BRAZILIAN ELECTRICITY DEMAND ESTIMATION: WHAT HAS CHANGED AFTER THE RATIONING IN 2001? An Application of Time Varying Parameter Error Correction Model

Amanda Pimenta Carlos*     Hilton Notini*++

Luiz Felipe Maciel*

*Graduate Student at Getulio Vargas Foundation – Graduate School of Economics, Rio de Janeiro, Brazil. 
++ANAC (National Civil Aviation Agency) Manager ;

Corresponding author: Amanda Pimenta - Email: amanda@fgvmail.br
Phone: +(55-21) 3799-5860. Fax: (55-21) 2552-4898

May 5, 2009

Abstract

In this article we search to fill a blank in Brazilian Energy Economics literature. To our knowledge there isn’t an article estimating the Brazilian electric energy demand that tests structural break and yet that tests constancy of coefficients demand over time. To achieve this objective, we apply the methodology of Time Varying Parameter in an Error Correction Model (TVP-ECM), originally proposed by Hall (1993), to the data of residential and industrial Brazilian sectors. As results, we found residential consumers more sensitive to variations in price than industrial ones and the Rationing Crisis as beeing a structural break in Brazilian demand. Finally, our State space estimates do not rule out the hyphotesis that coefficients vary over time. Also, the expansion of credit in Brasil could be a major factor to explain the decline of elasticities of residential demand.

JEL Codes: C22, C51, Q41

Keywords: Eletric Energy Demand Modelling, VECM, TVP-ECM, Kalman Filter.
1 Introduction

After the privatization of Brazilian infrastructure, the amount of investments in the electricity sector has increased in a substantial way. The installed capacity of the sector was 54 GW in 1994 and already exceed 100 GW in 2007. Analysts forecast continuity in this expansion, once electric energy is a relevant strategic component of a economy, specially in a development one.

An important issue of the electricity sector planning and regulation is understanding electricity demand, its main determinants and its answer to specific shocks on its exogenous variables. There are some estimates for Brazilian electricity demand parameters, using the Cointegration and Vector Error Correction Model (VECM) approach that became the standard method for electricity applied research in demand topic since the seminal works of Engle and Granger (1987 and 1989), but all of them are for a period that exclude the severe power Rationing Crisis, occurred in 2001.

With the present paper we search to fill a blank in the economics literature: to the our knowledge, there isn’t a paper testing the stability of the coefficients for the demand equation. It’s necessary to test if the 2001 crisis changed the Brazilian power consumer behaviour\(^1\), occasioning a shift in the demand income and price-elasticity. Furthermore, we include other determinants of electricity demand found constantly in international literature, like temperature.

To achieve this objective, we apply the methodology of Time Varying Parameter in an Error Correction Model (TVP-ECM), originally proposed by Hall (1993), to the data of residential and industrial Brazilian consumers sectors. The model we use is a new approach over the Johansen Cointegration-VECM model. The procedure consists of four steps, after confirm that the variables are non-stationary: first, we estimate the cointegration equation with the variables of any sector, what give us the long-run relationship between them; then we analyse the short-run dynamics, with an Error-Correction Model. These two steps are the traditional one in the electricity demand estimation and give us the long and short-run electricity demand elasticities, respectively. In the third step, we test structural break in the equation from the Error Correction Model; with a break, we are justified to let the coefficients of the Error Correction Model to vary over time. Finally, we run a State Space model with the Error Correction Model equation as the measurement equation and state equations that gives the dynamics of the elasticities we want to test stability. This model is suitable to catch long run relationship between electricity demand and its determinants and, besides that, allows to deal with instabilities or short-run adjustment dynamics. The State Space model is a useful framework when coefficients vary over time and when we want to test if some variables could affect the dynamic of the coefficients.

As results, we found that residential consumers are more sensible to price and to income than industrial ones and this can be seen as a consequence of the Rationing period. It is intuitive that residential consumers adjusted their behaviour after the Crisis. As expected, our tests shown that 2001 Crisis is as a structural break in electricity demand and our State Space estimates don’t rule out the hyphotesis that short run elasticities vary over time.

2 Brazilian Electricity Sector

Brazilian electricity sector has changed severely in the recent years. The first fact in the restructurering process was the extinction of guaranteed rat-of-return regulation in 1993. After that, the reform encompasses institutional

\(^1\)Additionally to the obvious aspect of efficient residential and industrial consumption of energy, current Brazilian industrial data shows that the velocity of demand growth is more and more influenced by participation of self-production of electricity. Industries invest in their own power plants to avoid instabilities, like the one occurred in 2001.
changes and large privatization. Around 60% of distribution market and 20% of generation market was privatized between 1995 and 2000.

