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Measuring efficiency and productivity change (PTF) in the Peruvian electricity distribution companies after reforms ☆

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ABSTRACT

This paper analyzes the evolution of productivity of the electricity distribution companies in Peru, to assess whether reforms have improved the efficiency in this sector. The paper also identifies potential sources of productivity changes, based on market restructuring the electricity sector and changes in property. To do this, we rely on a set of data for 14 distribution companies, for the period 1996–2006. Our analysis suggests that improvements in the efficiency and productivity of electricity distribution in Peru have occurred, and that there is a relationship between the restructuring of distribution sector and the enhancement of productivity.

1. Introduction

Until 1992, the Peruvian electrical system was centrally managed by public companies. From 1986 to 1990, the electricity system went through an important crisis, which was both financial and economic. The former was due to the high external debt, and the latter to the electricity rates being fixed according to political criteria. These rates did not ensure that the production costs were covered, thus generating large losses and an important fiscal deficit for the companies in the sector. These factors made it difficult for the companies to fulfil their operative aims, and to carry out their investment projects.

To resolve this situation, the government instigated several measures. In August 1990, the electricity rates were increased, allowing Electro Peru to be restructured.[1] Secondly, the Government vertically divested the industry into three activities: generation, transmission and distribution. Since 1994 several state-owned companies have been privatized.

The purpose of the paper is to analyze the evolution in the productivity of electricity distribution companies in Peru, in order to know if the 1993 reforms have achieved their objectives. This paper provides a comparative assessment of the technical efficiency levels of the distribution companies, between 1996 and 2006, by using a two-step procedure. First of all, we assess the efficiency levels and the total factor productivity changes using a Malmquist total factor productivity (TFP) index, and breakdown the total change by relying on a non-parametric data envelopment analysis (DEA) framework, as outlined by Färe et al. (1990, 1994).[2] In the second stage, we analyze, using parametric and non parametric procedures, the relationship between the efficiency scores obtained in the first stage and a set of variables that may explain the efficiency of the firms.

The paper is organized as follows. Section 2 summarizes the reforms in Peru's electricity sector. In Section 3, we present the methodology that we follow to measure efficiency and productivity changes. Section 4 provides a brief review of the literature on these measurements in the electricity distribution sector. Afterwards, in Section 5, we discuss the data and its limitations, and present the estimated models and the results obtained. Lastly, Section 6 concludes by drawing the main lessons for policy.

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[1] During this time, the state controlled the management of the electricity system by means of this public company.

[2] Malmquist indexes have been used to measure efficiency changes in electricity utilities (Hjalmarsson and Veiderpass, 1992). For recent surveys, see Jamasb and Pollitt (2003) and Jamasb et al. (2005). Malmquist indexes have also been used to measure efficiency changes in other regulated infrastructure services, such as ports (Estache et al., 2004), airports (Abbot and Wu, 2002) and the natural gas industry (Waddams-Price and Weyman-Jones, 1996).

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2. The reform process and the institutional design of the electricity sector in Peru

As part of the 1993 reform process, the generation and distribution activities of Electro Lima[3] were separated. Once broken down vertically, the privatization of the resulting distribution company started.[4] To promote ex-ante competition, and following the steps of the Argentinean experience, the distribution company for the department of Lima was divided into four concessions. Lima city was divided in two areas, which were Lima South and Lima North and were granted to Edelsur, subsequently called Luz del Sur, and Edelnor, respectively. The rest of the department of Lima was also divided into two concessions that were granted to EdeChancay and EdeCañete. These concessions were granted by public auction in July 1994.

The reform of the country's other distribution companies did not commence until March 1997, with the privatization of the south coast distribution company, Electro Sur Medio. In December 1998, the north coast, north and central mountains distribution companies, Electro Norte, Electro Noroeste, Hidrandina and Electro Centro, were publicly auctioned. However, at the beginning of 2002 these companies were renationalized, due to the concessionaires' non-compliance with the investment commitments.

When the reform process began the intention was to privatize all the firms, but due to resistance from citizens in the southern Andes and in the Amazon rain forest, certain distribution companies have remained state owned; these firms are Seal, Electro Sur, Electro Sur Este, Electro Oriente and Electro Ucayali. One of these firms, Seal, is located in Arequipa, Peru's second largest city; another, Electro Sur Este, is located in Cuzco. This is a major international tourist destination that is associated with Machu Picchu. The main reason that southern firms were not reformed is because this region rejected privatization.

The 1992 reform implied the adjustment of the distribution activities rates.[5] The rate adjustment of the distribution companies differs, depending on the type of customer. The legislation contemplates two types of customers, regulated and free. Free customers are those whose demand for electrical power is over 1 MW, and the rest are regulated customers.[6] Free customers negotiate the rate in a competition framework with the distributors or generators, while for regulated customers the rate is established by the regulatory body: OSINERGMIN (Energy and Mining Investment Supervisory Body).

The regulatory mechanism used in the rate adjustment is a hybrid of the efficient model company approach combined with yardstick competition. This regulatory process is carried out with a four year regulatory lag, which means that to date there have been four rate revisions, in 1993, 1997, 2001 and 2005.

The State's level of intervention in the rate adjustments was reduced when the Law of Electrical Concessions, hereinafter LCE was passed and an independent regulatory commission was set up to impose the criteria established by the law. These included rate-revision periods, methodological criteria, the cost of capital, and rate-revision mechanisms. The reform initially increases the rates of distribution, and subsequently tried to correct prior distortions. Since then, the rate-revision process has acted in accordance with the cost parameters of an efficient company, as established by the regulatory framework.

The reforms were an attempt to attract private capital to finance the expansion of the power supply mainly in the generation process, and as Fig. 1 shows, this was achieved. Private investment growth averaged 34% per year during the period analyzed. This growth rate could have been higher, but a significant important group of privatized companies were renationalized in 2002.

Fig. 1 shows that the first half of the 90 s was marked by a complete lack of private investment. The reform process began in 1994, and between 1995 and 2000 period, investment in power distribution grew, and this was explained by the investment done by the private firms; 8 out of 14 distribution companies were privatized. From 2002 onwards, with the return of Hidrandina, Electro Norte, Electro Centro and Electro Noroeste to state control, public investment has grown; nevertheless, it is still lower than the private sector's contribution.[7] Therefore, the installed power capacity increased by 50% during the 1990–2006 period. Moreover, there has been substantial improvement in several of the indicators associated with the power generation capacity, coverage and efficiency of the public service electrical companies.[8]

The recent evolution of the sector is relevant to the analysis conducted in this paper. Table 1 shows the variations of the factors that demonstrate the characteristics of the distribution companies during the 1996–2006 period.[9] The output variables improved significantly during this period; the number of customers has increased substantially, with about 5.2% and 8.5% more low- and medium-voltage customers, respectively. This is matched by increased low and medium voltage (MV) sales of 7.2% and 9.9% respectively. Moreover, the length of distribution network has grown by 8%.

Employment has increased by 0.4%, but the figures range widely. Some operators, such as Ucayali and Electro Puno, have seen respective employment increases of 11.9% and 8.9%. Others, such as Electro Centro and Hidrandina, have seen respective drops of 6.7% and 4.7%. Capital input has also increased by an average of 3.1%, although here the range is more restricted. In fact, all firms have increased their net fixed assets by 8.9%, except for Electro Oriente whose net fixed assets dropped by 4.2%.

Finally, Table 1 also shows we have three kinds of firms, those that were never privatized, those that were in the private sector for some years, and thirdly those that were privatized and remain so. We refer to the firms that belong to the second and third groups as "reformed".

Table 2 shows some partial productivity indicators for Peruvian power distribution companies during the 1996–2006 period. We can see that, at an industry level, the partial productivity indicators have improved, which suggests that the reform process has been favourable. In general, results are also positive at a firm level, although in some cases they are negative.

