Non-linear Demand and Price: An Empirical Analysis of the Brazilian Industrial Electricity Consumption*

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Abstract

In this paper we proposed an econometric model for industrial electricity demand in Brazil. Differently from residential customers, industries in Brazil, in addition to purchasing energy and capacity, also face a tariff menu with Time of Use pricing. Each item in this menu also has different components and price discrimination structure. All these characteristics pose an empirical problem that, so far, has not been faced together in the literature. This methodology was applied in a non-experimental micro data sample of 646 large Brazilian industrial customers (with demands over 300 KW) between January 2002 and December 2006. The results indicate demands for the various services (capacity and energy, separated between peak and non-peak hours) are price elastic, and at least in the AZUL tariff, there is complementarity between energy and capacity in the different periods. Thus, policies on tariff structures based on assumptions of an inelastic aggregate electricity demand could have effects that are quite different from what was intended.

Keywords: Tariff Menu; Price Discrimination; Discrete-Continuous Model.

JEL Codes: L51; L60.

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1. Introduction

The importance of efficient use of electricity is ever-growing, due to potential emissions of green-house effect gases by the different energy sources. To make electricity use more efficient, it is especially important to develop electricity pricing policies – which demands a deep understanding of the demand for electricity, a good that cannot be stored and has variable demand through the day. If we add that the belief that one of the possible technological paths for the auto industry is the development of electric cars, the question of the use of electricity throughout the day is another motivation for the study of electricity demand. Additionally, the tariff's design must deal with the fact that consumers respond to price signals, reorganizing their demand, both in total amount of electricity use and in terms of usage throughout the day.

Usually electricity consumers are divided into two large categories – those that demand high voltage electricity (voltage above 2.3kV in Brazil) – and those that demand low voltage electricity. The residential and commercial consumers are usually in the second group, and the industrial consumers are more commonly found in the first group. The division between high and low voltage is also reflected in terms of behavior of the group of consumers – both in terms of price sensitivity and in usage substitution throughout the day.

The greater part of empirical studies on the industrial demand of electricity in developing countries – where a large part of the additional demand will be in the next few years¹ – ignores the fact that this consumer faces a tariff menu that is much more complex than that of the residential consumers. The industrial consumers, especially the large consumers in this category, not only face the need to buy energy and capacity, but also face different prices for energy and capacity purchased at different times during the day.

The discussion on those tariff menus is especially important for Brazil, where the tariff structure is already in need of change. The present tariff structure is based on a collaboration between Eletrobrás, the Departamento Nacional de Águas e Energia Elétrica [National Department of Water and Power] and the *Electricité de France* as a consultant for two projects. In the first project, between 1977 and 1979, studies were carried out to determine the marginal cost of supplying electricity to consumers and to evaluate the possibility of basing the tariff structure on those costs. The second, between 1980 and 1981, resulted in the publication of a document named “Estrutura Tarifária de Referência para Energia Elétrica” (Energy Reference Tariff Structure) ANEEL (2009). The different tariffs developed at that time were based on a demand structure that was vertically integrated with the supply of electricity and the capital and operational costs of generation and transmission were taken into account in the distribution tariffs.

¹(MME/EPE, 2012, p. 38) shows that, even though the expected growth rate of for industrial consumption is lower than the residential and commercial one, it is still proportionally the largest category in terms of consumption, and will continue to be so in the near future.

Also according to ANEEL (2009), between 1982 and 1999, the tariff structure underwent only minor changes. In the year 1999, the tariff structure was changed to reflect the deverticalization of the sector. Even with those alterations, the price structure related to energy and capacity during the day is still inefficient. Consequently, there is sub-optimal use of diesel generators to reduce the demand at peak time or high-voltage consumers attempting to find direct connections to avoid the distribution network.

Even from the theoretical point of view, there are certain controversies on the capability of the real time pricing arrangements to consistently generate efficiency gains. Even papers which are clearly favorable to Real Time Pricing, such as Borenstein and Holland (2005), state that in some cases the increase of consumer participation in this arrangement can benefit those which use the more traditional price structure, as well as hurt those that were already using the Real Time Pricing structure.

Thus, a discussion on the price levels of electricity that does not take into consideration the fact that this product is sold according to a non-linear price structure can cause biased estimation of the relevant parameters, which could eventually lead to a worsening of the problems discussed above.²

The price elasticity estimates of industrial electricity in the Brazilian literature evaluate, basically, the average consumption, as it will be shown in the Literature Review Section. However, the pricing system adopted by the Agency recognizes the importance of distinguishing the use of energy and capacity (kW), and that the last one determines the dimension of the distribution systems, and consequently, of investments. Without adequate information the investment predictions can be excessive or insufficient, thus the importance of knowing the degree of substitution between energy and capacity, which is the original contribution of this paper to the literature.

To deal with this problem, the present paper develops a methodology, using the classic contribution of Train and Mehzrez (1994), to deal with two characteristics of the electricity industrial tariff structure: the existence of different prices for energy and capacity, discriminated by time of the day. Additionally, the application presented here also deals with the fact that there are several tariff levels, creating a tariff menu (self-selecting tariffs). The methodology presented here was applied to microdata database of energy and capacity consumption of large industrial Brazilian consumers in which the modality of tariff chosen, as well as the amount of services in that modality (energy and capacity) is registered, for the period between January 2002 and December 2006. This microdata database was essential for the development of our application.

²More specifically, the presence of different tariff menus tends to generate biased estimates because it is not always possible to separate a change in the demand for electricity in an item of the tariff menu from the effect of an increase in one of the prices on the choice of items from the tariff menu.

Before we present the data and model, the next section describes the more general literature that the presented methodology belongs to. This literature deals with both the previous attempts of estimating electricity industrial demand as well as the time of use pricing literature. After this literature review, we present the econometric approach, as well as the estimations of the parameters per se. The fourth section presents our conclusions.

2. Literature Review

In this article the literature review is relevant because the research covers two separate themes. The first is the electricity price sensitivity estimation, focused in the industrial demand of electricity in Brazil, the second is the international literature on Time of Use Pricing.

The focus regarding the estimations of price elasticity of electricity in Brazil was the estimation of aggregated elasticities, using the average income as a proxy for the price of marginal Kwh. Modiano (1984), using data from 1963 to 1982 is the first study to use a modern econometric approach. The author uses a double log demand specification, with the demand being described by lags, and estimated using Ordinary Least Squares, with correction for serial correlation through the Cochrane-Orcutt process.

This study was considered state-of-the art research for 13 years, until Andrade and Lobão (1997) decided to extend the sample used by Eduardo Modiano and apply the most modern techniques available at the time, carrying out their analysis for residential electricity demand only. From a methodological point of view, the authors used some models of the Instrumental Variables method, but their main results stem from the Error Correction Vectors system.

Schmidt and Lima (2004), updated the data from the previous article, and also used a methodology of Vector Autoregression and Error Correction Vectors. Differently from Andrade and Lobão (1997), Schmidt and Lima (2004) worked with three classes of consumers, residential, commercial and industrial. From the functionality point of view, the authors kept the double log form, which allows them to calculate the long and short term elasticity more easily.

