Econometric Modeling of the Efficiency in the Generation of Electric Power in Chile

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Abstract. This research proposes the estimation of stochastic frontiers model using panel data, to measure the technical efficiencies in 4 perspectives for the electricity generation sector in Chile for the period 2010–2015. The first perspective is to analyze the main companies in the sector; the second is about generation plants based on their contribution only as energy generates; the third is also power plants, but this time considering its contribution as generation and security to the system; and a fourth analysis is following the third model, but this time only considering the year 2015 in order to get a greater sampling of power plants and generation sources. The estimation also used 2 functional forms of production for each analysis: Cobb-Douglas and Translogarithmic that are compared to obtain the best representation of the data. The results show to which companies, plants and generation sources are the most and least efficient.

Keywords: Electric power · Econometric modeling · Technical efficiency - energy generation

1 Introduction

In the last decade, energy issue in Chile has had a great impact on the national debate, being among the topics most commented on by Chileans, overcoming traditional issues of national interest such as health, education or citizen security. The reason of this great media growth was the protest marches of discontent citizens against the project that pretend to be the country's largest power station: the HidroAysén project, led by the country's biggest energy companies: Colbún and Endesa. The dam would be located on the Baker River, in the Aysén region, and would require 3,200 km. of construction in transmission lines. After much debate, for a long period of time, the project was rejected and abandoned, but it was not the only project in sight. The disappointment also encompassed projects such as: Punta de Choros (IV Region), Hidroeléctrica Alto Maipo (RM, currently under construction) and transmission lines, currently protests in Olmué against the Polpaico-Cardones line that would connect the electric transmission systems from the north (SING) and the central and south (SIC), part of Chile. This

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situation of disconformity with some big electrical generation projects are not only present in Chile but in several countries of the world. In general, people expect to move towards a more diversify energy matrix and to empower the contribution in the electrical generation of renewable non-conventional sources, to produce clean, renewable and sustainable energy.

In Chile, for example, the laws called Ley Corta I (2004), Ley Corta II (2005) and Pro Non-Conventional Energy (NCRE) Law (2007) aim to clarify transmission charges, to liberate of those charges small generators, to facilitate participation in bidding processes, to promote investment in the generation sector and to encourage the creation of non-conventional renewable energy (NCRE) projects with a goal of reaching a 20% contribution of NCRE throughout the matrix to the year 2020, which will be fulfilled by 2019. These regulations modified and facilitate investment in sustainable energies, after the supply crisis that occurred due to changes in the economic policy of our provider, which at that time propitiated the internal provision.

In 2011, during the first government of Sebastián Piñera, motivated by social protests to large generation projects, the Advisory Commission for Electrical Development (CADE) was created. Its main objective is to recommend a policy to develop energy growth base in clean, safe and economical sources to comply with the imminent growth of energy demand. Thus, the great conclusions of the panel of experts of this commission focused on taking advantage of the sources of water in the south of the country, generating progress for the eventual use of nuclear energy in the future and promoting the NCRE to make them more competitive.

These proposals deal with the situation of the Chilean generation system at that time, where in the north it is mainly supported by thermal energy sources, and in the south-central part by a mix of water and thermal sources. Therefore, according to the conclusions of the commission and facing the future and imminent union of the Interconnected System of the Great North (SING) and the Central Interconnected System (SIC), it can be inferred that the great nourishment for the energy matrix in Chile would be hydroelectric sources, both to large mining projects in the north, as well as to industrial and residential consumption.

However, there are some natural inquiries to this proposal. First, does it really respond to people's demand? Second, would it be possible to depend only on hydroelectrical power considering climate change and the floods that require their construction? Currently, there is no source of energy capable of satisfying all the demands of society, presenting all the positive characteristics that are sought in an energy matrix: clean, safe and cheap, and practically without generating negative externalities in its construction path. Hydroelectrical power is not completely secure because its supply depends on rainfall and requires the construction of reservoirs that flood big land portions. There are doubts about building nuclear power plants in a seismic country, as shows Japan experience, which is also prone to earthquakes. Consequently, there is a national consensus that the energy matrix of our economy must have mixed sources of generation. All sources of energy have their advantages and disadvantages, but it is the duty of those who plan the energy supply strategy to find the best combination of sources that guarantees energy consumption, economic growth, a clean and renewable environment, according to the available and feasible sources [1–4].

Therefore, the question is to find out the most efficient resource to generate electrical power. Thus, the present research, using stochastic production frontiers, assesses the efficiency in the production of electrical power according to the different technologies and sizes of the generation plants in Chile.