The first privatizations were accomplished in a environment of expressive regulatory risk. This risk was because the absence of clear rules to the operation in the sector and to the uncertainties regarding to the new institutional paradigm and market structure. As we mentioned before, the new regulatory agency, ANEEL, was established by the Law 9427 of December 1996, after the sale of Escelsa, Light and Cerj. The Agency is an autonomous organ, with an independent board of directors and has the following five primordial objectives:

(i) Elaboration of technical parameters to ensure the service quality to the consumers; (ii) Request of biddings to new concessions of generation, transmission and distribution; (iii) Operation warranty of the Electric Energy Wholesale Market (MAE) in a competitive way; (iv) Establishment of criteria to the transmission cost; (v) Establishment and implementation of taxes in the retail market.

With restructuring, the energy supply industry became distributed in four businesses: generation, transmission, distribution and commercialization, which need to be counted separately. The sale of the energy is contracted apart from the access and use of the transmission and distribution lines. Besides of that, the decree No. 2655/98 states that distribution companies must registry in a separate way their incomes, expenses and costs related to the distribution, commercialization in the captive market and in the free market. Such companies must also restrict themselves to the limit of the allowed market share.2

The economic regulation turns out to be with incentives to the efficiency for the transmission and distribution, with taxes for the utilization of these systems, considering the long term marginal costs

Criticisms were that the reform profile adopted in Brazil has been adopted without taking in consideration technical and physical peculiarities of the Brazilian electric sector. However, we don’t deny the importance of its realization, once the state’s role as an investor, in the current world economic context, is lowermost. Reform, thus, was necessary to attract new investors, as much national capital as foreign, to keep suitable the sector capacity in Brazil, besides the gain in efficiency that comes with private administration.

In June 2001, nevertheless, even after restructuring, a serious supply crisis took place in the Brazilian electric energy market because a strong drought, which even led to a rationing in the consumer’s quantities in some regions (South region didn’t suffer the rationing, because it faced a rainy period), and was named as the Rationing Crisis.

From that scenario, Castro & Rosental (2008) state that it is coming a change in the platform in the demand elasticity request by Brazilian electric energy. This phenomenon would be consequence of the more rational and efficient use of such input, specially by the industrial consumers, which has been using methods and "energy saver" equipment, after the blackout of 2001. Residential consumption also has presented a behaviour change which can act on this change of elasticity tendency, once it has acquired more efficient durable goods regarding the use of the electric energy.

Nevertheless, we can’t deny that Rationing Crisis changed the consumption patterns of the consumers. According to Carreno et al. (2006),

"Residential class was the sector who better put in practice all recommendations. After the rationing period ended, its consume lowered in almost 30% of the historical expected medium, 10% more of the quantity asked. This behavior can be explained in the following way: After the rationing period ended, many consumers already had made investments in energy efficient equipment and renewed their way of life, all this because they were scared of the consequences of not doing so. In short, consumers were

2 A single company cannot have more than 35% of the distribution markets of the North or Northeast, 25% of the South, Southeast or Center West, or still, 20% of the national distribution market.
forced to adopt a new behavior in load consumption, and there was no reason to return to the old consumption levels."

Finally, authors stand out the fact that studies of supply and demand of energy still use the mean of elasticity found in previous periods for Brazil, which is of 1.3, to foresee possible instabilities in this balance, and this can baffle political decisions.

3 Supply and Demand Equilibrium in Brazilian Market

The current paper has the main objective to estimate the national electric energy demand for the residential and industrial consumption categories. However, in order to understand the demand formation in the Brazilian market, it's essential to understand the dynamics of the equilibrium between supply and demand of energy for this market. It's what we search in this section.

As explained above, Brazilian electric sector restructuring, based on the Britain reform, deverticalizated the companies, in order to allow competition in the stages of generation and commercialization of electric energy.

Electric energy supply is made by generators. In the Brazilian current electric energy sector model, these agents have two options to send their production: the captive market and the free market. To offer in the captive market, generators participate in the generation auctions (or energy auctions for existent plants or energy auctions for new plants, in which the concessionary is responsible for the construction of a new hydroelectric or thermoelectric) with which they will serve the distributers’ demand, contracting in a long term basis. Distributers support the captive demand, necessarily composed by residential, commercial and industrial consumers with contracted demand lower than 500 kW (these consumers can also buy energy from a holder who has authorization or concession of hydraulic utilization with characteristics of a small hydroelectric central (PCH) or alternative source - biomass, solar or wind energy). On the other hand, the great industrial consumers have the option to participate in the captive market or free market.

Practically beginning in 2004, free market finished the year 2005 with about 500 consumers and reached to almost 700 in 2007, adding up to more than 25% of the national consumption this year. One of the advantages to the consumer in participating in the free market is to be able to manage absolutely the "input" electric energy, in the same way he manages other items related to his productive activity (work force and raw materials in general).

According to Augusto (2007), for the electric sector, the amplification of the free market is interesting because it increases the market liquidity, encourages competition and reduces prices to the final consumers. Dealers bring near generators and consumers, with their know-how, in order to contribute to the disclosure and improvement of the rules and procedures of the energy market. Besides of that, they accept risks of prices, terms, credit and performance of consumers and generators.