The largest part of the subsequent research followed the same methodological line, using a double log specification and an Autoregressive Vectors or Error Correction Vectors system. de Mattos and de Lima (2005) follows the same methodology, in their analysis of residential electricity consumption in the State of Minas Gerais. de Mattos (2005) also applies this methodology to the case of electricity industrial demand. In more recent papers, only Irffi et al. (2009) use a different econometric methodology, Dynamic Ordinary Least Squares and Regime-Switching Model. The functional form is still the double log.

Only in Siqueira et al. (2006) do we find the addition of the Instrumental Variables methods to the framework VAR+VEC used in the other models. The table below summarizes the values calculated for the elasticities for all the papers

mentioned.

Table 1
Calculated Elasticities – Long Term

Paper	Method	Residential demand	Commercial demand	Industrial demand
Modiano (1984)	MQO+CORC	-0.40	-0.182	-1.22
Andrade and Lobão (1997)	VAR+VEC	-0.058		
Schmidt and Lima (2004)	VAR+VEC	-0.085	-0.174	-0.545
Mattos (2005)	VAR+VEC			-0.094 (NS)
Mattos and Lima (2005)	VAR+VEC	-0.258		
Irff et al. (2005)	DOLS+MS	-0.68		
SCC (2006)	IV	-0.778	-0.824	-1.019
SCC (2006)	VAR+VEC	-0.412	-0.502	-0.982

Source: Prepared by the authors. DOLS: Dinamic OLS. MS: Markov Switching.

SCC: Siqueira, Cordeiro Junior and Castelar (2006).

One of the conclusions reached by these studies is the smaller magnitude, in absolute terms, of the price elasticity of the demand in the Brazilian case. This result for Brazil is in agreement with those found for other Latin America countries, which originated the comment by Westley quoted in Schmidt and Lima (2004) p. 70 that reads: “the consumption of electricity grows at a fixed proportion with income and its elasticity is nearly zero”. However, the definition of the database and the price structure of the sectors cause a few problems in the studies which support this claim. For example, the approximation of the marginal KWh using the mean cost can cause serious econometric problems, especially in the case of non-linear price structures, as already demonstrated by the review of Taylor (1975). Intuitively, the problem of using the mean cost as an approximation of the marginal KWh price, in the case of non-linear prices, is a variation of the omitted-variable bias problem. Shocks to the demand equation cause changes in prices paid by companies, since it can place them in different levels of the price scale. Additionally, the estimation of the price elasticity in the demand of electricity – even when carried out in the most correct form possible – as a whole tends to be lower in absolute terms than the estimate demand for electricity during different times in the day. Policies based on these times estimates can incur serious errors.

The international literature on the theme of price elasticity in the electricity demand is vast, meriting several reviews throughout the years. The first review, already a classic, the Taylor (1975) focus mostly on the criticism to the previous studies, concluding that the elasticity magnitudes are greatly dependent on the methodology used. For the industrial demand, the long term elasticity computed vary from -1.25 to -1.94, a lot higher than the figures found in the table above.

The paper by Taylor (1975) was updated by Bohi and Zimmerman (1984) which, in the case of industrial electricity demand, finds the short term elasticity in the range of -0.18 to -0.60, and in the long term, elasticity in the order of -1.5. Only in one of the studies reviewed elasticities below one (in absolute terms) were estimated.

After the contribution of Bohi and Zimmerman (1984), the next review was Griffin (1993), which focused less on demand price elasticity and more on the new methodologies for econometric modeling of the electricity demand, both on the demand for electricity and its relation to the choice in domestic appliances. In the years following those reviews there were a few studies, and those that were closer to the present study in terms of data structure and methodology are Bjorner et al. (2001), and Filippini (1995), which used microdata to estimate the elasticity in the industrial demand for electricity, in the first study, and residential demand in the second. In Bjorner et al. (2001), we observe elasticities of around -0.5 , and even lower in models which incorporate non-observable heterogeneity such as fixed effects.

Another important piece of literature is related to the studies used to evaluate the sensitivity of the demand to different prices during the day, known as Time of Use pricing. The greater part of those studies involves experiments and gathering of microdata from consumers in the period around the introduction of this methodology. There are two important reviews on this theme, carried out by Ahmeed Faruqui and his co-authors (Faruqui and Malko (1983) and Faruqui and Sergici (2010), in addition to Aigner (1985). In the first article, the authors describe the results of 12 experiments with residential consumption and show that the price elasticity of the demand is very close to zero and there are consumption substitutions between different times of the day in response to this price structure. This review was updated with 15 new experiments by Faruqui and Sergici (2010), and found similar conclusions.

In regards to Industrial consumers, Sheen et al. (1995) carried out a study – non-experimental – on the industrial demand for electricity in Taiwan, and found very elastic demands for the different prices during the day. Another classic study on the topic is that of Aigner and Hirschberg (1985), which found a significant substitution elasticity in absolute numbers between peak time and non-peak time for large industrial consumers. A more recent one, and closed to the contemporary literature is that of Train and Mehrez (1994), which uses a methodology similar to ours.³

Despite all that, the existence of different prices at different times of the day is only one part of the price structure that an industrial consumer is faced with regarding electricity. In the next section we go into more detail on the depth of price structure for electricity in Brazil.

2.1 Tariff Structure for Industrial Electricity

An important point, with important effects on the results of the empirical modeling, is the fact that the prices used for electricity are not linear, and present important distinctions both in regards to the paradigm of linear prices and in how

³With the difference that they allow heterogeneity in the coefficients of the individual demand function, allowing only one pricing tariff.

residential electricity is sold.

In Brazil, the industrial consumers of electricity are classified into two large groups relating to the level of voltage they are connected with. Those groups were defined in the 1980s, in the publication “Estrutura Tarifária de Referência para Energia Elétrica” [“Energy Tariff Structure Reference”] (ANEEL, 2009), and are the same for all the electricity distributors in Brazil:

- Group A: Consumers connected to voltage equal or superior to 2,300 volts, and divided in the following subgroups:
 - Subgroup A1 – Voltage equal or superior to 230kV;
 - Subgroup A2 – Voltage between 88 kV and 138 kV;
 - Subgroup A3 – Voltage of 69 kV;
 - Subgroup A3a – Voltage between 30 kV and 44 kV;
 - Subgroup A4 – Voltage between 2.3 kV and 25 kV
 - Subgroup AS – Voltage bellow 2.3 kV, supplied by the underground distribution network and optionally billed in this group.
- Group B: Consumer connected to voltage bellow 2,300 volts.

For consumers in the groups A3a and A4, with purchased power of up to 300 kW, two tariffs are offered, AZUL or VERDE, and also Convencional, thus creating a tariff menu and an system of non-linear prices.⁴ Each of these tariffs differs from the others – and the residential tariff- because it works with two prices: price of electricity and price of capacity. The first price, of electricity, is related to the monetary value paid for the supply of Kwh for the consumer, and the price of capacity is the price paid by the consumer to have the electricity available to him.⁵ If the consumer uses more electricity than the contracted capacity, it pays a much higher price than that of the hired energy.