[3] Electro Lima supplied the department of Lima, whose capital is the country's main city in terms of population and industrial production. Lima is home to 8 million of the total Peruvian population of 27 million and to about 70% of the country's industrial estates.

[4] Electro Lima was divided in two generation companies (Etevensa, a thermal power plant, and Edegel, hydroelectric power plants), four distribution companies (Edelsur, Edelnor, EdeChancay and EdeCañete), and also their transmission assets were transferred to Etecen, the new state transmission company for the central-north interconnected system. In 1999 Edelnor took over EdeChancay.

[5] In Peru the concessionary distribution companies carry out the operational activity, such as metering, invoicing, collection, etc.

[6] As a point of reference, a regular home in an average income neighbourhood contracts a 10 kW energy supply, which is the hundredth part of the threshold required to be a free customer.

[7] Increases in public investment are also explained by the larger mining royalties obtained by regional governments, which have been used in part to increase power supply, especially in rural areas.

[8] Dammert et al. (2005) show the evolution of the Peruvian electrical sector's main indicators before and after the reform process.

[9] These companies represent nearly all the Peruvian distribution sector. Evidence of this is that for the year 2006 they jointly made up 99.5% of the sales, 99.4% of the clients and 97.5% of the employment.

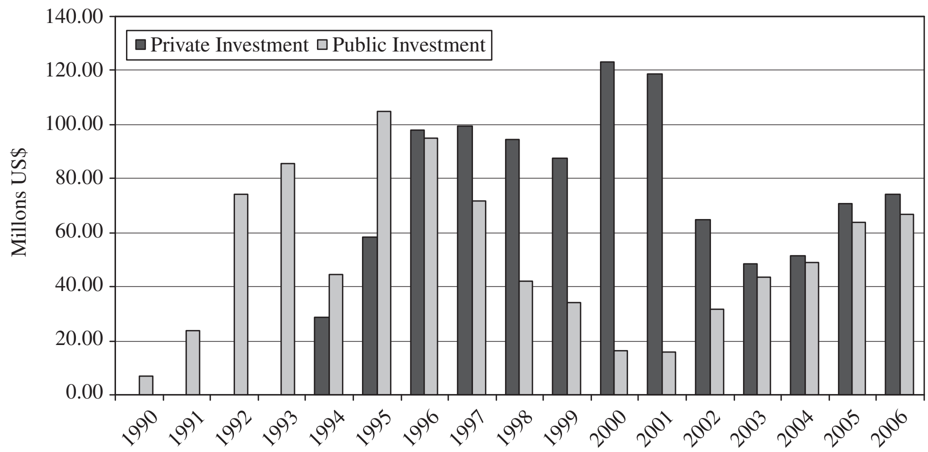

Fig. 1. Investment in electrical distribution activity: 1990–2006. *Source*: Ministry for Energy and Mines, Peru. Own elaborated.

Table 1
Variation of the main variables of the electricity distribution companies in Peru: 1996–2006.

Company	Low-voltage customers (%)	Medium-voltage customers (%)	Low-voltage sales (%)	Medium-voltage sales (%)	Distribution network (%)	Workers (%)	Net fixed assets (thousand of soles in 1994) (%)	Demand areas	Property		
	1996–2006	1996–2006	1996–2006	1996–2006	1996–2004	1996–2006	1996–2006	2004	1996	2000	2006
Edecañete	3.4	14.1	4.1	11.3	1.6	0.4	6.3	2	P	P	P
Edelnor	1.9	5.5	4.4	5.1	3.6	−2.9	6.4	1	P	P	P
Electro oriente	7.3	8.7	6.3	9.7	7.4	4.4	−4.2	2 and 5	E	E	E
Electro puno[a]	7.7	9.2	36.2	36.2	14.4	8.9	−0.1	2, 3 and 4	E	E	E
Electro sur este[a]	5.5	7.7	1.1	2.6	11.7	1.6	3.3	2, 3 and 4	E	E	E
Electro sur medio	4.4	4.2	4.3	7.8	9.4	2.1	4.3	2, 4 and 5	P	P	P
Electro ucayali	7.7	7.2	9.6	9.5	8.4	11.9	−0.1	2 and 3	E	E	E
Electro centro	6.7	6.0	5.5	4.8	10.8	−6.7	2.1	3, 4 and 5	E	P	E
Electro noroeste	6.1	14.7	4.8	13.2	7.6	−2.4	1.8	2 and 4	E	P	E
Electro norte	6.0	9.4	5.6	12.4	14.2	−2.1	3.5	2, 3 and 4	E	P	E
Electro sur	4.8	4.9	4.7	5.2	6.4	−1.0	2.6	2 and 3	E	E	E
Hidrandina	5.0	7.5	5.6	3.1	7.5	−4.7	2.8	2 and 3	E	P	E
Luz del sur	2.3	9.0	4.2	9.7	2.7	−0.9	8.9	1	P	P	P
Seal	3.7	11.3	4.6	8.5	5.9	−2.8	5.5	2 and 3	E	E	E
Average	5.2	8.5	7.2	9.9	8.0	0.4	3.1				

E = state, P = private.
Source: energy investment supervisory body of Peru, OSINERG. Own elaborated from Statistical yearbooks.
[a] Percentage variation refers to period 1999–2006, with the exception of the distribution network km data.

Sector	Type of demand
1	High-density urban
2	Medium-density urban
3	Low-density urban
4	Urban Rural
5	Rural

Even when there is some consensus regarding the usage of these indicators to evaluate the development of efficiency in the electricity distribution companies, only a partial perspective is offered. This is because these indicators may be affected by factors, such as the technology underlying the distribution systems, the capital substitution of the workforce or the density of the area of influence of the distribution companies. This is why these deficiencies can be resolved by using a total factor productivity index.

3. Measuring and decomposing the changes in productivity: the conceptual background

Interest in productivity and efficiency analyses of companies has significantly grown in recent decades, and is due to the potential of these techniques as regulatory tools. They are especially relevant in sectors where adjustment is normal; e.g. infrastructure industries and public utilities. Indeed, the possibility of comparing the performance of regulated companies does

Table 2
Partial productivity indicators of the electricity distribution in Peru: 1996–2006.

Company	Sales/customers (MWh)			Sales/worker (MWh)			Losses/customers (MWh)			Property
	1996	2006	Var. (%)	1996	2006	Var. (%)	1996	2006	Var. (%)	
Edecañete	1.86	2.80	4.2	5,507	2,983	–5.9	0.41	0.28	–3.6	Private
Edelnor	3.50	4.58	2.7	3,625	7,692	7.8	0.58	0.43	–2.9	Private
Electro Oriente	1.90	1.90	0.0	1,043	1,369	2.8	0.75	0.22	–11.4	Public
Electro Puno[a]	0.24	1.24	26.4	276	1,317	25.0	0.02	0.18	37.2	Public
Electro Sur Este	1.45	1.11	–2.6	842	1,233	3.9	0.28	0.15	–5.7	Public
Electro Sur Medio	3.08	3.73	1.9	1,145	1,723	4.2	0.75	0.52	–3.5	Private
Electro Ucayali	2.57	3.04	1.7	2,229	1,802	–2.1	1.51	0.30	–15.0	Public
Electro Centro[b]	1.16	1.02	–1.3	424	1,425	12.9	0.31	0.10	–10.3	Public
Electro Noroeste[b]	1.82	2.26	2.2	925	2,649	11.1	0.68	0.25	–9.5	Public
Electro Norte[b]	1.51	1.70	1.2	692	1,737	9.6	0.53	0.17	–10.7	Public
Electro Sur	2.05	2.06	0.0	830	1,476	5.9	0.36	0.19	–6.4	Public
Hidrandina[b]	2.06	1.97	–0.4	953	2,410	9.7	0.80	0.22	–12.0	Public
Luz del Sur	4.30	6.06	3.5	3,699	7,168	6.8	0.63	0.45	–3.2	Private
Seal	1.81	2.20	2.0	1,283	2,994	8.8	0.54	0.26	–7.1	Public
Mean	2.09	2.55	0.03	1,677	2,713	0.07	0.58	0.27	–0.05	

Source: Energy Investment Supervisory Body of Peru, OSINERG. Own elaborated from statistical yearbooks.
[a] This indicator refers to Electro Puno's first year of existence, 1999.
[b] These companies were privatized jointly in 1998 and returned to the Peruvian State in 2002.

contribute to easing the problem of information asymmetries, by increasing efficiency in the regulatory agencies.