The price charged from the final consumer, in the free market of energy, besides the price of the energy freely negotiated, is made of others factors, which are:

(i) TUST – Tax for using the transmission system: tax payed for the use of the basic transmission network and conexion costs between the producing company and the basic network and, from this, with the local network of the consuming company ;

(ii) TUSD – Tax for using the distribution system: tax in which are incorporated the demand taxes (in the peak and outside peak) and the taxes of reactive excess;

(iii) CC – Conexiion cost: rates that seek to cover expenses with conexiion and establishment of measuring systems;
(iv) Technical losses: loss calculation in the energy transmission.

However, there is still improvements needed to be made in the free market, as well as your amplification. One of them is the imposition to liquidate what was not demanded by the Difference Liquidation Price (PLD), which is the proxy of the spot price in the Brazilian market. The problem with PLD is that it’s from the optimization of the programs that are based on the marginal cost of the system operation, variable too much influenced by drought periods, because the energy storage incapacity in the system essentially hydroelectric in Brazil. In such case, PLD is a price of difficult prevision and high volatility, not allowing precise calculations of risk by the agents (as we will see later on, the manner how spot price is formed also affects the generators’ investment decision.

Even more important for possible changes in the sector is the increase of self-production of energy, which has been more and more used as a tool to avoid price and supply instabilities - as the Rationing Crisis of 2001. Self-producers\(^3\), in general great industrial consumers of the intensive sectors in the use of electric energy, invest, currently, about R$3 billion each year and have the capacity to produce 5549 thousand MW of energy. In spite of the great investments and of the high capacity of energy generation, sector complains about the lack of government’s incentive to the self-production and tells that the energy generated by its plants could be used to supply the market.

In this context, the generators’ choice to supply energy to the captive market or to the free market depends on many factors, as the uncertainty of the spot price, which brings to the captive market attraction, where there is more security in terms of income to the generator.

Another characteristic of the Brazilian electric energy offer is that it is basically formed by hydroelectricity. Brazil is the third country in installed capacity of hydro power and 85% of the electric energy comes from the reservoirs. However, even with such capacity, annual demand is about 50% of the installed capacity. The point is that hydroelectric energy is subject to very severe oscillations in the supply - see the Rationing Crisis. As the average time to build a hidroelectric is not smaller than 5 years, future demand is the key variable to the expansion and capacity adjustment in a system which the base is the hydroelectricity.

In this way, it’s usual to analyze that the projection of electric energy demand in Brazil, system mainly based in hydroelectricity, leads future investments in the sector and, thus, causes the supply growth.

4 Literature Review

Economic literature about demand estimation of the electric energy is extensive. In this section we make a general summary about international and national relevant papers on the subject.

Espey & Espey (2004) make a meta-analysis of 36 studies published about the estimation of the residential electric energy demand, trying to summarize quantitatively this empirical literature, in a way to provide information to regulators, policy-makers and companies of the energy sector about the answer regarding the residential consumer’s behaviour to the price changes and in the electric energy income. That paper summarized that estimation of short term price elasticities vary in a range from -2.01 to -0.0004, with average -0.35, whereas the long term price elasticities remained between -2.25 and -0.04, with average -0.85. And short term income elasticities vary between 0.04 and 3.48, with average 0.28, and long term ones, between 0.02 and 5.74, with average 0.97.

Another relevant paper is that from authors Chang & Martinez-Combo (2003), who estimate the electric energy demand to Mexico with monthly data from January 1985 to May 2000. The authours estimated price elasticity and long term income with fixed coefficients to the industrial and residential sectors. As a result, they found, for the residential sector, -0.44 and 1.95 to the elasticities price and income, respectively. And for the industrial sector,

\(^3\)Presently, companies that invest in energy generation for its own consumption have 31 hidroelectrics, 9 thermoelectrics and 9 small hydroelectric centrals (PCHs). Abiape has great Brazilian companies as partners, like Vale, CSN Energy, Gerdau and Votorantim.
these values were -0.25 and 1.29. These authors test a demand configuration with coefficients that vary with time and the insertion of such dynamics into the model reduce the elasticity coefficients relatively to the estimation with coefficients fixed on time.

Kamerschen & Porter (2004) estimated the electric energy demand to the categories of residential and industrial consumers of the USA with samples from 1973 to 1998. By means of an estimation of simultaneous equations, determining price and quantity of electric energy in the market, they found, as price elasticity, an interval between -0.85 and -0.94 to the residential sector and between -0.34 and -0.55 to the industrial sector.

Silk & Joutz (1997) used cointegration to estimate the annual residential demand for electric energy in the USA from 1949 to 1993. Authors’ analysis suggests a drop in the residential consumption level during the 60’s, due to the electrical appliances substitution, specially air conditioning devices, because the fiscal policy of the decade and also because the fact that the observed prices don’t reflect the instability between supply and demand of energy, increasing the price payed by consumers.