In the “Tarifa Convencional”, the total bill of a client is given by, approximately:

$$T_C = d \times t_d + e \times t_e$$

where d represents the hired capacity and e the electricity used, t_d and t_e represent the tariffs for capacity and electricity, respectively. Additionally, there is also the discrimination of prices for the period of time in which the electricity was used, with non-linear tariffs.⁶ The first type of tariff is the VERDE tariff, in which

⁴This structure was created at the same time, in the publication mentioned above.

⁵Usually this separation of prices based on consumption is justified with the argument that the capacity tariff would help recover the fixed costs, and the energy tariff would cover the marginal cost of power generation.

⁶Notice that, in the case of residential tariffs, we have a non-linear pricing system regarding the amount of energy consumed, and not the Time of Use system as in the industrial case.

there is only one price for capacity and two prices for electricity – at peak time and off-peak time.⁷

$$T_V = dt_d^V + e_p t_{ep}^V + e_{fp} t_{efp}^V$$

In this type of tariff, e_p represents the electricity consumed at peak times, and e_{fp} the electricity billed at off-peak times. The tariffs during the different times of the day are denoted as t_{ep}^V and t_{efp}^V . Finally, according to the AZUL tariff, the consumers must hire levels of capacity both for peak time and off-peak time. Additionally, they need to pay for electricity used during the two periods. The total bill of for an industrial client in the AZUL tariff would be calculated as:

$$T_A = d_p t_{dp}^A + d_{fp} t_{dfp}^A + e_p t_{ep}^A + e_{fp} t_{efp}^A$$

- d_p - Hired Capacity for peak time
- d_{fp} - Hired Capacity for off-peak time
- e_p - Electricity used at peak time
- e_{fp} - Electricity used at off-peak time

In a way, both the AZUL tariff and the VERDE tariff can be considered as special cases of the known Two-part Tariff of the traditional microeconomy. The tariff structure is not only interesting as a key element in the institutional environment in which the company operates, but also shows one of the main limitations of previous studies on the demand of electricity. Such limitation can explain why studies carried out in Brazil usually find price elasticities that are so much lower than those found in the international literature, and it is related to the fact that the series used present mean prices. That is, the representative variables of prices in that study can be understood at average revenue of the energy operators, and only weakly related to the price of the marginal MWh demanded by the consumer. Those mean prices include the price of the marginal MWh used by the consumer, but also all the alterations on the units consumed bellow margin, and as a result, create a bias in the estimates of demand price elasticity.

To summarize, the electricity distribution regulation environment in Brazil uses several tariffs for different times of the day (TOU Pricing), in addition to the price of capacity and energy. In this sense, the adequate modeling of the industrial demand of energy in Brazil must go beyond the existing literature. Models as the ones used by Train and Mehrez (1994), despite being a step in the right direction, model the problem of self-election constraint, and do not deal with the question of energy and capacity demand, because they deal with domestic demand. Additionally, they only deal with one tariff line parallel to the constant pricing during the day.

⁷Peak time is defined as the 3 hour interval in the day with the greatest demand of capacity from the power distribution company, and it is valid only for the five business days of the week.

To deal with these problems, the present paper uses a database from companies, with prices they actually face, to estimate the demand elasticity of prices of the different tariff components. The next section describes the methodology used.

3. Empirical Analysis

In this article we propose a structural model to model the industrial demand for electricity that goes beyond those described above, and is able to integrate the choice of tariff modality with energy demand in the two periods of the day (peak and off-peak). We assume that the company uses the different types of energy and capacity mentioned before, thus the function can be described as:

$$Q = F(e_p, e_{fp}, d_p, d_{fp}, \mathbf{Z}) \quad (1)$$

where Q is the amount produced and $\mathbf{Z}$ amounts of other insumes, and the other variables previously defined. Assuming the weak separability and homotheticity in the production function we can rewrite this function as:

$$Q = F(EE(d_p, d_{fp}, e_p, e_{fp}), \mathbf{Z}) \quad (2)$$

where EE is the aggregated measure of energy. Given these hypothesis, we can describe the global cost function, in which C_{EE} is a measure of the Electric Power costs, as:

$$CT = C(C_{EE}(t_{ep}, t_{efp}, t_{dp}, t_{dfp}, Q), P_{\mathbf{Z}}, Q) \quad (3)$$

As a premise of homotheticity and weak separability, we have that the selection can be modeled in two steps, the first is choosing a tariff from the menu, and the second is determining the different demands for energy and capacity of the different products. Especially, $C_{EE} = C^A$, se $C^A < C^V$ C^A if and $C^A < C^C$, where C^A is the cost of an amount EE of energy in the AZUL tariff, is the cost of the same amount in VERDE tariff, and C^C is the cost in the conventional tariff. Similarly, $C_{EE} = C^V$ if the cost in the VERDE tariff is lower than in other tariffs.

In this paper we assume a functional form for the cost function in the PIGLOG form:

$$\ln C_{EE}(t_{ep}, t_{efp}, t_{dp}, t_{dfp}, Q) = \alpha_0 + \sum_k \alpha_k \ln t_k + \frac{1}{2} \sum_j \sum_k \gamma_{jk} \ln t_j \ln t_k + Q\beta_0 \prod_k t_k^{\beta_k} \quad (4)$$

When we carry out the logarithmic differentiation for each of the prices of the different types of energy, we have the following equations for each of the tariffs:⁸

$$s_k = \alpha_k + \sum_j \gamma_{jk} \ln t_j + \beta_k Q \beta_0 \prod_k t_k^{\beta_k} \quad (5)$$

⁸Greene (1984) carries out similar modeling for the case of diesel fuel oil demand.

where the variables s_k represent the participation in the total expenditure of the k -th type of service. We can write that as $C_{EE} = RT - P_Z \mathbf{Z}$, that is, the cost of energy is the same as the difference between the total revenue minus the expenditures with other insumes and economic profits. Assuming that $P_Z \mathbf{Z}$ is a function of C_{EE} , we can rewrite the equation as:

$$s_k = \alpha_k + \sum_j \gamma_{jk} \ln t_j + \beta_k \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \quad (6)$$

where C_{EE} is the total expenditure with energy, as previously defined and $\mathbf{P}$ is an energy price index, which in this paper assumes a linear form of the Stone Index:

$$\ln \mathbf{P} = \sum_k s_k \ln t_k$$

The coefficient β_k in the equation above measures the sensitivity of the different participations in the expenditure of the total volume spent with energy. This is a version of the Almost Ideal Demand System of Lee et al. (1980), often used for modeling the demand of homogenous products. Despite being interesting, this modeling presents additional difficulties for estimations, since the choice between tariffs and the type of energy consumed are inter-connected. The equations of the system components above will be different for each type of tariff chosen (AZUL, VERDE or Conventional). If we ignore this possibility, we might obtain biased coefficients, which would represent both the substitution in the use of energy between the different times of the day and the same modality with substitutions between the different tariff lines. A similar approach is used by Lee, Maddala and Trost (1980), and which can be applied here, is the characterization of this econometric problem as an application of the switching simultaneous equations. In this methodology we would have a model with two states. The first is the selection of tariff modality, and the second the services of that tariff modality. That is, if the tariff chosen was the AZUL, the demand for the four services would be:

$$\begin{aligned} s_{ep} &= \alpha_{ep} + \sum_j \gamma_{j,ep} \ln t_j + \beta_{ep} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \\ s_{efp} &= \alpha_{efp} + \sum_j \gamma_{j,efp} \ln t_j + \beta_{efp} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \\ s_{dp} &= \alpha_{dp} + \sum_j \gamma_{j,dp} \ln t_j + \beta_{dp} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \\ s_{dfp} &= \alpha_{dfp} + \sum_j \gamma_{j,dfp} \ln t_j + \beta_{dfp} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \end{aligned} \quad (7)$$

In the same manner, if the chosen tariff is the VERDE, we have:

$$\begin{aligned} s_{ep} &= \alpha_{ep} + \sum_j \gamma_{j,ep} \ln t_j + \beta_{ep} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \\ s_{efp} &= \alpha_{efp} + \sum_j \gamma_{j,efp} \ln t_j + \beta_{efp} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \\ s_{dp} &= \alpha_{dp} + \sum_j \gamma_{j,dp} \ln t_j + \beta_{dp} \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \end{aligned} \quad (8)$$

To deal with this problem, we propose the addition of a selectivity term in the equations estimated for each of the regimes. This term of selectivity depends on how the tariff choice is specified – since it is a discrete choice model. In this paper specifically, we have chosen to model the choice of tariff as a multinomial LOGIT, similarly to Dubin and McFadden (1984). With this modeling, a generic equation of the equation system above would be as follows – in the next example the tariff chosen is the AZUL:

$$E(s_k|M=A) = \alpha_k + \sum_j \gamma_{jk} \ln t_j + \beta_k \ln \left(\frac{C_{EE}}{\mathbf{P}} \right) \quad (9)$$

$$+ \sigma \left[r_1 \ln(P_A) + \sum_{j=V,C} r_j \frac{\ln(P_j)P_j}{(1-P_j)} \right]$$

where σ represents the standard deviation of errors in the original equation, and r_j the coefficients specific to each selectivity component – which are not identified separately from the coefficient r_j . Despite the fact that this specification produces estimates that are asymptotically consistent, we have a problem associated with inference. Especially, in the presence of the term estimated between brackets, the estimates are inefficient. To deal with this problem, the standard-errors were calculated using bootstrapping, with 100 replications and clustering for each company.⁹

The model for tariff selection, basis for the calculation of probability of choice and the selectivity correction factor discussed above, is based on the following utility function for the alternative $j = \text{VERDE, AZUL or Conventional}$:

$$U_{ij} = V_{ij} + \varepsilon_j \quad (10)$$

where V_{ij} denotes the deterministic part of the utility for the consumer i brought about by choosing the tariff j and the ε_j the idiosyncratic part.¹⁰ The mean utility for the choice of the Conventional tariff was normalized in zero¹¹ and the following parametrization of the term V_j was adopted:

$$V_{ij} = \phi_{j0} + \phi_{j1}g_i + \phi_{j2}lfp_i + \phi_{j3}lp_i + \phi_{j4}C_{EEi} + \phi_{j5} \ln \mathbf{P}_i + f_s + t_i \quad (11)$$

⁹We have also tested estimates using only the bootstrapping, without clustering, and the standard deviations calculated as usual. The results are available upon request, and were not reported. In general terms, the results of these alternative estimates were better in terms of significance of the coefficients, and the conclusions drawn in this paper would also be valid for the alternative method.

¹⁰Which we assume follows a Gumbel distribution (also known as extreme values distribution).

¹¹Because the companies in this paper are all above 300 kV, they could only choose between V or AZ. The binary selection models were necessary for VERDE-Conventional because some companies were not placed in the correct tariff, they increased the capacity but did not change contracts. Thus, it would not be adequate to explore this choice as a basis, we would need a basis with companies below 300 kV.

where f_s are fixed effects of the sector and t_i are fixed effects of time. The tariff “Conventional” was established as the base category, and therefore we assumed $V_{ij} = 0$ for this category. The variable lfp is the load factor during the off-peak time and lp is the load factor during peak time. Regardless of the time, the load factor is an index which demonstrates whether the use of energy is being done in a rational and economical manner. This index varies from zero to one, and is obtained using the relation between active energy consumed in a specific period of time and the total active energy that could be consumed, if the demand measured in the period (maximum demand) was used the whole time. Finally, the variable g represents the ratio between the peak time demand and the off-peak time demand. Differently from the load factor, which involves both energy and capacity, this variable is related only to the relative use of capacity in both periods. Those variables are important for the identification of coefficients.

The coefficients ϕ are indexed according to the alternative (thus the subscript j), in an attempt to capture part of the non-observable heterogeneity,¹² and the standard errors in this level are calculated as clustering for each company. This model for choosing the tariff modality was estimated using Maximum Likelihood.

The models in the lower level, which correspond to the system equations presented in (9), were estimated using Seemingly Unrelated Regression, with the possible imposition of homogeneity and symmetry restrictions in the Slutsky matrix and fixed effects for each company in the equations in the upper level. The main reason for choosing to include the individual effects only in the equation of the upper level is that, when those effects are present in the AIDS equations the resulting system is no longer invariant to the unit of price, according to Alston et al. (2001).

The symmetry conditions are given by:

$$\beta_{ij} = \beta_{ji}$$

and the homogeneity conditions by:

$$\sum_j \beta_{ij} = 0$$

If we assume that the agents always spend 100% of the expenses in these four products, we can also recover the coefficients of the equation that was not directly

¹²Notice that this paper does not attempt a structural interpretation of the estimate coefficients in the tariff selection model, the goal is simply to characterize the probability of different choices of tariff to build the posterior of the sample selection term.

estimated – the so called adding-up restriction:

$$\begin{aligned}\sum_i \alpha_i &= 1 \\ \sum_i \beta_{ij} &= 0 \\ \sum_i \gamma_i &= 0\end{aligned}$$

3.1 Data

For this paper we compiled an energy consumption database for each company, in the period of January 2002 to December 2006. This database was built using information from Eletropaulo on industrial consumers belonging to the following voltage (voltage) groups in the supply end:

- A2 – From 88 to 138 kV
- A3a – From 30 to 44 kV
- A4 – From 2.3 to 25 kV
- AS – Voltage below 2.3, supplied by the normal distribution network and exceptionally billed in this group.¹³

These companies have the characteristic of having consumed over 500kW, which puts them in the category special free consumers. This information regards the 646 companies in the industrial sector, whose division, according to the CNAE classification up to two digits, is given in Table 2.