Productivity and efficiency are related but different concepts. Productivity is the ratio between the products obtained and the factors used in its production. On the other hand, technical efficiency is the capacity of obtaining the maximum amount of output from certain inputs (output orientation). Alternatively, as the capacity of obtaining a given output level using the minimum amount of inputs (input orientation). Also, a company presents efficiencies of scale, if it reaches the maximum productivity with the current technology. With the previous definitions we can easily deduce that technical efficiency is only one of the factors that determine productivity.

Productivity measurement has a long history, and the earliest approach was based on single or partial factor productivity measurement. Although it is easy to calculate, in practice this index is too simple and could give a misleading picture of performance, when there is more than a single output or a single input. In the real world firms usually use multiple inputs to get multiple outputs, so the measuring of productivity must be done using total factor productivity (TFP) measurement. Thus, TFP is a generalization of single factor productivity measurement. TFP growth refers to the change in productivity over a period of time. There are several approaches to productivity measurement. In order to take into account the contribution of efficiency change to productivity change, we use a non parametric frontier approach.[10]

Among the most used indexes in measuring productivity changes we find the Fisher index (1922), the Törnqvist index (1936) and the Malmquist index (1953). Of the first two indexes, the Malmquist index has the advantage of not requiring input prices or behavioural assumptions. These two characteristics make the Malmquist index very suitable for analyzing productivity changes in both public and regulated sectors. Moreover, the change in productivity measured with the Malmquist index 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 the available technology improvement (Nishimizu and Page (1982) and Grifell and Lovell (1993). Finally, the Malmquist index can also be used to separate the catching-up effect into technical efficiency and scale efficiency. This gives a sense of the extent to which the efficiency gains are achieved purely from changes in input mix or from better adjustment of the size to the demand.

To illustrate the Malmquist index calculation[11] it is necessary to define the technology of reference. Technology can be represented through the input distance function[12] used by Caves et al. (1982), $D_i^t(y^t, x^t) = \text{Max}\ \mu\ [\ \mu \geqslant 1: T(y^t, x^t/\mu) = 0]$. Scalar $\boldsymbol{\mu}$ is the maximum deflation of the inputs vector (x^t), so the resulting deflated inputs vector (x^t/μ) and the outputs vector ($\mathbf{y}^t$) are on the frontier. Thus, $D_i^t(y^t, x^t) \geqslant 1$; i.e. the distance equals one when the evaluated company is efficient and is on the frontier.

As the analysis of productivity change takes place during two time periods, the Malmquist index is required to compare the input output vector of one period of time, with the technology present in a different period. Thus, with $D_i^t(y^t, x^t)$ and $D_i^{t+1}(y^{t+1}, x^{t+1})$ we are comparing each company with the frontier of the period it belongs to, while in $D_i^{t+1}(y^t, x^t)$ and $D_i^t(y^{t+1}, x^{t+1})$ the observations are from a period different to the frontier they are being compared with; therefore, the distance function can be less than one.

To sum up, the Malmquist index calculates the productivity change of a company by measuring the distance in two periods of time t and t+1, in relation to the existing technological frontier in t; it determines this productivity change in relation to the existing technological frontier in t+1. To avoid problems derived from the ad hoc choice of the technology of reference, Caves et al. (1982) propose using the geometric mean of both periods. The Malmquist index is as follows:

$$M_i^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_i^t(y^{t+1}, x^{t+1})}{D_i^t(y^t, x^t)} \quad \frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^t, x^t)}\right]^{1/2}$$

This is the approach used by Färe et al. (1990), and given that they accept inefficient behaviour they may decompose the index

[10] For a more in depth discussion of the relationship between efficiency and productivity see Grosskopf (1993).

[11] Readers who are not interested in the mechanics of the indexes can skip to Section 4.

[12] In this paper input orientation is used, as it is suitable for regulated industries that are generally characterized by endogenous inputs and exogenous outputs.

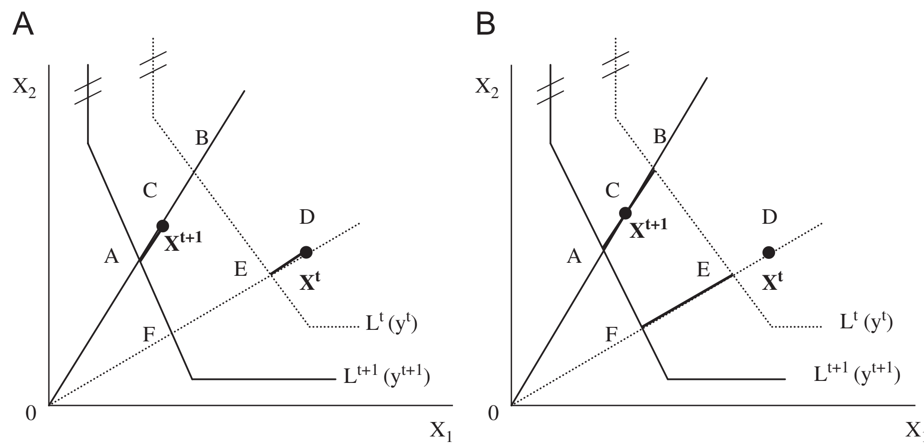

Fig. 2. Change in technical efficiency and technological change. (A) Change in technical efficiency (E_i^{t+1}). (B) Shift in the Frontier. Technical change (T_i^{t+1}). (a) Change in technical efficiency E_i^{t+1}. (b) Shift in the frontier technical change (T_i^{t+1}).

as follows:

$$M_i^{t+1}(y^{t+1},x^{t+1},y^t,x^t) = \frac{D_i^{t+1}(y^{t+1},x^{t+1})}{D_i^t(y^t,x^t)} \times \left[\frac{D_i^t(y^{t+1},x^{t+1})}{D_i^{t+1}(y^{t+1},x^{t+1})} \quad \frac{D_i^t(y^t,x^t)}{D_i^{t+1}(y^t,x^t)}\right]^{1/2} = E_i^{t+1}\,T_i^{t+1}$$

where E_i^{t+1} is the catching-up period, and T_i^{t+1}, is the frontier shift. The following figure illustrates the concepts that we have just defined for one product (y) and two productive factors (x_1, x_2). To that end both isoquants, $L^t(y^t)$ and $L^{t+1}(y^{t+1})$, which correspond to both periods of time t and t+1 are represented. We assume that $y^t = y^{t+1}$.

Fig. 2 shows the situation of a company that uses the combination of factors X^t in the moment t (at point D) and the combination X^{t+1} in the moment t+1 (at point C). In terms of the given distances, the Malmquist index is determined by

$$M_i^{t+1}(y^{t+1},x^{t+1},y^t,x^t) = \frac{OE/OD}{OA/OC}\left[\frac{OA/OC}{OC/OB}\frac{OF/OD}{OE/OD}\right]^{1/2} = \frac{OE/OD}{OA/OC}\left[\frac{OA}{OB}\frac{OF}{OE}\right]^{1/2} = E_i^{t+1}\,T_i^{t+1}$$

If in both periods the company is at its respective frontiers, the first term will be equal to 1 and the productive change between both periods can only be explained by the movement of the frontier. If the second term equals 1, then the frontier has not shifted and the estimated productivity changes can only be explained by changes in the company's efficiency in both periods; i.e. catching-up. In all other cases, productive changes reflected in M_i^{t+1} are a mix of efficiency changes and frontier shifts.