Regarding the literature of energy demand estimation for Brazil, we have three important papers. Modiano (1984) is the first of these papers. The authors evaluate quantitatively the response of the electric energy demand to the real income variations and real tax to all distinctive categories of consumers - residential, commercial, industrial and others - from 1966 to 1981. Econometric models used in that paper were a regression with fixed coefficients in time and an Vector Auto-Regression (VAR). In the regression model, to the exception of the industrial class, consumers demonstrate sensitivity to the real taxes from 5% of significance. Regarding the real income sensitivity, in all categories it is not possible to refuse the hypothesis that elasticity is higher than the unit. And with the VAR model, the results show sensitivity to the real taxes only for the industrial class. Short term price elasticity of the industrial consumption is estimated in -0.45 and that of long term, -1.22. Short term and long term income elasticities also have been estimated, to the industrial class, in 0.50 and 1.36, respectively.

Later, Andrade & Lobão (1997) estimated income elasticity and price elasticity of the residential demand for electric energy in Brazil for the period from 1963 to 1995, and used the econometric model to project the demanded quantity to the period from 1997 to 2005. Regarding Modiano model, the authors added, in their demand model, besides the variables of income and tax, even present in the earlier paper, the price of the electrical appliances. Thus, the income elasticity of the model catches not only the direct effect that income has on the energy use, but also an indirect effect on the electrical appliances quantity. Model estimations, made by different methods, presented themselves quite inelastic in relation to this variable, the same happening in relation to the two other explicative variables: the electric energy tax and price of the electrical appliances.

The more recent paper for Brazil, which agrees with the two papers cited earlier for the Brazilian case, is Schmidt & Lima’s (2004). Unlike the others, the authors’ paper - who work as much the industrial sector as the residential one - include a time interval from 1963 to 2000. In this way, with the annual data and applying cointegration, they come to the long term price elasticities of -0.15 to the residential sector and -0.13 to the industrial and long term income elasticities of 1.05 and 1.71 to the residential and industrial sectors, respectively.

A characteristic of the three papers cited previously to the Brazilian demand estimation of electric energy is the utilization of a small sample (the bigger sample between the three is the more recent paper, from Schmidt & Lima and, even that, presents less than 40 observations). We know that the model estimation of temporal series presents low performance (and many times they are invalidated) with too small samples.
5 Motivation

We have mentioned yet the restructuring of the electric sector in Brazil, which reached a regulation model based on incentives, to DISCO’s and concessionaries of transmission lines, made by the determination of an optimum tax of electric energy. In such process, the appropriate calculation of how consumption of electric energy responds to the changes in the tax (price elasticity) is essential to the regulator "game" versus regulated company. For example, in 2009, Brazil is going over a second stage of DISCO’s rate revision, within the new model. Thus, measurement of adequate elasticities to the consumers of energy are essential to the regulator (who needs to know what is the ideal tax for each distributor to provide them with the right incentives of quality and investment, without letting it to appropriate of all the existent informational income due to the assymetry in relation to the real costs of service provision and that estimated by the regulator) and for the companies (that need to know the lower limit of tax that enables company’s profitability).

Besides of that, due to the manner the balance between demand and supply is achieved, with demand predefining supply, it’s essential to the policy-makers a good notion on how electric energy consumption reacts to the income variations (income elasticity), in order to determine the best policies to stimulate investment on generation plants.

In this way, we believe that there is, according to the literature about current Brazilian Energy Economics, space to the update and refining of the electric energy demand estimation, following the actual international papers, with new techniques and new empirical evidence of expressive variables.

However, we’d like to point out in that paper to justify this demand re-estimation and elasticities to the Brazilian electric sector, the possibility of a more profound change in the standard of the demand elasticity after the Rationing Crisis of 2001, hypothesis cited by Castro & Rosental (2008) and by Carreno et al. (2006), yet explained in this paper. We will make, thus, the test that the crisis of 2001 would have represented a structural fall in the Brazilian electric energy demand.

We also proposed in this paper a stability test of the demand coefficients of Brazilian electric energy, following the patterns made by Chang & Martinez-Combo (2003) for Mexico. If 2001 Rationing Crisis represents a structural break for Brazilian Eletric Demand, it is reasonable to assume that demand elasticities varies along time, due to the impacts on variables that determine it or external factors. Using the State Space model, we can estimate demand allowing that elasticities varies across time. This procedure permits to model each coefficient dynamic and see how it varies before and after 2001. The econometric model will be explained in next section.

After the estimation of elasticities dynamics, we will provide some possible determinants for each coefficient behaviour. The evolution of credit supply in Brazil, the higher temperatures and the increase in volatility of tariffs will be tested as explanatory variables in the law of movement for each elasticity.