We can observe that there is a good dispersion in terms of sectors covered by the companies in the sample, with the companies in the Plastic and Rubber sectors having greatest participation, with only 13.7% of the sample. Energy intensive sectors such as metallurgy are relatively unimportant in the sample. In terms of choice of tariff, Figure 1 shows the distribution of companies throughout time in the different tariffs.

¹³Notice however, that there was only one company in this category, as well as in A3a.

Table 2
CNAE classification of the companies in the sample

	Freq.	Part.	Cum.
Plastic and Rubber	89	13,78	13,78
Automotive Vehicles	55	8,51	22,29
Food	51	7,89	30,19
Basic Metalurgy	51	7,89	38,08
Other Chemical Products	50	7,74	45,82
Metal Products (except machinery and equipment)	49	7,59	53,41
Machinery and Equipment	45	6,97	60,37
Textile	34	5,26	65,63
Machinery and Electrical equipment	32	4,95	70,59
Editing, printing and reproduction	31	4,8	75,39
Pharmaceutical	22	3,41	78,79
Clothing and Accessories	18	2,79	81,58
Non-metalic minerals	15	2,32	83,9
Pulp and paper	14	2,17	86,07
Other	13	2,01	88,08
Electronic and Communication mat.	13	2,01	90,09
Perfumery, soap, detergent	11	1,7	91,8
Extrative	9	1,39	93,19
Furniture	7	1,08	94,27
Office machines and equipment	7	1,08	95,36
Computers			
Shoes and leather	5	0,77	96,13
Other transportation equipment	4	0,62	96,75
Metal products (excluido machinery and equipment)	4	0,62	97,37
Oil and alchool refining	4	0,62	97,99
Hospital Equipment	3	0,46	98,45
Electrical machinery and equipment	3	0,46	98,92
Tabacco	2	0,31	99,23
Machinery and Equipment	2	0,31	99,54
Drinks	1	0,15	99,69
Wood	1	0,15	99,85
Electronic communication material	1	0,15	100
Total	646	100	

Source: prepared by the authors.

Figure 1
Energy categories

As we can see in Figure 1, most of the companies – approximately 50% – uses the AZUL tariff, while approximately 42% uses the VERDE tariff. The rest of the observations (pair of company/month) belong to companies that, during the period, changed to the tariff Conventional.¹⁴ The existence of observations in the tariff Conventional makes it possible to use this category as the basis in the selection step of the model.

In Table 3 the variables s_{efp} , s_{ep} , s_{dp} and s_{dfp} are related to the participation of energy costs in the expenses of a company in a given month (off-peak and peak time, respectively), and with the acquisition of capacity (off-peak and peak time, respectively). In term of value, the variables v_{ep} , v_{efp} , v_{dp} and v_{dfp} are related to the expenditure with energy and capacity both for off-peak and peak time. From the notation in the last section, we have that $C_{EE} = v_{ep} + v_{efp} + v_{dp} + v_{dfp}$.

From the previous table we can see that, in average, the largest participation in expenditure is energy at off-peak time (s_{efp}), corresponding to, in average, 51% of the expenditure, while the expenditure with capacity comes in second, but neither type of expenditure with capacity represents more than 20% of expenditure. In terms of prices, the values are much greater for consumption than capacity.

¹⁴From the total of 38,512 initial observations, we have 233 observations regarding the change of tariff. Of these 233, the most common change was from AZUL tariff to VERDE tariff, with 158 observations, and 34 observations from Conventional to VERDE and 21 Conventional to AZUL. Only 16 changed from VERDE to AZUL and the remaining cases changed to the Conventional tariff. In terms of companies, it means 208 out of the 646. Only in 22 cases do we have more than one change for the same company. There seems to be no defined temporal standard for tariff switch.

Table 3
Descriptive statistics

	<i>N</i>	Mean	Maximum	Minimum	Standard deviation
<i>svep</i>	38331,000	0,137	1,000	0,000	0,129
<i>svefp</i>	38331,000	0,508	1,000	0,000	0,147
<i>svdp</i>	38331,000	0,166	0,786	0,000	0,184
<i>svdfp</i>	38331,000	0,190	1,000	0,000	0,123
<i>vcp</i>	38510,000	12573,659	3,47e+05	0,000	19521,663
<i>vefp</i>	38510,000	57178,121	2,70e+06	0,000	1,19e+05
<i>vdcp</i>	38510,000	26963,723	9,53e+05	0,000	60657,893
<i>vdcp</i>	38510,000	12197,661	2,34e+05	0,000	13749,684
<i>tdcp</i>	38510,000	18,290	34,534	7,470	9,511
<i>tdfp</i>	38510,000	8,975	34,347	3,093	3,124
<i>tecp</i>	38510,000	445,482	910,143	72,099	312,854
<i>tefp</i>	38510,000	106,429	182,343	50,779	29,953
<i>g</i>	38508,000	0,727	3,500	0,000	0,281
<i>lp</i>	38425,000	0,661	2,046	0,000	0,233
<i>lfp</i>	38508,000	0,504	1,745	0,002	0,183
P	38510,000	4,007	4,538	3,234	0,221
<i>C_{EE}</i>	38331,000	10,865	15,203	5,069	1,251

Before we go on to the results of the empirical model, we must make some considerations in regards to the identification strategies used. Firstly, it is important to keep in mind that it is a microdata database for company, and there are no first-degree discriminations, that is to say, all the companies face the same prices in a same tariff. In this sense, there is no endogeneity between the prices charged to a company and the amount of service consumed by said company. Additionally, these prices are determined within a regulatory tariff review processes, in advance, and based on criteria from the price regulating agency. That is, the price here is not determined by the intersection between the curve of marginal revenue and the curve of marginal cost, but based on decisions from ANEEL.

Finally, the question of omitted demand characteristics of the company in the model of demand for service, inside a tariff, is solved with the tariff selection model. In this modality of simultaneous-switching equations, the term of selectivity correction also considers the effects of the company's characteristics, using sectorial dummies. Those characteristics controlled by the dummies are common for companies in the same sector and constant in time. That is, a limitation of the present paper is that the companies' specific and unobserved characteristics could create a bias in the results.¹⁵ With these considerations, we present the results of the model for modality discreet choice.

As we can observe from the table above, the difference between the two columns is the incorporation of dummy variables of time and sector, which elevates the Pseudo-R² to approximately 50%. We can observe that in both cases, an increase in the average price of energy, measured by the index **P**, reduces the willingness

¹⁵The absence of additional information about the companies precluded the use of more robust methods to control the effects of these on the estimates.

