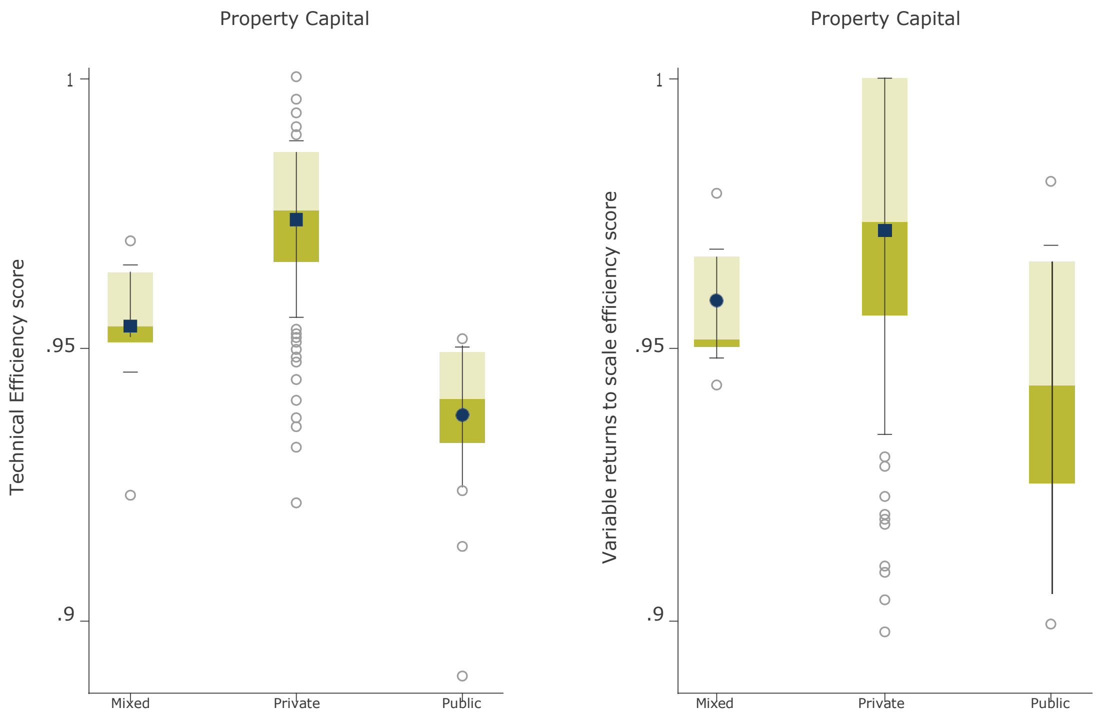
(b) Model 2

Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 21. Mean efficiency of electricity distribution firms by type of ownership (Restricted sample).