6 Econometric Model

In this paper, the econometric setting we use to deal with the long-run relationship between the electricity demand and its determinants is a Time Varying Parameter Error Correction Model, TVP-ECM. This model was first proposed by Hall (1993). Ramajo (2001) and Li, Wong, Song & Witt (2006) also presented applications of the model.

The TVP-ECM model is adequate to capture the long-run relationship between the variables and allow a flexible way to model their short-run dynamics.\footnote{Gang & Li (2008) says that the advantages of using the ECM in demand estimation and forecasting lie in its ability to capture the short-run dynamic characteristics of demand given the long-run cointegration (equilibrium) relationship. In other words, the} We define the TVP-ECM for each demand - residential and industrial
- using three equations. The first one deals with the long-run relationship, that is, the cointegration between the variables and it is stated as follow:

\[
d_t = \alpha_0 + \alpha_1 z_t + \epsilon_t, \quad \epsilon_t \sim NID(0, \sigma^2)
\]  

(1)

where \(d_t\) and \(z_t\) are respectively electricity demand and its determinants, \(t = (t = 1, ..., n)\), \(\alpha_0\) are \(\alpha_1\) fixed scalars and \(\epsilon_t\) is a error term.

The second step deals with the short-run dynamics of the relationship between demand and its determinants. Replacing the error term \(\epsilon_{t-1}\) by its estimate, \(\hat{\epsilon}_{t-1}\), we run the second equation, the TVP-ECM measurement equation, which is given by:

\[
\Delta d_t = \beta_1 t \epsilon_{t-1} + \sum_{i=1}^{p} \gamma_{it} \Delta d_{t-i} + \sum_{i=1}^{p} \lambda_{it} \Delta z_{t-i} + \epsilon_t, \quad \epsilon_t \sim NID(0, \sigma^2)
\]  

(2)

where \(\Delta d_t = d_t - d_{t-1}\) \((j = 1, 2)\), \(\epsilon_{t-1}\) is the error term from equation (1), \(\beta_{1t}, \gamma_{1,t}, \gamma_{p,t}, \lambda_{1,t}, \ldots, \lambda_{p,t}\) are the time varying coefficients.

Evolution of second equation over time is given by the third equation of the model, the state equation, that follows. Measurement and state equations are estimated in a State Space Model simultaneously, with Kalman Filter algorithm. This is the state equation:

\[
\beta_t = \phi + \Phi \beta_{t-1} + u_t, \quad u_t \sim NID(0, \Sigma)
\]  

(3)

where \(\beta_t = (\beta_{1t}, \gamma_{1,t}, \gamma_{p,t}, \lambda_{1,t}, \ldots, \lambda_{p,t})^T\) is the \(2p + 1 \times 1\) state vector in time \(t\), \(\phi\) is a \(2p \times 1\) vector, \(\Phi\) is a diagonal \(2p + 1 \times 2p + 1\) matrix, \(u_t\) is a \(2p + 1 \times 1\) vector of error terms with a \(2p + 1 \times 2p + 1\) covariance matrix, \(\Sigma\).

### 6.1 Model Estimation

In this topic we show our estimation procedure, after test for non-stationarity in series. The better way for estimate a demand relationship in economics is with a Vector Auto-Regression (VAR), that includes the variables we believe influence demand and the lags of these variables. This is reasonable, once not only contemporaneous variables impact demand but also previous values of these determinants can do it. Notwithstanding, dealing with non-stationary series we are not allowed to use VAR approach; in this case, we need to test Cointegration and so estimate a VECM\(^5\). Basically, there are three alternative procedure to test cointegration: Johansen (1988), Stock & Watson (1988) and Engle & Granger (1987).

Gonzalo (1994) compares several methods of estimating cointegrating vectors. Examining the asymptotic distribution of the estimators resulting from these methods, he shows that maximum likelihood in a fully specified error correction model (Johansen’s approach) has clearly better properties than the others methods. Johansen’s method incorporates all prior knowledge about the presence of unit roots and this is the reason we choosed this cointegration method for our demand estimation.

So, after we confirm the presence of a stochastic trend in each variable, we start the cointegration test to know if there is a long-run relationship between the variables (as we will see, the temperature variable doesn’t participate

\(^5\)This is the best way to incorporate all the necessary information about the data in a specification.
from the cointegrating process (because it is stationary). Firstly, we use Bayesian Information Criteria to select the appropriate number of lags to the VAR. After this, if we have evidence of the existence of a cointegrating vector, we have the long run elasticities for our demand estimate. With a long-run relationship, we still need to estimate and test a general specification, that include differences of the variables that impact the demand, that is the Error Correction Model. We analyze the performance of this model that includes the short-run adjustment (in fact, in our context, these coefficients will be the short-run electricity elasticities).

Finally, we test if there is stability in the ECM coefficients. So, in the third step of estimation, we perform a Kalman filter and smoother (Kalman, 1960) and the prediction error decomposition (Harvey, 1989) to obtain the filtered and smoothed states and the estimates of the parameters of the model. 