Table 4
Model – Modality

	Model 1		Model 2	
<i>g</i>	-2,285 (-14,968)	***	-1,366 (-1,940)	
<i>lp</i>	-0,622 (-2,902)	**	-1,055 (-0,872)	
<i>lfp</i>	-0,953 (-2,695)	**	-1,433 (-0,735)	
P	-7,080 (-37,766)	***	-82,770 (-24,619)	***
<i>C_{EE}</i>	3,096 (69,346)	***	2,476 (12,107)	***
Constante	1,408 (1,770)		293,140 (15,709)	***
Mod. VERDE				
<i>g</i>	-2,909 (-19,959)	***	-1,969 (-2,803)	**
<i>lp</i>	-3,788 (-18,455)	***	-4,679 (-3,874)	***
<i>lfp</i>	0,396 (1,151)		0,414 (0,212)	
P	-3,670 (-20,601)	***	-75,763 (-22,588)	***
<i>C_{EE}</i>	2,223 (54,333)	***	1,663 (8,165)	***
Constante	-0,966 (-1,260)		277,708 (14,898)	***
Dummies de Tempo	Não		Sim	
Dummies de Setor	Não		Sim	
Número de Obs.	38246		38246	
Pseudo R ²	0,363		0,500	
Qui-Quadrado.	25233,632		34792,983	
<i>P</i> -Val. Qui2	0,000		0,000	

Note: asymptotic statistics *t* between parentheses.

Caption: *P*-value < 0.01***, *P*-value < 0.05** and *P*-value < 0.1*.

of choosing either tariff, in relation to the basis of the Conventional tariff. Additionally, the greater the expenditure with energy, the greater the incentive for the consumer to go from the Conventional tariff to either AZUL or VERDE. In terms of implications on the behavior of the consumer, the model with sector and time dummies shows results that are apparently more plausible. In the table below, we have the elasticities crossed between tariffs VERDE and AZUL in both models.

Table 5
Elasticities – Upper level

	<i>N</i>	Median	Minimum	Maximum	Standard deviation
Elast Azul-Verde (1)	38246	0,020	0,000	0,055	0,010
Elast Verde-Azul (1)	38246	0,010	0,000	0,028	0,005
Elast Azul-Verde (2)	38246	0,222	0,000	0,604	0,133
Elast Verde-Azul (2)	38246	0,203	0,000	0,553	0,121

Table 5 shows a greater substitution between tariffs in the case with the sector and time dummies, with a mean elasticity between companies of 0.2 – that is, with a 1% increase in **P**, there is a change among between tariffs of 0.2%. In the models without fixed effects of time and sector, this substitution is of 0.02, implicating that there is no substitution between tariffs, which doesn't seem plausible. In regards to the specific models for the AZUL and VERDE tariffs, the results are as follows: In each table we observe four columns, two associated to with each one of the discreet choice models, with and without the time and sector dummies – with selection values that are specific for each model. In each pair of columns we have the model being estimated with and without symmetry and homogeneity restrictions.¹⁶

From the results in the table above we can observe that the selection terms of the different equations are significant in all of them, indicating that if we ignore the effects of prices on the probability of tariff switch we could cause a significant bias in the price sensitivity of the relevant energy demand margins. From those estimates, it is possible to calculate the elasticity for each type of service on each tariff:

From the results, we can draw some important conclusions on the characteristics of industrial demand for energy, Firstly, we have that for all services the demand is greatly elastic for price, indicating that the response of the amount of service demanded (energy or capacity) to an increase of 1% in the price of the service is much greater than 1%. Additionally, the pattern of crossed elasticity is such that there is substitution during the day, that is, in response to an increase in price only during one part of the day, consumers shift their demand for the time of the day in which the price did not increase. Another interesting point is the

¹⁶The third restriction, the adding-up, is used to recover the coefficients of the equation that was not estimated.

Table 6
AZUL tariff model

	Without R. (a)	With R. (b)	Without R. (c)	With R. (d)
Eq. (s_{ep})				
$\ln(t_{DP})$	-0,058*** (-4,519)	-0,034*** (-6,577)	-0,021 (-1,558)	-0,057*** (-10,461)
$\ln(t_{DFP})$	0,088*** (12,930)	0,040*** (12,301)	0,075*** (10,460)	0,057*** (15,925)
$\ln(t_{EP})$	-0,089*** (-19,254)	-0,014*** (-3,344)	-0,096*** (-20,989)	-0,032*** (-7,486)
$\ln(t_{EFP})$	0,111*** (17,988)	0,008 (1,821)	0,101*** (16,187)	0,033*** (7,062)
$\ln(C_{EE}/P)$	-0,015*** (-18,355)	-0,004*** (-4,526)	-0,014*** (-22,964)	-0,009*** (-14,726)
$\ln(P_A)$ -Mod.1	0,035*** (40,700)	0,035*** (40,225)		
$\ln(P_C)P_C/(1 - P_C)$ -Mod.1	-0,080*** (-13,505)	-0,148*** (-25,844)		
$\ln(P_V)P_V/(1 - P_V)$ -Mod.1	0,089*** (25,027)	0,021*** (7,287)		
$\ln(P_A)$ -Mod.2			0,019*** (24,585)	0,018*** (23,245)
$\ln(P_C)P_C/(1 - P_C)$ -Mod.2			-0,087*** (-4,941)	-0,110*** (-6,279)
$\ln(P_V)P_V/(1 - P_V)$ -Mod.2			0,089*** (32,730)	0,043*** (18,599)
Constant	0,223*** (16,837)	0,197*** (20,532)	0,199*** (14,844)	0,270*** (31,272)
Eq. (s_{efp})				
$\ln(t_{DP})$	-0,109*** (-3,685)	0,198*** (24,687)	-0,174*** (-5,584)	0,176*** (20,958)
$\ln(t_{DFP})$	0,105*** (6,696)	-0,138*** (-28,535)	0,144*** (8,704)	-0,142*** (-27,244)
$\ln(t_{EP})$	-0,260*** (-24,269)	0,008 (1,821)	-0,254*** (-24,032)	0,033*** (7,062)
$\ln(t_{EFP})$	0,289*** (20,228)	-0,069*** (-10,381)	0,317*** (22,147)	-0,067*** (-9,921)
$\ln(C_{EE}/P)$	0,056*** (28,906)	0,078*** (45,214)	0,052*** (36,143)	0,065*** (47,716)
$\ln(P_A)$ -Mod.1	-0,040*** (-19,968)	-0,043*** (-21,371)		
$\ln(P_C)P_C/(1 - P_C)$ -Mod.1	0,167*** (12,132)	0,056*** (4,291)		
$\ln(P_V)P_V/(1 - P_V)$ -Mod.1	-0,099*** (-12,034)	-0,191*** (-28,953)		
$\ln(P_A)$ -Mod.2			-0,018*** (-10,373)	-0,023*** (-13,514)
$\ln(P_C)P_C/(1 - P_C)$ -Mod.2			0,290*** (7,108)	0,103* (2,556)
$\ln(P_V)P_V/(1 - P_V)$ -Mod.2			-0,056*** (-8,922)	-0,130*** (-25,027)
Constant	0,149*** (4,854)	-0,348*** (-20,875)	0,180*** (5,827)	-0,265*** (-18,863)
Eq. (s_{dp})				
$\ln(t_{DP})$	0,234*** (7,791)	-0,326*** (-25,700)	0,329*** (10,186)	-0,251*** (-18,365)
$\ln(t_{DFP})$	-0,206*** (-12,918)	0,162*** (21,776)	-0,261*** (-15,233)	0,132*** (15,916)
$\ln(t_{EP})$	0,245*** (22,476)	-0,034*** (-6,577)	0,229*** (20,875)	-0,057*** (-10,461)
$\ln(t_{EFP})$	-0,239*** (-16,497)	0,198*** (24,687)	-0,270*** (-18,171)	0,176*** (20,958)
$\ln(C_{EE}/P)$	-0,031*** (-15,955)	-0,051*** (-28,720)	-0,029*** (-19,787)	-0,041*** (-28,953)
$\ln(P_A)$ -Mod.1	0,050*** (24,637)	0,053*** (26,055)		
$\ln(P_C)P_C/(1 - P_C)$ -Mod.1	-0,286*** (-20,477)	-0,195*** (-14,512)		
$\ln(P_V)P_V/(1 - P_V)$ -Mod.1	0,118*** (14,077)	0,186*** (26,871)		
$\ln(P_A)$ -Mod.2			0,016*** (8,703)	0,020*** (11,322)
$\ln(P_C)P_C/(1 - P_C)$ -Mod.2			-0,419*** (-9,922)	-0,169*** (-4,028)
$\ln(P_V)P_V/(1 - P_V)$ -Mod.2			0,072*** (11,107)	0,125*** (22,388)
Constant	0,109*** (3,483)	0,835*** (47,046)	0,088** (2,758)	0,755*** (49,031)
Number of Obs.	19042	19042	19039	19039
R-sq 1st eq.	0,181	0,143	0,144	0,106
R-sq 2nd eq.	0,246	0,214	0,220	0,177
R-sq 3rd eq.	0,132	0,088	0,070	0,020