The purpose of this research is to determine and evaluate the technical efficiencies of the generation market in Chile, through two different considerations: the main generation plants and the main generation companies in Chile, both for the period of 2010–2015. This evaluation will build a ranking of the most efficient plants and companies and analyze the existence of common patterns in the different types of generation sources (thermal, hydroelectric, and renewable).

2 Methodology

Regardless of the type of organization (companies, organizations, countries, branches, plants, etc.) there is a basic principle of production that encompasses them all. To produce goods and services is necessary to use scarce resources: productive factors, which due to management can be combined in different and multiple ways to reach a production level. The choice of this combination of a better productive method aims to maximize the benefits given a certain proportion of productive factors or to a minimize production costs associated to a level of production [5, 6]. This maximum level of production is represented theoretically by the production possibilities frontiers (FPP) or production boundary functions.

In practice, productive economic agents are not always using their resources at the optimum level that would leads to its maximum benefit, hence, production may incorporate certain inefficiencies.

Economists usually use an enterprise production function to summarize information about the technically efficient production methods available to each company. The production function of a firm shows the maximum amount of output that can be obtained with a given number of factors and shows the results of different technically efficient production methods [7].

Productivity is a measure of efficiency; this can be expressed as the ratio between the amount of goods and services produced and the amount of resources used. On the other hand, efficiency is the relationship you have between effective production and the inputs required to achieve the minimum cost for that level of production. The mathematical expression of the production function is given by the following array:

$$\ln(y_{it}) = x_{it}\beta + v_{it} - u_{it} \tag{1}$$

The production frontier shows the maximum production level considering technology and the endowment of resources, implying that is the level of production that provides the highest level of utility or satisfaction that can be reached, given the resource constrains. The relationship between inputs and output shows the opportunity costs relevant for the economy [7–9].

As the production frontier is the limit of what is possible to produce given the factor endowment, any point situated beyond the boundary is unattainable while the ones located inside the frontier represent inefficient situations characterized by idle resources.

The production frontier is modelled under two alternative production functions, the ones that usually are considered in the related literature [7], the Cobb-Douglas (Eq. 2) and the Translogarithmic (Eq. 3).

$$q = f(K, L) = AK^{\alpha}L^{\beta} \tag{2}$$

$$\ln q = \beta_0 + \sum_{i=1}^{n} \beta_1 \ln X_i + 0,5 \sum_{i=1}^{n} \sum_{i=1}^{n} \beta_i \ln X_i \ln X_j \tag{3}$$

3 Results

We will work with a panel data structure, presented by quarter, given that the financial statements of large companies (SA) are presented quarterly, and will cover from 2010 to 2015. The analysis will be carried out in two instances: companies and power plants, whose results will allow to analyze the company's strategies and the mix of energy sources that they manage.

3.1 Analysis of Companies Behaviour

This analysis for the period 2010–2015 includes 4 companies that operate in the sector: AES Gener, Endesa, Colbún and E-CL. Although there may seem few companies to study the market, it is justified because the first three mentioned capture more than 75% of the market in the SIC, and the last almost 50% of participation in the SING, capturing more than 80% of the generation in both lines.

The production frontier is estimated using the Cobb-Douglas functional forms (Table 1) and the Translogarithmic (Table 2), and the results are as follows:

Table 1. Cobb-Douglas estimation companies

	Coefficient	Standard-error	t-ratio
beta 0	6.44	1.60	4.02
Costo Venta	−0.01	0.00	−13.50
Gasto ADM	0.58	0.12	4.99
Capacidad Neta	0.01	0.00	4.13
sigma-squared	0.08	0.07	1.25
Gamma	0.91	0.07	13.76
Mu	0.55	0.62	0.89
Eta	0.00	0.01	0.18

log likelihood function: 67.20
LR test of the one-sided error: 148.44
With number of restrictions: 3

Table 2. Translogarithmic estimation companies

	Coefficient	Standard-error	t-ratio
beta 0	13.70	1.13	12.17
Costo Venta (CV)	−0.01	0.00	−26.57
Gasto ADM (GA)	−0.51	0.10	−4.97
Capacidad Neta (cap)	−0.01	0.00	−5.02
0,5*CV*GA	−1.01	0.13	−7.87
0,5*CV*cap	−0.01	0.00	−6.81
0,5*GA*cap	0.68	0.07	9.31
CV^2	0.01	0.00	6.21
GA^2	0.17	0.02	8.30
Cap^2	0.00	0.00	4.10
sigma-squared	0.02	0.00	4.02
gamma	0.60	0.15	4.00
mu	0.21	0.10	2.15
eta	−0.02	0.01	−2.66

log likelihood function: 91.37
LR test of the one-sided error: 29.37
With number of restrictions: 3

In the first place, it is verified that both models, Cobb-Douglas and Translogarithmic, have the presence of technical inefficiency at 99% confidence interval given the values of their maximum likelihood ratios.