Summarizing, step-by-step for estimation is, once series are non-stationary:

1. Johansen VECM-Cointegration approach:
   (a) With the variables for each model (residential demand and industrial demand) we run a VAR and, with the information criteria, select the optimal number of lags;
   (b) Using these lags, we test cointegration;
   (c) If there is a cointegration relationship between the \( I(1) \) variables, we already have the long-run elasticities.

Besides, we can identify the short-run elasticities with the Error Correction Model.
   (d) The VECM gives the short-run coefficients fixed over time.

2. We get the ECM equation relative to electricity demand and test structural break.

3. If we find a break, we get started with the analysis of short-run elasticities dynamics, with the ECM equation as the observable equation of a Kalman Filter.

So, our steps will culminate in the following estimate pair of equations:

The first step gives us this equation, that is the cointegration equation:

\[
\log_{res}\ t = \alpha_0 + \alpha_1 \log_{tres}\ t + \alpha_2 \log_{pib}\ t + \alpha_3 \log_{apelm}\ t + \alpha_4 \log_{glp}\ t + \epsilon_t, \tag{4}
\]

where \( \log_{res} \) is the log of residential electric energy demand, \( \log_{tres} \) is the log of residential tariff, \( \log_{pib} \) is the log of GDP, \( \log_{apelm} \) is the log of appliances price index, \( \log_{glp} \) is the log of liquefied petroleum gas (LPG) barrels and \( \epsilon_t \) is an error.

The second step uses the ECM equation, that is the next equation, and tests structural break in their parameters.

\[
\Delta \log_{res} t = \beta_{1t} \log_{res}\ t_{-1} + \sum_{i=1}^{p} \gamma_{it} \Delta \log_{res}\ t_{-i} + \sum_{i=1}^{p} \lambda_{it} \Delta \log_{tres}\ t_{-i} + \sum_{i=1}^{p} \phi_{it} \Delta \log_{pib}\ t_{-i} + \sum_{i=1}^{p} \varphi_{it} \Delta \log_{apelm}\ t_{-i} + \sum_{i=1}^{p} \eta_{it} \Delta \log_{glp}\ t_{-i} + \epsilon_t, \tag{5}
\]

where \( \Delta \log_{res} \) is the first difference of log of residential electric energy demand, \( \Delta \log_{tres} \) is the first difference of log of residential tariff, \( \Delta \log_{pib} \) is the first difference of log of GDP, \( \Delta \log_{apelm} \) is the first difference of log of appliances price index, \( \Delta \log_{glp} \) is the first difference of log of liquefied petroleum gas (LPG) barrels and \( \log_{res} \) is an error from the residential cointegrating equation.

The third step still utilizes the ECM equation and models a State Space in which the ECM equation is the observable equation, to test if its coefficients are fixed or if they vary in time.

In the same way, we have the pair of equations for industrial demand.

\footnote{Durbin and Koopman (2001) have a very good presentation of state space models setting and estimation.}
\[ l\text{ind}_t = \alpha_0 + \alpha_1 l\text{tind}_t + \alpha_2 l\text{proindsa}_t + \alpha_3 l\text{ipa}_t + \alpha_4 l\text{pice}_t + \epsilon_t, \]  

where \( L\text{ind} \) is the log of industrial electric energy demand, \( L\text{tind} \) is the log of industrial tariff, \( L\text{proindsa} \) is the log of Industrial Production, \( L\text{ipa} \) is the log of Machines and Equipments price index, \( L\text{pice} \) is the log of Oil price index and \( \epsilon_t \) is an error.

\[
\Delta l\text{ind}_t = \beta_1 \epsilon_{t-1} + \sum_{i=1}^{p} \gamma_{i1} \Delta l\text{ind}_{t-i} + \sum_{i=1}^{p} \lambda_{i1} \Delta l\text{tind}_{t-i} + \sum_{i=1}^{p} \phi_{i1} \Delta l\text{proindsa}_{t-i} + \sum_{i=1}^{p} \varphi_{i1} \Delta l\text{ipa}_{t-i} + \sum_{i=1}^{p} \eta_{i1} \Delta l\text{pice}_{t-i} + \epsilon_t,
\]

where \( \Delta L\text{ind} \) is the first difference of log of industrial electric energy demand, \( \Delta L\text{tind} \) is the first difference of log of industrial tariff, \( \Delta L\text{proindsa} \) is the first difference of log of Industrial Production, \( \Delta L\text{ipa} \) is the first difference of log of Machines and Equipments price index, \( \Delta L\text{pice} \) is the first difference of log of Oil price index and \( \epsilon_{t-1} \) is the lag of the error from the Industrial cointegrating equation.

### 7 Data

Our data set are at a monthly frequency and cover the period from January 1999 to December 2007. In Table 1, we present the data set and its source. As one can see, our sample size is at least double of others Brazilian applications. But previous articles for Brazilian electric energy demand estimation used annual data. We already mentioned that annual data doesn’t have enough spam of time for an adequate time series study.