Subsequently, Färe et al. (1994) proposed an even larger decomposition of this index, when they distinguished between full technical efficiency and changes in scale efficiency within the term that takes the change in technical efficiency, E_i^{t+1}.

$$E_i^{t+1} = \frac{D_i^{t+1}(y^{t+1},x^{t+1})}{D_i^t(y^t,x^t)} = \left(\frac{D_i^{t+1}(y^{t+1},x^{t+1})}{D_i^t(y^t,x^t)}\right)_{VRS} \times \left(\frac{D_i^{t+1}(y^{t+1},x^{t+1})_{crs}/D_i^{t+1}(y^{t+1},x^{t+1})_{vrs}}{D_i^t(y^t,x^t)_{crs}/D_i^t(y^t,x^t)_{vrs}}\right) = ETP_i^{t+1}\,ES_i^{t+1}$$

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; however, it is not situated in the optimum production scale, because it is not adequately sized. Therefore, the changes in productivity that are strictly related to technical efficiency appear in ETP_i^{t+1}, while these related to the productive unit size appear in ES_i^{t+1}.[13]

These indexes use the distance function notion, so their calculation requires the prior estimation of the corresponding frontier. Estimating the efficiency frontier can be done by using parametric and non-parametric methods.[14] Both techniques allow the relative efficiency ratios within a group of analyzed units to be derived, so that the unit's efficiency is compared with efficiency envelopment.

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 in order to calculate the Malmquist index. Here is one standard format for presenting the input oriented DEA linear programming problem that is used in this paper:

$$\begin{aligned} &\text{Min } \theta_0 \\ \text{s.a.}\quad &Y\lambda \geqslant Y_0 \\ &\theta X_0 - \lambda X \leqslant 0 \\ &\lambda \geqslant 0 \end{aligned}$$

λ is a vector that describes the percentage of other companies, and is used for constructing the efficient company. $\boldsymbol{X}$ and $\boldsymbol{Y}$ are the companies' input and output vectors, and $\boldsymbol{X_0}$ and $\boldsymbol{Y_0}$ are the inputs and outputs of the company that is being evaluated. The efficiency of the evaluated company is represented by $\boldsymbol{\theta_0}$.

4. Brief review of the literature

Table 3 shows the different studies that analyze the efficiency and/or productivity of the electricity distribution companies.

With empirical applications, the authors have had to deal with the problem of defining the input and output variables. Table 3 presents a summary of the input and output variables used in the majority of electricity distribution efficiency studies. Most papers consider more than one output dimension. Some authors follow

[13] This decomposition has been criticized by some authors because it measures technical change against CRS technology instead of VRS technology. Various alternatives have been proposed; however, none of them have gained widespread acceptance. See Grifell and Lovell (1999) and Balk (1999) for discussion on this issue.

[14] For a comparative discussion of the advantages and disadvantages in both techniques, see Lovell (1993).

Table 3
Summary of empirical evidence on electricity distribution efficiency.

Authors	Inputs	Outputs	Data	Models and measures
Weyman-Jones (1991)	Financial capital or network length, labor	Sales, customers	12 distribution companies in England and Wales in 1986 and 1987	DEA CRS
Miliotis (1992)	Length of lines (km), installed capacity (kV A), general expenses, technical and administrative work (h)	Customers, energy supplied (kWh) and total area provided	45 electricity distribution districts of the *Greek Public Power Corporation* (PPC). The author does not mention the year	DEA
Hjalmarsson and Veiderpass (1992)	Workforce (h), high-voltage lines (km), low-voltage lines (km) and transformation capacity (kV A).	High- and low-voltage energy sales (kWh), number of customers for high and low voltage	Electricity distribution sector in Sweden for the 1970–1986 period	DEA CRS MI
Pollit (1994)	Number of employees, transformers (MV A) and circuit kilometers.	Number of customers, residential sales (GWh), non-residential sales (GWh), service area (km^2) *y* maximum demand (MW)	145 distribution system in the United States and the United Kingdom in 1990	DEA OLS
Bagdadioglu et al. (1996)	Workforce, transformation capacity (MV A), network size (km), network general expenses and losses (MWh).	Number of customers, offered electricity (MWh), maximum demand (MW) and service area (km^2)	70 retail distribution companies in Turkey in 1991	DEA CCR and VRS (5 specifications)
Scarsi (1999	Work (number of full-time workers), capital (kilometers of distribution lines).	Distributed energy (GWh), number of customers	39 ENELs and 37 MUNIs in Italia for the 1994–1996 period	DEA CRS Model 1: two outputs and two inputs Model 2: one output (customers) and two inputs Model 3: one product (sales) and two inputs *y* SFA (Stochastic Frontiers)
Hattori et al. (2003)	Operational costs, total operational costs (includes capital costs), density (customers/network km) and load factor.	Sales (MWh), number of customers	21 companies (12 from the United Kingdom and 9 from Japan) for: 1985/86 and 1997/1998.	DEA CRS and VRS with different costs specifications Y SFA
Sanhueza (2003)	Operational and maintenance costs, capital costs, number of workers, remunerations, not sold energy	Energy sales (kWh), maximum demand (kW), number of customers , distribution network (km)	35 distribution companies in Chile for 2000	DEA VRS with *bootstrap*
Giannakis et al. (2003)	Operational costs, total operational costs (includes capital costs)	Energy sales (kWh), number of consumers, distribution network length (km)	14 companies from the United Kingdom for the 1991/92 and 1998/99 periods	DEA TFP (MI) Quality indicators: supply quality (frequency and duration of interruptions), commercial quality (relationship between operators and customers), product quality (frequency, amplitude and wave)
Motta (2004)	Operational costs, total operational costs (includes capital costs)	Total sales (MWh), number of consumers and kilometers of distribution lines	14 companies privatized in Brazil and 72 companies from the United States for years 1994 and 2000	DEA CRS and VRR TFP (MI) and SFA Environmental variables: Maximum demand (MW), density (customers/ network km) and residential customers/total customers ratio
Pombo and Taborda (2006)	Number of employees, number of transformers, network size (km).	Energy sales (GWh), number of customers.	12 companies that supply 20 cities that are part of the National Interconnected System (SIN) for the 1985–2001 period	DEA TFP (IM) Environmental variables: regional GDP per-cápita, national installed capacity, urban area provided

Table 3 (*continued*)

Authors	Inputs	Outputs	Data	Models and measures
Abbot, (2006)	Physical capital (distribution lines, capacity lines of transmission stations and generation capacity lines), energy usage (TJ).	Energy consumption (MWh)	7 electricity distribution jurisdiction in Australia for the 1969–1999 period	DEA TFP (MI)
Yu et al. (2007)	Operational costs, total operational costs (includes capital costs), duration of energy interruptions and losses (with its respective prices)	Number of consumers, delivered energy (GWh) and Length of lines (km)	14 companies from the United Kingdom for the 1990/91–2003/2004 period	DEA TE and AE
Estache et al. (2008)	Installed capacity (MW) and number of workers	Generation (GWh), Number of consumers and Sales (GWh).	12 companies that provide services in 12 state members of the *Southern Africa Power Pool* (SAPP) between 1998 and 2005	DEA TFP (MI)

TE = technical efficiency; TFP = total factor productivity; IM = Malmquist index; DEA = data envelopment analysis; SFA = Stochastic Frontier analysis; CRS = constant returns to scale; VRS = voltage returns to scale.
Source: own elaborated from several studies.

the approach developed by Hjalmarsson and Veiderpass (1992) that considers four outputs: medium- and low-voltage sales, as well as medium- and low-voltage customers. Others, like Hattori et al. (2003) and Pombo and Taborda (2006) and the authors of this paper, follow Neuberg (1977) who argues that at the very least both the number of customers served and total energy sold qualify as potential outputs in this sector. Jamasb and Pollitt (2003) point out that by including both these outputs the spread of demand among the connection points is considered.