Another comparison is obtained by the gamma coefficients, where the closer to 1 indicates that the deviations obtained by companies are more linked to technical inefficiency, and by reviewing the gamma coefficients of both functional forms, it is observed that the Cobb-Douglas may be a better representation, since its gamma of 0.91 indicates that 91% of the deviations are due to technical inefficiencies versus the 0.60 gamma of the Translogarithmic function.

To know which representation is best suited to the data, a test must be performed calculating a generalized likelihood ratio (LR). To calculate the generalized likelihood ratio, the test uses the values of the logarithmic likelihood functions of both estimated functions, using as a null hypothesis the Cobb-Douglas functional form and as an alternative hypothesis to the functional form the Translogarithmic one. According to the test, if the value obtained LR is greater than the chi-square, taking as degrees of freedom the number of parameters of the second order of the null hypothesis at 95% confidence, then the null hypothesis is rejected. In this case the Cobb-Douglas model would be rejected, to accept the alternative hypothesis, the Translogarithmic function. Vice-versa in case it is less.

In the estimations made, a log-likelihood function value of likelihood was obtained for the Cobb-Douglas function of 148.44, and a value of 29.37 for the Translogarithmic function. Therefore, replacing the values according to the formula of the test results in an LR of:

$$LR = -2[(148.44) - (29.37)] = -238.14$$

This value is compared with the corresponding chi-square value of 9.4877, so that since LR is a smaller value, the null hypothesis that the Cobb-Douglas boundary is a better representation for the data is accepted.

The first conclusion reviewing this model is about the coefficient of the eta value, which turns out to be zero which indicates that there is no decrease or increase in technical efficiency in the analysis period for this sector according to these estimates.

Afterwards, the evolution of the technical efficiency in the time of the analysis by company is processed, ranking them according to its efficiency calculated by the average of the efficiencies of the companies along the time. The results shows that Endesa remains in the first place reaching an average efficiency of 85.07% and being the only one above the general average of the 4 companies; followed by Aes Gener with 48.98%, then in third place Colbún with an average efficiency of 43.99% and finally E-CL with 36.33%.

Regarding the efficiency over time as general averages, this rises by 0.75% in the 6 years considered by the study. This small increase can be considered as the technical efficiency in the sector practically remains unchanged over time.

3.2 Power Plants Analysis

This analysis is carried out for 92 plants present in this research for the period 2010–2015, which includes 24 quarters. Although there are many more centers operating in the SIC and SING lines, the Balanced Panel Data methodology requires monitoring of the data within the study period, and many plants, especially new NCRE plants, have started operations mostly in the years of 2014 and 2015, so they can not be incorporated into the study. This mean that solar plants were not included in the sample of power plants, which began their biggest operations since 2014.

The production frontier estimates using the Cobb-Douglas functional forms (Table 3) and the Translogarithmic (Table 4) are the following:

Table 3. Cobb-Douglas estimation power plants

	Coefficient	Standard-error	t-ratio
beta 0	6.72	0.83	8.12
Costo Marginal	−0.13	0.09	−1.46
Capacidad	1.13	0.07	16.04
sigma-squared	139.55	30.16	4.63
gamma	0.9551	0.01	94.75
mu	−23.09	4.16	−5.55
eta	−0.03	0.00	−13.35

log likelihood function: −5,304.06
LR test of the one-sided error: 1,570.56
With number of restrictions: 3

Table 4. Translogarithmic estimation power plants

	Coefficient	Standard-error	t-ratio
beta 0	5.10	5.52	0.92
Costo Marginal (Cmg)	0.72	0.48	1.50
Capacidad (Cap)	1.18	1.03	1.15
0,5*Cmg*CMg	−0.16	0.12	−1.34
CMg^2	−0.01	0.05	−0.21
Cap^2	0.01	0.05	0.25
sigma-squared	138.22	28.72	4.81
gamma	0.9550	0.01	90.29
mu	−22.98	6.50	−3.53
eta	−0.03	0.00	−11.79

log likelihood function: −5,302.47
LR test of the one-sided error: 1,234.75
With number of restrictions: 3

The likelihood ratio test is carried out, confirming that in both functional forms the presence of technical inefficiency at 99% confidence is found. Both models also showed gamma coefficients close to 1 (0.955) indicating that deviations between plants are strongly explained by technical inefficiency.