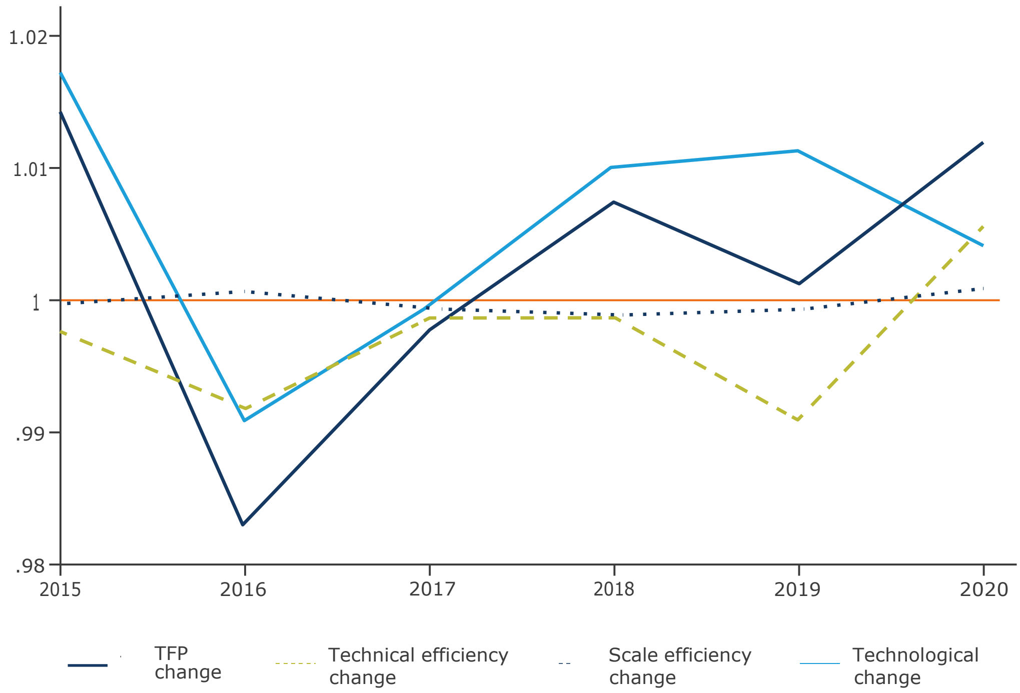
(a) Model 1



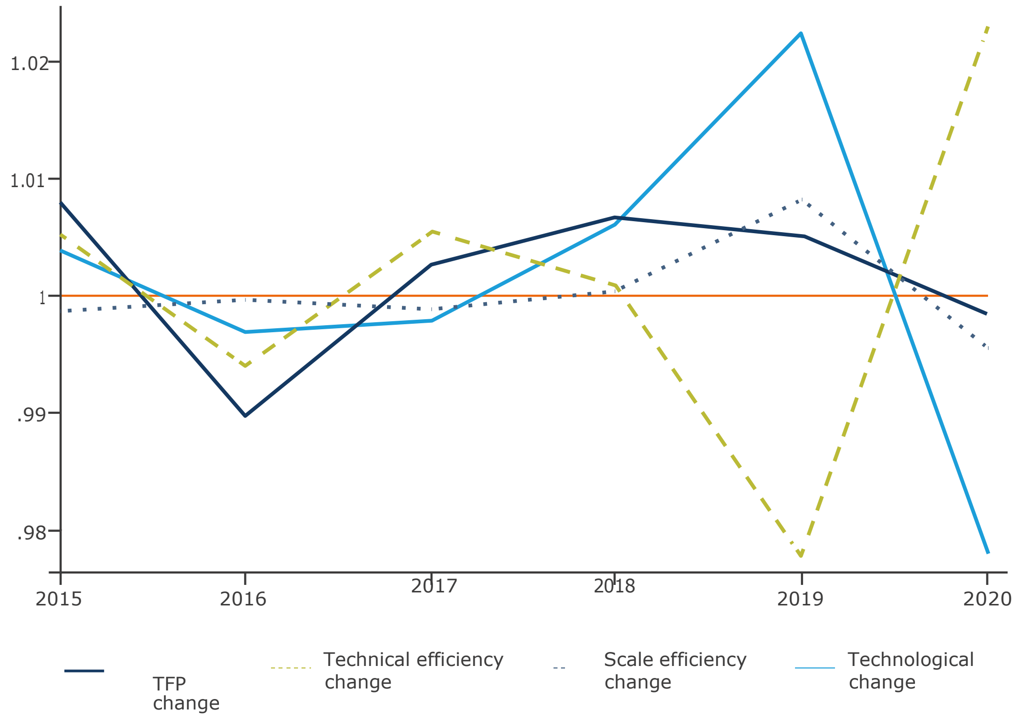
(b) Model 2

Note: The blue point separating the two small boxes represents the mean, the white line separating the two small boxes represents the median and the box represents the dispersion. The dot points are the companies considered as outliers of the distribution. The whiskers of the box represent the confidence interval of the sample.

Figure 22. Malmquist index summary of annual means (Restricted sample).



(a) Model1



(b) Model 2

8.6 Drivers of efficiency: Tobit approach

Once the efficiency scores of the energy distribution firms in LAC are calculated by using the DEA approach, we might study the relationship between efficiency and several firm characteristics by using an econometric approach. In this sense, we estimate two different Tobit models by using equation (7).

Table 4 shows the results of our Tobit models by using the CRS efficiency score (1) and the variable returns to scale (VRS) efficiency score (2) as dependent variables. We use four covariates (firm characteristics) that might affect efficiency: consumer satisfaction index, firm size, a dummy for having a council, and a dummy for ownership. We also include year and country fixed effects tocontrol for possible macroeconomic shocks[31].

We find evidence that suggests that an increase in the consumer satisfaction index is positively related to efficiency. Moreover, the larger the company, the better levels of efficiency it will have. Also, there is a positive relationship between corporate governance across firms and the relative efficiency levels of these firms. Finally, private firms are more efficient than public firms.

Overall, our results confirm in several ways that there are important firm characteristics that drive efficiency. Failure to consider these contextual variables could lead to inaccurate conclusions. In particular, the effect of having corporate governance and having high levels of customer satisfaction occurs more in private firms. This would help improve the quality of the energy supply more efficiently and therefore reduce energy waste and uncollectible portfolio that is often assumed by the state, among others.

Table 4. Tobit model results

Variable	(1) Technical efficiency	(2) VRS Efficiency
Consumer satisfaction index	0.009*** (0.002)	0.012*** (0.003)
Size	0.006*** (0.002)	0.010*** (0.002)
Dummy for council	0.013*** (0.004)	0.009* (0.005)
Dummy for ownership	0.028*** (0.007)	0.031*** (0.011)
Constant	0.893*** (0.013)	1.047*** (0.017)
Uncensored observations	240	205
Censored observations	5	40
Log-likelihood	553.9	399.1
Observations	245	245

Notes: We include year and country fixed effects. Robust standard errors in parentheses.
* p<0.10, ** p<0.05, *** p<0.01.

31 We also do this exercise by using the restricted sample. Results of this exercise are available upon request.

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