With regard to inputs, the distribution company requires labour and a network infrastructure; e.g. poles, wires, substations, underground cameras, etc. The standard practice is to consider the number of employees, the transformer capacity, the length of the network and the operating cost; the latter if cost is used as input variable, see Jamasb and Pollitt (2003). Finally, power distribution has several unwanted effects, such as the number and duration of power service interruptions. Authors like Giannakis et al. (2003) and Yu et al. (2007) have incorporated these undesirable effects into the specification of the DEA models, in order to analyze the productivity efficiency and the changes in distribution companies.

While various studies applied to the distribution activity differ slightly with regard to the inputs and outputs they use, there is a certain consensus concerning the methodology; see also Qassim et al. (2005) and Pombo and Taborda (2006). Most of these papers have used non-parametric methods and DEA orientation models. The input oriented model represents the company behaviour regarding the decision over what quantity of inputs to use, given that a determined demand of goods or services need to be satisfied; see Thanassoulis (2002) and Pombo and Taborda (2006). This type of orientation better represents the public electricity service provision, where the companies must attend to a determined exogenous demand for the concession of distribution in a specific geographic area; for this reason we use this orientation in our empirical application.

The objective of most of the recent papers is to analyze changes in efficiency and/or productivity, due to sector reforms that usually include some type of private involvement. Some authors such as Hjalmarsson and Veiderpass (1992) for Sweden, Bagdadioglu et al. (1996) for Turkey and Pollit (1994) for the USA and the United Kingdom found no evidence of differences in efficiency between public and private companies. However, others authors such as Motta (2004) for Brazil, Sanhueza (2003) for Chile and Pombo and Taborda (2006) for Colombia conclude that the impact of privatization upon the efficiency of electrical distribution companies is positive.

In general terms, the evidence rejects the relationship between greater efficiency and private property for developed countries; however, in Latin America the results appear to be different. These results could be due to the distribution firms having several operative problems prior to the reforms; these may include capital restraints, excess of possibly unskilled labour linked to political cycles, complicated and corrupted behaviour with respect to procurement, political influence and so forth. The latter problem seems to be related to the institutional environment,[15] rather than the property regime; nonetheless, we will test both possibilities.

Finally, other authors have tried to identify efficiency drivers. Pollit (1994) found that average efficiency is reduced as the size of the firm increases. Miliotis (1992) analyzed the impact of geographical characteristics, size and density, and concluded that the divisions operating in urban centres have higher efficiency indexes than those operating in areas where the population is scattered.

5. Measuring efficiency and productivity change

5.1. Data and models

The choice of variables is based on the availability of data, and on our previous discussion of the current literature. We would have liked to consider four outputs: medium- and low-voltage sales, as well as medium- and low-voltage customers. However, due to data restrictions we have followed the steps of Neuberg (1977), who considered two outputs: sales (MWh) and the numbers of customers.[16]

[15] It should be noted that Colombia, Chile and Brazil introduced important macroeconomic reforms at the same time as the electricity reforms.

[16] Estimations with four outputs were made: sales and customers, but disaggregated into low and medium voltage, respectively. As expected, due to the high number of variables and the reduced number of observations, most companies were located on the frontier. This provides evidence for the reduced discriminatory power of these models.

Table 4
Statistics of the variables used in Model 1.

Variable	Sales (MWh)	Customers (number)	Workers (number)	Network length (km)	SED	Losses (MWh)
Mean	711,742	236,875	261	1.854	2.234	92.305
Minimum	52,237	19,743	19	112	146	5.107
Maximum	3,971,199	912,175	761	6.864	7.362	455.171
Standard deviat.	1,135,534	239,831	201	1.490	2.008	118.404

SED = medium and low-voltage conversion substations.
Source: Energy Investment Supervisory Body of Peru, OSINERG. Own elaborated from Statistical yearbooks.

As regard inputs, as we have previously stated, the distribution company requires labour and a network infrastructure. Labour is related to the number of employees. With respect to the measurement of the network infrastructure, the numbers of kilometres of medium voltage and of low voltage (LV) distribution lines were initially used; and the numbers of MV to LV conversion substations. Unfortunately, in Peru this information is only available for the years 1996, 2000 and 2004, which significantly reduces the number of available observations. Therefore, we sought an alternative measure that was reported annually. The correlations between the physical variables of the companies and the value of the land, machinery and equipment were analyzed for the indicated years. The high correlation between them shows that it is possible to substitute physical capital variables for land, machinery and the value of equipment.

Finally, the only undesirable factors incorporated in our analysis are the power losses.[17] There are losses associated with transportation (technical losses) and losses associated with theft (trade losses). Both affect power supply because more losses mean that the distribution companies have to increase the power of the generators, in order to supply the same levels of electrical energy.

To sum up, two models, which differ in the way they measure capital inputs and in the number of available observations, have been proposed. Model 1 has 42 observations, from 14 observed companies during the years 1996, 2000 and 2004, while Model 2 has 151 observations from 14 observed companies between 1996 and 2006. Both models consider two products: (i) annual sales in MWh, and (ii) number of customers. Table 4 shows the statistics for the variables used in Model 1.

In Model 1, four inputs have been considered: (i) the number of workers; (ii) the distribution power losses in MWh; (iii) the medium-voltage and low-voltage network kilometres; and (iv) the number of substations. While in Model 2, three inputs have been considered: (i) the number of workers; (ii) distribution power losses in MWh; and (iii) the monetary value of the active capital during the period (the net fixed assets exploited) measured at 1994 prices. Table 5 shows the statistics for the variables used in Model 2.

5.2. Estimation of technical efficiencies and Malmquist indexes

To measure efficiency and productivity changes in electrical distribution companies, input-oriented DEA models are used. In Table 6 the firm efficiency, which has been estimated[18] using both models for 1996 and 2006, is presented.[19] Here, we can observe that relative mean efficiency in both models is high, and that there have been improvements in the period analyzed. Also, we can see that it is mainly the reformed firms that show improvements in relative efficiency. This seems to indicate that the 1993 reforms have had a positive effect upon the sector's efficiency. The exception was Electro Puno whose efficiency has evolved negatively. This is probably associated with the management problems that this company has had since its divesture from Electro Sureste.[20]

Mostly, it is the same companies that are located on the relative efficiency frontier for both models; they are EdeCañete, Edelnor, Electro Centro, Electro Norte, Electro Noroeste and Luz del Sur. Three of these companies, Edelnor, Luz del Sur and EdeCañete are private companies; the rest were privatized and subsequently returned to the State. These latter firms, Electro Centro, Electro Noreoeste, Electro Norte and Hidrandina; supply four of the country's main cities; their respective areas of activity are Huancayo, which is in the Andes, and on the northern Peruvian coast Chiclayo, Piura and Trujillo, which all form part of an agricultural exporting area. These cities have densely populated urban areas, and in some cases industry that must be supplied. As we will see, these latter points positively affect efficiency.

As we have stated previously, the problem of technical efficiency for Electro Sureste is related to the divesture of Electro Puno in 1998, which created some initial disruptions; it was not until the year 2000 that the geographical concession areas, and low and medium voltage customers were distributed permanently.

Conversely, the results for Electro Centro, Electro Noroeste, Electro Norte and Hidrandina seem to be directly related to their privatization in 1998 and to their return to the State at the end of 2001. Under private management, an investment programme was set up; it focused on replacing outdated machinery, the infrastructure and enhancing maintenance operations.[21] Also, aggressive energy-loss reduction programmes were implemented, which led to a reduction from 19.1% in 1998 to 10.8% in 2001. Finally, personnel reduction programmes were also implemented, saving 50% between 1998 and 2000. These facts are reflected in the evolution of the technical efficiency for these companies during the period.