So, in table 1, firstly, we have the variables for the residential demand and below, the ones for industrial demand estimation.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Variables and Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Name</td>
</tr>
<tr>
<td>Residential Demand (MWh)</td>
<td>Lres</td>
</tr>
<tr>
<td>Residential Tariff (R$/MWh)</td>
<td>Ltres</td>
</tr>
<tr>
<td>GDP (R$)</td>
<td>Lpib</td>
</tr>
<tr>
<td>PPI - Appliances</td>
<td>Lipaelm</td>
</tr>
<tr>
<td>LPG gas (Thousands of barrels)</td>
<td>Lglp</td>
</tr>
<tr>
<td>Consumer Loan Operations (R$)</td>
<td>Lcredifs</td>
</tr>
<tr>
<td>Median Temperature (°C)</td>
<td>Ltemp</td>
</tr>
<tr>
<td>Industrial Demand (MWh)</td>
<td>Lind</td>
</tr>
<tr>
<td>Industrial Tariff (R$/MWh)</td>
<td>Ltind</td>
</tr>
<tr>
<td>Industrial Production (R$)</td>
<td>Lproind</td>
</tr>
<tr>
<td>PPI - Machines and Equipments</td>
<td>Lipaq</td>
</tr>
<tr>
<td>PPI - Oil</td>
<td>Lipaq</td>
</tr>
<tr>
<td>Corporate Loan Operations (R$)</td>
<td>Lipac</td>
</tr>
</tbody>
</table>
Graph 1 gives the residential and industrial electric energy consumption series plotted. Specially in the residential case, 2001 seems like a relevant shock in the magnitude of electricity demanded in Brazil.

In Graph 2 we try to see if there is a same trend between the income series and the electricity consumption series in Brazil. For residential and industrial cases, as we expect, income and electricity demand have a strong correlation.

Another variable that is very important for the electricity demand is the electric energy price, or the tariff. Brazilian electricity tariff had a characteristic that residential consumers usually pay more than industrial one. Graph 3 shows the log of tariff for this two segments and we can see that fact. Since 2003, however, Federal government starts to apply a tariff realignment in the annual adjusts, whose objective is to finish with cross-subsidy. Besides Rationing Crisis, this regulatory behavior could be another reason for a change in the elasticities of electricity demand in Brazil in recent years.
Unit root tests\(^7\) indicate that all the variables can be characterized as non-stationary, except the temperature. The first difference of the series is stationary.

### 8 Estimation and Results

We want to investigate the behaviour of income and tariff elasticities of Brazilian electricity demand during 1999 until 2007 and the effect of the 2001 Crisis over this behaviour. The first step will be estimate the fixed coefficients using a Vector Error Correction Model and present the fixed elasticities as other studies. In the second step we test for the existence of a change in the pattern of brazilian consumption, or, if the 2001 crisis was a structural break in Brazilian demand. After testing this behaviour change, we can let income and tariff elasticities vary over time using a State Space Model, in a manner that, we observe the dynamics of short-run elasticities in Brazil. At last, we can include variables in the measurement equation to test possible determinants of each elasticity dynamic.

First of all, we choose 3 lags as the optimal number of lags using Schwarz or Bayesian Information Criteria (BIC) for both residential and industrial VAR’s. After the decision of the number of lags, the long-run relationship is estimated using Johansen technique and Vector Error Correction can be used.

The results will be presented behind for Residential and Industrial demands.

**Long and short run elasticities (VECM - fixed coefficients)**

- **Residential** The Johansen cointegration test\(^8\) indicates the existence of two common stochastic trends between residential demand and its determinants. The estimated long run relationship was significant for all coefficients but the constant (standard errors in parentheses):

---

\(^7\)The unit root tests were not reported in this article, but one can request the results to the authors.

\(^8\)Following the estimation procedure described, first we applied the Johansen cointegration test. As we already said, the optimal number of lags was selected by Bayesian Information Criteria (BIC), for a matter of parsimoniousness.
These coefficient estimates suggest that:

- the long run elasticities of the residential electric demand with respect to PPI and the GNP are 0.93 and 1.76, respectively;
- an absolute one-percentage point increase in the variability of the residential tariff reduces residential electricity demand by 0.97%;

The residential consumption has a tariff-elasticity close to one in the long run, meaning that a decrease of 1% in tariffs induces 0.97% increase in quantity consumed. The residential consumption is elastic to income, where a 1% variation of the income causes a variation of 1.76% in the same direction over residential electricity consumption. Another result is the positive cross elasticity between residential demand and appliances.