To define the model that best fits the data, the generalized likelihood ratio (LR) is calculated, although it should be mentioned that there were no large differences in the rankings by more efficient sources and plants.

The LR obtained a value of −671.61, which is less than the chi-square value corresponding to this model, which is a value of 7.81, and therefore in this case the null hypothesis that the Cobb frontier is accepted. Cobb-Douglas is a better representation for the data and consequently its results are accepted as conclusive.

The Cobb-Douglas model showed that there is a decrease in technical efficiency within the analysis period, where the average technical efficiency of the sample falls 12 points from 2010 to 2015. The presence of decrease is aligned with the trend indicated by the coefficient eta. This indicator has the same negative coefficient in the Translogarithmic function.

Regarding the power plants studied, there is no source that has 100% efficiency, or an approximate value. The preceding result is aligned with the reality and opinion of experts, since there are no sources with continuous supply and high plant factors, and at the same time with low operating costs.

According to the results, the most efficient generation means correspond to coal (with an average technical efficiency of 63%), followed by run-off-the-river hydroplant (59% of technical efficiency) and thirdly, biomass plants (46% technical efficiency). In the middle places are hydroelectric dams (41%), wind turbines (25%) and combined cycle power plants (23%). In the last places of the ranking are the petroleum power plants, which are hyper-inefficient regardless of their size, with results lower than 10% technical efficiency on average.

4 Conclusions

Technical efficiency is achieved when power plants maximize output using all the available inputs. Determining its level provides with a valuable insight into the behavior of the companies and power plants in the period under review and allows comparing the results each other. If power plants are not using their resources properly, they can make economic adjustments that permit them to increase production and improve efficiency [10].

Regarding the results and efficiency differences obtained by the companies, these may be related to the mix of energies they have implemented. Endesa, which has the highest efficiency and increases the average for the sector, is the most diversified in the technologies it uses to generate power. Of the four large companies, it has the most in installed hydro capacity (run-of-river and dams) and ERNC (solar, biomass and wind), both nominally and in proportion, with the latter having the lowest marginal cost. In addition, it is the one who least concentrates its activity in oil power plants, which are the most expensive to operate in the system. About thermal energies, Endesa centralizes its matrix in combined cycle plants, that is, in plants that can alternate their production between diesel or natural gas, seeking an advantage in gas that is cheaper.

Ensuing is Aes Gener, a company that concentrates its matrix in thermal coal and followed by combined cycle. Both sources have medium average costs, since coal and natural gas tend to conflict with hydroelectric resources over which are cheaper, although this is very volatile (it depends on hydrological and climatic activity). In addition, these sources usually have a high contribution in installed electrical power, which allows greater gains in power and have a high activity, allowing gains in power and energy.

In the third place, Colbún is positioned, even though is a company that also has a very diversified matrix, which after Endesa is the one with the most installed capacity in hydroelectric power. However, it is worth mentioning that it has the most installed capacity in purely diesel oil plants, both nominally and proportionately, being the most expensive type of energy, which could be pushing it to worse efficiency results compared to the previous two competitors.

Finally, the company E-CL is the least efficient. Its matrix is similar to Aes Gener in proportions, although more concentrate on thermal since it is concentrated in the SING so its geographical behavior matches with thermal dependence. Both companies concentrate their activity on coal followed by the combined cycle, and they have similar proportions of their capacity as diesel power plants (14% E-CL and 12% Aes Gener). Although their similarities in their matrices, the efficiencies results are different, so the compositions of E-CL matrix may not be the only cause that explain the efficiency differences, otherwise it would have obtained similar results to Aes Gener.

Regarding the results obtained from the analysis by power plants, the oil power plants have the worst results, despite that they represent the largest group in the sample. None of these plants occupied a position above the general average. Moreover, most of them are under 10% efficiency, and a considerable group of these plants have efficiencies on average less than 1. This could be explained given that oil plants are recognized as having higher marginal costs, so their greater contribution is to the installed electrical power more than to the generation of energy [11]. These plants go through long periods of time with no production. Therefore, these kinds of plants have low technical efficiency results.

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