Tables 7 and 8 show the total factor productivity changes by year and by company, respectively. Table 7 shows that for both

[17] In Peru, statistical information on interruptions and quality of the distribution networks has been available since 2004.

[18] The programs used for the estimation of efficiency are Win4DEAP and DEAP Version 2.1.

[19] In order to be brief, we only report average results. However, the annual results are available from the authors upon request.

[20] Electro Puno was part of Electro Sureste, the power supplier for Cuzco and Puno up to the end of 1998. At this time the Government decided to split Electro Sureste's electricity system from the regional department of Puno. Electro Sureste kept supplying Cuzco, but Puno was supplied by a new company, Electro Puno, which started operating at the beginning of 1999. This new firm, Electro Puno, had to face several difficulties. First of all, they had problems with administering the medium-voltage sales, until these industrial customers were transferred in 2000. Secondly, they received an electrical system that had had little network maintenance investment, so it had higher technical and commercial losses than other networks in Electro Sureste. Lastly, they supply a low-income family area with a significant presence of low-voltage semi-rural or urban consumers.

[21] Investments in the four enterprises during the 1998–2001 period exceeded US$98 million.

Table 5
Statistics of the variables used in Model 2.

Variable	Sales (MWh)	Customers (number)	Workers (number)	IMyE thousand of Soles in 1994	Losses (MWh)
Mean	731,146	246,596	262	585,523	88,696
Minimum	4,609,000	951,563	761	2,934,705	455,171
Maximum	18,518	19,743	19	27,558	1,217
Standard deviat.	1,166,258	240,837	192	602,759	110,714

IMyE = real state, machinery and equipments in monetary value.
Source: Energy Investment Supervisory Body of Peru, OSINERG. Own elaborated from Statistical yearbooks.

Table 6
Efficiency of distribution companies: 1996–2006. Models 1 and 2.

Firm	Model 1						Model 2					
	TE CRS		TE VRS		ES		TE CRS		TE VRS		ES	
	1996	2006	1996	2006	1996	2006	1996	2006	1996	2006	1996	2006
Edecañete	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.853	1.000	1.000	1.000	0.853
Edelnor	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Electro oriente	0.737	1.000	0.898	1.000	0.821	1.000	0.632	0.770	0.644	0.787	0.981	0.978
Electro puno[a]	0.955	0.803	1.000	0.818	0.955	0.982		0.806		0.852		0.946
Electro sur este	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.837	1.000	0.849	1.000	0.986
Electro sur medio	0.740	0.796	0.798	0.803	0.927	0.991	0.697	0.808	0.718	0.857	0.971	0.943
Electro ucayali	0.838	1.000	1.000	1.000	0.838	1.000	0.838	0.824	1.000	0.927	0.838	0.889
Electro centro	1.000	1.000	1.000	1.000	1.000	1.000	0.955	1.000	1.000	1.000	0.955	1.000
Electro noroeste	0.783	1.000	0.785	1.000	0.997	1.000	0.780	1.000	0.786	1.000	0.992	1.000
Electro norte	1.000	1.000	1.000	1.000	1.000	1.000	0.961	1.000	0.983	1.000	0.978	1.000
Electro sur	1.000	0.948	1.000	0.951	1.000	0.997	1.000	0.973	1.000	1.000	1.000	0.973
Hidrandina	0.770	1.000	0.786	1.000	0.980	1.000	0.572	0.845	0.630	0.846	0.908	0.999
Luz del sur	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Seal	0.989	0.907	0.998	0.907	0.991	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean	0.915	0.961	0.948	0.963	0.965	0.998	0.880	0.908	0.905	0.937	0.971	0.969

TE = technical efficiency; CRS = constant returns to scale; CVR = variable returns to scale; ES = scale efficiency.
[a] The available information for Electro Puno starts from its creation in 1999.

Table 7
Malmquist TFP index: annual average.

Year	Model 1[a]					Model 2				
	Effch	Techch	Pech	Sech	Tfpch	Effch	Techch	Pech	Sech	Tfpch
1997						0.914	1.210	0.952	0.960	1.105
1998						1.033	1.036	1.026	1.007	1.071
1999						1.049	1.068	1.049	1.001	1.121
2000	1.066	1.262	1.029	1.036	1.345	1.035	0.980	1.019	1.016	1.015
2001						1.011	1.014	0.992	1.019	1.025
2002						0.955	1.034	0.961	0.994	0.988
2003						1.026	0.962	1.010	1.016	0.988
2004	0.989	0.997	0.989	1.000	0.986	1.033	0.998	1.022	1.011	1.031
2005						0.982	1.122	0.986	0.996	1.101
2006						1.004	0.996	1.028	0.976	1.000
Annual average	1.007	1.029	1.002	1.004	1.036	1.003	1.040	1.004	0.999	1.043
Period average	1.027	1.121	1.009	1.018	1.152					

Effch = efficiency change; Techch = technical change; Pech = pure efficiency change; Sech = scale efficiency change; Tpch = total factor productivity change (Malmquist index).
[a] In model 1 the variations are from a four year period, so a four years' average variation of 15.2% equals a compound annual growth rate of 3.6%.

models the first years of reforms have been associated with total factor productivity improvements, due to the technical efficiency, technological change and scale effects. The changes in productivity were bigger in the first years of the period analyzed. Since 2001, except 2005, the improvements in productivity have been smaller, and we can even see a slight decline in the evolution of productivity for the years 2002 and 2003. This seems to indicate that the reforms had a substantial effect at the beginning of the period, which is normal and expected.

The TFP annual average variation is 3.6% for Model 1 and 4.3% for Model 2, which are similar results. Nevertheless, Model 2 guarantees a higher degree of discretionary power due to the

Table 8
Malmquist TFP index: annual results by company.

Firm	Model 2				
	Effch	Techch	Pech	Sech	Tfpch
Edecañete	0.985	1.049	1.000	0.985	1.033
Edelnor	1.000	1.050	1.000	1.000	1.050
Electro Oriente	1.021	1.072	1.022	1.000	1.091
Electro Puno(1)	0.970	0.904	0.977	0.992	0.876
Electro sur este	0.983	1.077	0.984	1.000	1.057
Electro sur medio	1.015	1.012	1.018	0.997	1.027
Electro ucayali	1.001	1.059	0.993	1.006	1.056
Electro centro	1.005	1.112	1.000	1.005	1.118
Electro noroeste	1.025	1.032	1.024	1.001	1.059
Electro norte	1.004	1.018	1.002	1.002	1.023
Electro sur	0.998	1.038	1.000	0.998	1.035
Hidrandina	1.044	1.069	1.033	1.010	1.125
Luz del SUR	1.000	1.032	1.000	1.000	1.032
Seal	1.000	1.010	1.000	1.000	1.010

Effch = efficiency change; Techch = technical change; Pech = pure efficiency change; Sech = scale efficiency change; Tpch = total factor productivity change (Malmquist index).

larger quantity of data available and the fewer inputs; and from this point we will now continue using only Model 2.[22] Its results in Table 7 indicate that the main source of factor productivity change has been technological change, which is a situation specific to this industry. Unlike telecommunications it has not faced technological changes that are external to the firms; hence it is feasible to consider technological change as taking place within the company. Also, technological change happens during the first stage, so it is more likely to be linked to the reform process.

Table 8 shows that all companies have experienced increases in their total factor productivity, with the exception of Electro Puno whose decrease is probably explained by the aforementioned divesture process from Electro Sur Este. The companies with the most significant changes are Electro Centro, Hidrandina, Electro Oriente, Electro Ucayali and Edelnor. All of them, except Edelnor, are regional state owned companies owned that provide services to important Peruvian cities; this implies that such distribution networks have a predominantly high urban density. As previously stated, the first two were privatized in 1998 and returned to the Stated at the end of 2001; thus, the empirical evidence shows that the temporary property transfer had positive effects on the total factor productivity.