Note: asymptotic statistics t between parentheses. Caption: P -value < 0.01***, P -value < 0.05**, and P -value < 0.1*.

Table 7
VERDE tariff model

	Without R. (e)	With R. (f)	Without Restr. (g)	With Restr. (h)
Eq. (sep)				
$\ln(t_{DFP})$	-0,303*** (-4,775)	-0,080 (-1,923)	0,095 (1,405)	0,114** (2,616)
$\ln(t_{EP})$	0,504*** (7,243)	0,131** (3,000)	-0,069 (-0,930)	-0,071 (-1,561)
$\ln(t_{EFP})$	-0,068*** (-12,033)	-0,051*** (-9,733)	-0,042*** (-7,406)	-0,043*** (-8,756)
$\ln(C_{EE}/P)$	-0,046*** (-15,875)	-0,038*** (-13,624)	-0,031*** (-17,993)	-0,031*** (-18,009)
$\ln(P_V)$ -Mod.1	0,030*** (9,156)	0,034*** (10,450)		
$\ln(P_C)P_C/(1 - P_C)$ -Mod.1	-0,236*** (-19,283)	-0,262*** (-21,953)		
$\ln(P_A)P_A/(1 - P_A)$ -Mod.1	-0,571*** (-62,224)	-0,555*** (-61,347)		
$\ln(P_V)$ -Mod.2			-0,034*** (-13,348)	-0,034*** (-13,645)
$\ln(P_A)P_A/(1 - P_A)$ -Mod.2			-0,352*** (-49,538)	-0,351*** (-49,640)
$\ln(P_C)P_C/(1 - P_C)$ -Mod.2			-0,320*** (-5,183)	-0,326*** (-5,329)
Constante	-2,176*** (-6,902)	-0,296 (-1,543)	0,662* (1,983)	0,643** (3,213)
Eq. ($sefp$)				
$\ln(t_{DFP})$	0,118* (1,985)	-0,119*** (-13,061)	-0,092 (-1,482)	-0,121*** (-13,029)
$\ln(t_{EP})$	-0,408*** (-6,252)	-0,051*** (-9,733)	-0,061 (-0,895)	-0,043*** (-8,756)
$\ln(t_{EFP})$	0,185*** (35,065)	0,169*** (36,702)	0,204*** (38,995)	0,204*** (48,187)
$\ln(C_{EE}/P)$	0,131*** (48,265)	0,125*** (47,236)	0,085*** (53,471)	0,085*** (53,486)
$\ln(P_V)$ -Mod.1	0,005 (1,627)	0,002 (0,619)		
$\ln(P_C)P_C/(1 - P_C)$ -Mod.1	-0,032** (-2,772)	-0,012 (-1,090)		
$\ln(P_A)P_A/(1 - P_A)$ -Mod.1	0,402*** (46,646)	0,389*** (45,601)		
$\ln(P_V)$ -Mod.2			0,024*** (10,194)	0,024*** (10,379)
$\ln(P_A)P_A/(1 - P_A)$ -Mod.2			0,220*** (33,519)	0,220*** (33,616)
$\ln(P_C)P_C/(1 - P_C)$ -Mod.2			0,008 (0,135)	0,015 (0,257)
Constante	1,527*** (5,163)	-0,230*** (-8,445)	-0,198 (-0,642)	-0,257*** (-11,306)
Número de Obs.	16228	16228	16228	16228
R-sq 1a eq.	0,356	0,352	0,299	0,299
R-sq 2a eq.	0,355	0,352	0,315	0,315

Note: asymptotic statistics t between parentheses. Caption: P -value < 0.01***, P -value < 0.05**, and P -value < 0.1*.

Table 8
Elasticities – AZUL Tariff

Model (a)				Model (b)			
	t_{ep}	t_{efp}	t_{dp}	t_{dfp}			
e_p	-1,636*** (0,034)	0,869*** (0,046)	-0,404*** (0,094)	0,662*** (0,050)	-1,099*** (0,031)	0,073** (0,034)	-0,246*** (0,038)
e_{fp}	-0,527*** (0,021)	-0,487*** (0,029)	-0,233*** (0,058)	0,186*** (0,031)	-0,005* (0,009)	-1,213*** (0,014)	0,364*** (0,016)
d_p	1,500*** (0,065)	-1,347*** (0,009)	0,443** (0,181)	-1,205*** (0,096)	-0,164*** (0,031)	1,349*** (0,051)	-2,912*** (0,076)
d_{fp}	0,556*** (0,024)	-0,820*** (0,034)	-0,348*** (0,068)	-0,920*** (0,036)	0,229*** (0,017)	-0,661*** (0,026)	0,875*** (0,039)
Model (c)				Model (d)			
	t_{ep}	t_{efp}	t_{dp}	t_{dfp}			
e_p	-1,692*** (0,033)	0,790*** (0,046)	-0,137* (0,099)	0,571*** (0,053)	-1,227*** (0,031)	0,274*** (0,035)	-0,409*** (0,040)
e_{fp}	-0,515*** (0,021)	-0,426*** (0,029)	-0,360*** (0,062)	0,265*** (0,033)	0,047*** (0,009)	-1,197*** (0,014)	0,326*** (0,016)
d_p	1,402*** (0,066)	-1,535*** (0,091)	1,014*** (0,195)	-1,541*** (0,103)	-0,312*** (0,033)	1,189*** (0,052)	-2,471*** (0,082)
d_{fp}	0,650*** (0,026)	-0,762*** (0,036)	-0,698*** (0,077)	-0,772*** (0,041)	0,310*** (0,019)	-0,709*** (0,028)	0,708*** (0,044)

Note: Standard Deviations calculated using the Delta Method.