The decomposition of the Malmquist index shows that, at company level, productivity increases are explained by improvements in technical efficiency, as well as by positive technological change. Only three companies, Electro Puno, Electro Sureste and EdeCañete, show negative results; the first two cases are related to Electro Sureste's divesture of Electro Puno and the subsequent process of adaptation. Electro Puno's productivity and efficiency problems could also be related to its small size. What the results do show is that for Electro Puno the level of pure technical inefficiency is higher than is derive from scale efficiency.

Lastly, regarding the third company, EdeCañete, decomposition of the Malmquist index shows that the results reflect a problem of scale. This company can attain additional productivity increments if it adjusted its size.

5.3. *Efficiency drivers*

One relevant aspect regarding efficiency and productivity analysis is the identification of variables that explain technical efficiency in companies. Our results suggest certain differences in the efficiency between reformed and unreformed firms. Reformed firms are those companies which were privatized, regardless of whether they were later returned to state ownership. We are interested in analyzing whether the reform process, rather than the property regime, is the main reason behind the efficiency improvement of the firms.

In order to test the hypothesis we use both, a non parametric test, the Mann–Whitney (MW) test, and a parametric one, a censored regression model (Tobit). The MW test was applied to prove the hypothesis related to discrete (binary) variables.[23] We tested four hypothesized drivers that may explain some differences in the firms' efficiency, these drivers were public or private ownership of the companies, location in mountains, location in jungle, and whether they are reformed or unreformed firms. The null hypothesis is the lack of difference in efficiency reported by each type of firm. Table 9 presents the results of the test for technical efficiency under variable returns to scale (VRS)[24] for each year, and were taken from Model 2.

From the MW test results, we can deduce that, depending on the reform process, there is a difference in efficiency. The reformed firms are the most efficient, insofar as the probability is that their technical efficiency is higher than for the unreformed firms. This is shown in the first row of Table 9. The last row shows the results when the driver is publicly and privately owned, and these results are lower when the driver is reformed and unreformed firms. For this reason we have concluded that the reform process, via privatization, opened the door to new investment. This happened for at least long enough for firms to be able to adjust labour, modernize capital and so on. Finally, Table 9 also shows that the geographical location is not relevant when explaining the differences between firms, not even in the case of the Amazon jungle.

The estimation of a Tobit regression parametric model is complementary to the non parametric MW test. It was initiated so as to explain the determinant factors in the technical efficiency of the distribution companies under variable returns to scale. To that end and in accordance with Pombo-Taborda (2006), a censored regression model was estimated.

$$y_{it} = \begin{cases} x'_{it}\beta + \varepsilon_{it}, & \text{when } 0 < y_{it} < 1 \\ 0, & \text{for others values of } y_{it} \end{cases}$$

This is called second stage analysis. In the first stage efficiency is estimated, and in the second stage efficiency measurements are used as endogenously, with the aim to analyze which variables explain these measurements. Simar and Wilson (2000, 2007) assert that this type of non-linear regressions faces endogeneity problems, and that these estimators have a problem of bias; this is because the variables considered in the Tobit regression tend to be correlated with its endogenous variable. There is also a problem related to the sample selection of the firms considered. These combined difficulties generate a problem of consistency with the estimator.

Simar and Wilson (2007) suggest correcting consistency problems through the application of two bootstrap procedures. Another alternative would be to estimate the Tobit model with instrument variables. A second option, which is used in this paper, is to consider the environmental variables that are not correlated with input or output variables, but that are considered in the efficiency estimation model. Furthermore, our data are not a

[22] The authors will make the results for Model 1 available upon request.

[23] This test is only applied to discrete (binary) variables.

[24] When dealing with companies that are considered natural monopolies, due the existence of sub-additivity in its costs, it seems reasonable to assume that the electricity distribution companies operate under variable returns to scale (VRS).

Table 9
Mann–Whitney test. Model 2: variable return scale.

Variable	Statistics	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Property (dprop)	z	−1.445	−0.503	−0.671	−0.903	−2.216	−1.956	−1.104	−1.157	−1.057	−0.810	−1.018
	Prob $\|z\|$	0.148	0.615	0.502	0.367	0.027	0.051	0.270	0.247	0.290	0.418	0.309
	Prob (ET private ⩾ET public)	0.750	0.583	0.611	0.625	0.823	0.771	0.687	0.700	0.675	0.638	0.662
Reform	z	−1.445	−0.503	−0.671	−0.903	−2.216	−1.956	−2.284	−1.981	−1.516	−1.411	−1.430
	Prob $\|z\|$	0.148	0.615	0.502	0.367	0.027	0.051	0.022	0.048	0.129	0.158	0.153
	Prob (ET reform ⩾ET No reform)	0.750	0.583	0.611	0.625	0.823	0.771	0.854	0.812	0.729	0.719	0.708
Jungle	z	0.563	1.931	1.717	2.341	2.022	2.553	2.280	2.054	2.145	1.330	1.618
	Prob $\|z\|$	0.574	0.054	0.086	0.019	0.043	0.011	0.023	0.040	0.032	0.184	0.106
	Prob (ET jungle ⩾ET No jungle)	0.386	0.091	0.136	0.042	0.083	0.000	0.000	0.042	0.042	0.208	0.167
Mountains	z	0.000	−0.466	−0.621	−0.670	0.708	0.074	0.199	0.719	0.341	1.263	0.991
	Prob $\|z\|$	1.000	0.641	0.535	0.503	0.479	0.941	0.842	0.472	0.733	0.206	0.322
	Prob (ET mountains ⩾ET No mountains)	0.500	0.571	0.595	0.592	0.398	0.490	0.469	0.388	0.449	0.306	0.357

random sample as we have information about 14 firms that represents almost 98% of the total electricity distribution sales.

The estimated model has the technical efficiency measurement obtained though DEA as one endogenous variable, and a series of indicators as dependent variables. Five efficiency explanatory variables were considered.

The first one was investment per customer (I/N), which is a way of representing the company's network density, since the more investment per customer, the less network density.[25] Moreover, we sought to represent the business structure through a second variable that measures the rate of low-voltage sales over medium voltage for each firm; LV/MV. This variable reflects the relevance of the attended area's industrial activity.[26] The third variable, Jungle, accounts for the fact that the distribution firm located in the Amazon and is both the distribution firm and its own main generator,[27] and is typical for distribution networks that are isolated from the national interconnected grid. The fourth variable, Mountains, is one when a firm is located in the Andean mountains, mainly. Finally, a qualitative variable was considered to test the reform; i.e. reformed versus unreformed firms).[28] Sales according to voltage and customers according to voltage were other pre-determined variables that were evaluated; however, they were excluded by omitted variable test, because they did not improve the variance of the model being estimated.

In Table 10 summarizes statistics for the variables used in the Tobit model. We can see high variability in the data, which as already mentioned is good for an econometric estimate.

By calculating this censored regression through panel data with random effects[29] we obtain the results for the different econometric specifications that are indicated in Table 11. The table shows that for all the specifications we have considered the qualitative value always represents the reform regime, and the distribution firms always show individual relevance and a positive sign. This implies that after being reformed the distribution firms had higher technical efficiency. This is evidence of a positive correlation between the reforms and the efficiency in electrical distribution firms in Peru.

The mountains, jungle and parameter ratios for medium- to low-voltage sales are not significant individually, but a global significance test rejects the zero hypothesis in the parameters of the specification that were considered. This is evidence of multicollinearity problems, and so, we must not omit this variable. The parameters estimated show an inverse correlation between these variables and efficiency. This suggests that companies with a high proportion of low-voltage network residential customers are less efficient than companies with a preponderance of medium-voltage industrial and commercial users. The firms located in the jungle and mountains have lower efficiencies, due to deployment problems in the Andean mountains and in the Amazon rainforest.