Caption: P -value < 0.01***, P -value < 0.05**, and P -value < 0.1*.

result that this shift of demand is even more intense from peak time to off-peak time than the inverse.

Finally, the negative crossed elasticities between energy and capacity are indicative of complementarity between both products – that is, an increase in the price of energy in the off-peak time reduces the demand for energy at that time in addition to reducing the capacity.

In Table 9 we have the calculation of the price and crossed elasticity for the companies in the VERDE tariff.

Table 9
Elasticities – VERDE Tariff

Model (e)			Model (f)		
	t_{ep}	t_{efp}	t_d		
e_p	2,735*** (0,509)	-0,323*** (0,046)	-2,154*** (0,465)	-0,005 (0,319)	-0,232*** (0,044)
e_{fp}	-0,839*** (0,129)	-0,768*** (0,012)	0,184* (0,117)	-0,134*** (0,010)	-0,793*** (0,011)
d	-0,444* (0,233)	-0,389*** (0,021)	0,060* (0,212)	-0,359 (0,219)	-0,388*** (0,021)
Model (g)			Model (h)		
	t_{ep}	t_{efp}	t_d		
e_p	-1,471*** (0,540)	-0,191*** (0,043)	0,735 (0,493)	-1,493*** (0,335)	-0,200*** (0,037)
e_{fp}	-0,143 (0,135)	-0,684*** (0,011)	-0,213 (0,123)	-0,107*** (0,010)	-0,684*** (0,009)
d	0,723*** (0,244)	-0,709*** (0,019)	-0,958*** (0,222)	0,642*** (0,231)	-0,703*** (0,019)

Note: Standard Deviations calculated using the Delta Method.

Caption: P -value < 0.01***, P -value < 0.05**, and P -value < 0.1*.

The results here indicate that the energy demand on peak time is elastic, while the energy demand on off-peak time and the demand for capacity are inelastic.

Regarding the substitution and complementarity pattern, only energy at peak time and capacity are substituted, while energy at off-peak time and capacity are complementary. That is, an increase in the price of off-peak energy causes a reduction of peak time energy and of hired capacity as well.

These results seem different from those obtained for the AZUL tariff, but it is important to keep in mind the role of hired capacity in this case. A unit of capacity used during peak time means that there is one less unit of capacity available for the off-peak time and vice-versa. In this sense, we can interpret the response to the increase in prices of off-peak energy as follows: in response to the increase in tariff, the company reduces its aggregated energy consumption. However, this reduction is asymmetric during the day, and the off-peak consumption is smaller and to absorb part of this shift the company acquires more units of capacity.

We can also draw some conclusions from the comparison of results for the VERDE and AZUL tariffs as presented in Table (1). Firstly, as expected, the different demands here represented are a lot more elastic than what was presented for the aggregated energy demand in the introduction. That is, the price sensitivity of the different components of industrial energy demand is much greater than that of the aggregated demand, in addition to the fact that the estimates mentioned in Table (1) could be biased due to the use of the average price as an approximation of the perceived cost of the marginal energy consumption.

Another dimension in which it is possible to argue that the results here presented constitute an advance in relation to the existing literature is the fact that, in this study, we estimate the crossed sensitivity between the different types of energy and capacity, making it possible to draw an analysis not only on the absolute level of tariffs, but also on how the tariff load is spread among the different services (energy and capacity at peak time and off-peak time). From the results of the elasticities previously discussed, we can carry out a simulation exercise on the tariff changes proposed from the 2012 and 2013, referring to the relative price between the different service tariffs. In the next table, we show the results computed from the elasticities of the models (d) , for the AZUL tariff, and (h) for the VERDE tariff.

Table 10
Tariff changes and effect on quantities

Type	AZUL		Type	VERDE	
	Price variation	Amount variation		Price variation	Amount variation
e_p	-9,10%	8,06%	e_p	-9,10%	-37,97%
e_{fp}	-9,30%	10,05%	e_{fp}	-9,30%	23,72%
d_p	-29,60%	40,06%	d	-60,70%	55,93%
d_{fp}	-29,60%	19,19%			

This table shows us that, with the proposed reduction in prices of services – and keeping the disposition to maintain the same type of tariffs – would cause a

shift in the consumption of energy, from peak time to off-peak time. In the case of the VERDE tariff, the movement is stronger, with a reduction of peak energy and an increase in off-peak energy. In the case of the AZUL tariff, is that the peak energy increases more than the off-peak. And all those changes would be even stronger than we could have predicted had we used the estimates of price elasticity of the industrial energy demand in Table (1).

4. Conclusions

In this paper we proposed an econometric model for the demand of energy and capacity by Brazilian industrial consumers. Differently from the residential consumers, the Brazilian industrial consumers, besides consuming energy and capacity, also face a tariff menu with Time of Use Pricing. Additionally, each of the three tariffs (AZUL, VERDE or Conventional) also has different components and price discriminations. All these characteristics combined pose an empirical problem, which, up to this moment, had not been faced by the literature.

Because the choice of those tariffs is not mandatory – the consumers can pick which one is more suitable to them – the estimate of energy and capacity demand in each of the tariffs without taking into account the problem of tariff selection could lead to a bias in the estimated coefficients of the demand function. To deal with this problem we, initially estimated a multinomial discrete selection model, and later used the selection probabilities in a way to assure that the coefficient estimates were not biased.

This methodology was applied to a non-random sample of 646 large Brazilian industrial consumers (with demand above 300 KW), for the period from January 2002 to December 2006. We observed that the demands for different services (peak and off-peak capacity and energy) are price elastic and that, at least in the AZUL tariff, there is complementarity between energy and capacity in the different times of the day.

Additionally, the conclusions on tariff structure are based on estimates of aggregated electricity demand price elasticity, with disaggregation of consumption at different times of the day, which could lead to incorrect policy conclusions. The industrial energy price elasticity estimates in the Brazilian literature evaluate mostly the average consumption of energy. However, the price system used by the Agency recognizes the importance of distinguishing the use of energy and capacity (kW), with the later determining the dimensioning of the distribution system, and consequently of investments. Thus, it is important to know the degree of substitution between energy and power in both periods, and this is an original contribution in this paper. The importance of this information was highlighted with a simulation exercise carried out in the end of the paper, in which we evaluate a proposition that, besides a reduction in prices, we would have also a change in the relative prices of energy and capacity. The obtained effects were much more important than what we would have obtained using the simple application of results found

in the literature.

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