Lastly, other variable with individual relevance is investment per customer, which has an inverse relationship. This means that an increase in investment per customer reduces the relative efficiency. This can be explained because the highest investment per customer is made in rural or urban zones a with low-network density, where it is not possible to take advantage of economies of density. This occurs especially in networks outside Lima, where there is electricity coverage to just over 50% of the families.

Finally, for those variables common to both the parametric Tobit model and non parametric MW tests, we can conclude that the empiric evidence indicates that there is a positive and

Table 10
Statistic of the Tobit model's variables. Model 2.

Variable	TE (VRS)	LV/MV	I/N	Jungle	Mountain	DProp	Reform
Mean	0.968	2.121	1.627	0.146	0.490	0.364	0.497
Minimum	1.000	5.720	4.573	1.000	0	1.000	0
Maximum	0.628	0.584	0.796	0.000	1	0.000	1
Standard deviat.	0.070	1.254	0.662	0.354	0.502	0.483	0.502

TE = technical efficiency; VRS = variable returns to scale; I/N: investment per client; LV/MV: low–medium voltage sales ratio; Jungle = dummy variable equal to 1 if the distribution company is located on Amazonas's jungle; Mountains = dummy variable equal to 1 if the distribution company is located on Andes's mountains; Reform = dummy variable equal to 1 if the firm is private or was privatized between 1996 and 2006 and DProp = dummy variable equal to 1 if the company is private.

[25] Less investment per customer is needed in higher density urban areas, compared to low-density rural areas. Moreover, by using two discrete variables, mountains and jungle, we tried to represent the geographical features such as orography, altitude, rain, temperature and so forth.

[26] Another option would have been to consider the variables that measure the participation of the industrial and commercial sectors in relation to the GDP of each department. However, as there are companies that distribute to more than one department, and more than one company that distributes to one department, this option was ruled out.

[27] According to the LCE regulations, companies that carry out two or more activities in the electrical sector (generation, transmission or distribution) must keep separate accounts. The data used, either inputs or outputs, only corresponds to the electrical distribution units.

[28] We also tested the property variable, but we get worse result than with reform variable; this is the same result we got with MW test.

[29] Stata 10.0 was used for the "xttobit" routine, with the minimum value equal to 0 and the maximum value equal to 1, for the endogenous value.

Table 11
Tobit model results.

Variable	Specification			
	(1)	(2)	(3)	(4)
Constant	0.990[a] (10.47)	0.942[a] (11.22)	0.931[a] (12.82)	0.996[a] (16.24)
LV/MV	0.029 (1.34)	0.031 (1.43)	0.030 (1.41)	
I/N	−0.033[a] (−2.03)	−0.039[a] (−2.42)	−0.039[a] (−2.41)	−0.035[a] (−2.18)
Jungle	−1.157 (−1.17)			
Mountains	−0.075 (−0.80)	−0.022 (−0.26)		
Reform	0.209[a] (5.86)	0.220[a] (6.33)	0.221[a] (6.35)	0.205[a] (6.28)
σ_μ	0.139	0.142	0.142	0.162
σ_ε	0.856	0.086	0.086	0.086
ρ	0.725	0.734	0.735	0.782
χ^2	45.03	44.35	44.35	42.40

I/N: investment per client; LV/MV: low–medium voltage sales ratio; Jungle = dummy variable equal to 1 if the distribution company is located on Amazonas's jungle; Mountains = dummy variable equal to 1 if the distribution company is located on Andes's mountains; Reform = dummy variable equal to 1 if the firm is private or was privatized between 1996 and 2006.

[a] Confidence level over 95%. The figures inside the parenthesis represent the statistical "*z*" in absolute value.

statistically significant correlation between the reformed firms and efficiency.[30] There is a negative correlation between productive efficiency and the location of the firms, but this correlation is not statistically significant.

6. Conclusions

The purpose of this research paper is to estimate efficiency and productivity changes in the 14 Peruvian electricity distribution companies during the period prior to the 1993 reform, and to verify if the changes in such indicators is explained by the reform process carried out since 1994. To that end, two alternative models, only differenced by the way they measure the capital, were estimated.

Efficiency estimates, obtained with DEA, as well as the total factor productivity change obtained using the Malmquist index, show that improvements in efficiency and productivity were higher in the first years following the implementations of the reforms within the sector.

Technical efficiency estimates using DEA show that the companies on the frontiers during the whole period are Edelnor, Luz del Sur, EdeCañete. The regional companies in northern and central Peru, which were privatized and then returned to the State, show significant and positive efficiency changes, even after they were returned. We have concluded that the reform process, through the privatization, has brought about an improvement in the allocation of resources; i.e. the reformed firms attain greater efficiency, even though some firms have subsequently returned to state ownership.

With regard to the total factor productivity that the Malmquist index reports for the 1996–2006 period, the annual average is 4.3%, the vast majority, 4.0%, is explained by technological changes. The results show that scale efficiency changes were minimal or irrelevant during the period analyzed.

Given the low technological dynamics of this industry, it is reasonable to assume that productivity gains achieved through technological change are explained by the reform process itself, which implies there was an exogenous environment that was more favourable for the development of both state and private companies. Technological change has been positive for all the companies except Puno. The specific problems that this company faced, which have already been mentioned, were the Electro Sur Este spin-off, management difficulties, a low-density concession area, low-income customers and networks with high energy losses.

Technical efficiency has been a lot more modest and favourable for all companies, with the exception of Electro Puno, Electro Sur Este, Electro Sur and EdeCañete. With the first two this is probably due to their spin-off in 1999, while the latter two had a scale-efficiency problem.

The results of the Mann–Whitney non-parametric test and the censored regression Tobit model show that the efficiency of the analyzed companies are directly correlated to their reform regime, and inversely correlated to investment per customer. The reformed versus unreformed contrast carried out in this paper aims to empirically validate the influence of the different private and public institutional environments on efficiency and productivity in Peru; and this is a consequence of the Peruvian State-s decision to not allow management autonomy in their state owned companies.

The opposite happened in Colombia, with Empresas Públicas de Medellín (EPM), an electricity distribution company that belongs to the municipality of Medellín. EPM is held in high regard in the region, due to its efficiency and its investment capacity in the region, and for its other activities within the power sector. EPM is the main shareholder in ISA, which owns the transmission networks in Colombia, Ecuador, Peru and Central America; in Brazil, ISA recently bought Sao Paulo's transport network. This is a good example of the separation between property and corporate governance.

With regard to the other variables included in the different Tobit specifications analyzed, the results show that investment per customer is negatively correlated with technical efficiency; this implies that those companies that invest more per customer are less efficient, due to network density economies. Of the other three variables, none show any individual relevance; these variables are the rate of low- over medium-voltage sales for each company, mountain location and a dummy if the firm is located in the jungle.

In general terms, our empirical evidence shows the need to introduce an incentive mechanism into the state electricity distribution companies. This would then allow them to act as

[30] This empirical evidence is not an evaluation of the positive aspects of the property regime per se nor does it evaluate any causal relationship. It looks at the characteristics of the institutional environment under which the private and State companies operate in Peru. Within the corporate governance framework, private companies must account to their minority shareholders for their actions, although they do not face investment restrictions when hiring, procuring services or consultancies. However, public distribution companies have to endure ever-increasing administrative restrictions in order to invest, complicated process of procurement of inputs and the ex-ante auditing process of the Government Offices.

private agents or with rules similar to those of private agents. Incentives based regulation would continue to be introduced, so that electrical distribution companies would keep on improving productivity. Moreover, this improvement could translate, via price regulation, into lower distribution rates. This in turn would increase the welfare for current customers and for potential consumers by easing the access to electricity. This is especially relevant in Peru, which has one of the lowest electricity access rates in Latin America.

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