After the cointegration, we start the Error Correction Model estimate. It is important to mention that the inclusion of the temperature exogenous variable $I(0)$ does not change the test statistics distribution.

\[
\begin{align*}
\text{lres}_t & = 0.95 - 0.97 \text{ltres}_t + 1.76 \text{lpib}_t + 0.93 \text{lipaelm}_t + \epsilon_t \\
& \quad (3.233) \quad (0.267) \quad (0.710) \quad (0.298)
\end{align*}
\]

Table 2 shows the estimated Error Correction Model for Residential sector. With the optimal lags, we can see that the terms of the cointegrating regressions (CointEq1 and CointEq2) affect the short run response of the residential demand. Besides that, we have the second lag of the first difference of residential demand, the second
lag of the first difference of electric appliances PPI, the first and the second lags of the first difference of GDP and 
the second lag of the first difference of tariff influencing the short run response of residential demand.

**Industrial**  All long-run coefficients present the *a priori* expected signs but only the industrial production 
variable is statistically significant at the 5% level. These coefficient estimates suggest that:

- the long run elasticities of the industrial electricity demand with respect to Machines and Equipments PPI and 
  the Industrial Production are 0.51 and 1.32, respectively;
- an absolute one-percentage point increase in the variability of the industrial tariff reduces industrial electricity 
  demand by 0.24%;

\[
l_{\text{ind}}_t = 1.93 - 0.24 \ l_{\text{ind}}_{t-1} + 1.32 \ l_{\text{proindsa}}_t + 0.51 \ l_{\text{ipaq}}_t + \epsilon_t \tag{9}
\]

(1.307)  (0.133)  (0.309)  (0.333)

The industrial consumption has a tariff-elasticity very inelastic in the long run, meaning that a increase of 1% 
in tariffs induces 0.24% increase in quantity consumed. Its important to note that industrial consumers are less 
sensitive to tariff variations compared to residential consumers. This results is expected because the industrial 
one can have self productions plants and can have different access to energy market than residential consumers, 
independently of the tariffs.

The industrial consumption is elastic to income, where a 1% variation of the income causes a variation of 1.32% 
in the same direction over electricity consumption. The cross elasticity between residential demand and machines 
and equipments is positive but not significative.

The next step after the long run relationship is to estimate the short run movements using the Error Correction 
Model. Table 3 shows the estimated Error Correction Model for Industrial sector. With the optimal lags, we can 
see that the terms of the cointegrating regressions (CointEq1 and CointEq2) affect the short run response of the 
residential demand. In the short run, the cross elasticity of machines and equipments with industrial demand is 
negative, that is, an increase in machines cost diminishes the industrial demand for these machines, decreasing 
the consumption of energy. Income do not seem to affect the consumption in the short run, but tariff-elasticity is 
significantly negative in the short term.
So, after we have confirmed the existence of a long-run relationship between the variables with the cointegration test we get the ECM model and test it for a structural break in the better fitting equation of this Error Correction Model, as showed in table 4.

The classic test of structural break is attributed to Chow (1960). This test consist to divide the sample into two parts, estimating the parameters of each period, and finally testing the equality of two sets of parameters estimated by a F statistical. However, an important limitation of the Chow test is that the period of the structural break should be known a priori.

Applying the Chow test, if F statistic rejects the null hypothesis of no break, it can mean that there is a single discrete break or there is a slow evolution of the parameters. Based on this test we reject the null hypothesis of no structural break, and the specific date of the structural break found was August 2001, what can be seen as a consequence of Rationing Crisis occurred that year.

### Has the consumption pattern changed after 2001? The Structural Break test

**Residential**  So, after we have confirmed the existence of a long-run relationship between the variables with the cointegration test we get the ECM model and test it for a structural break in the better fitting equation of this Error Correction Model, as showed in table 3 and test it for a structural break. Based on the Chow Structural Break Test (as we already know the possible break date) we can verify the hypothesis of structural break.

So, after we have confirmed the existence of a long-run relationship between the variables, we can run the VECM model showed in table 3 and test it for a structural break. Based on the Chow Structural Break Test (as we already know the possible break date) we can verify the hypothesis of structural break.

### TABLE 3

Error Correction Model for Industrial Demand

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>Standard-Errors</th>
<th>T-Stats</th>
</tr>
</thead>
<tbody>
<tr>
<td>CointEq1</td>
<td>-0.061213</td>
<td>(0.05786)</td>
<td>[-1.05786]</td>
</tr>
<tr>
<td>CointEq2</td>
<td>-0.016252</td>
<td>(0.01609)</td>
<td>[-1.01032]</td>
</tr>
<tr>
<td>D(Lind(-1))</td>
<td>0.080928</td>
<td>(0.10755)</td>
<td>[0.75249]</td>
</tr>
<tr>
<td>D(Lind(-2))</td>
<td>-0.067861</td>
<td>(0.10773)</td>
<td>[-0.62993]</td>
</tr>
<tr>
<td>D(Lipac(-1))</td>
<td>0.063663</td>
<td>(0.12674)</td>
<td>[0.50231]</td>
</tr>
<tr>
<td>D(Lipac(-2))</td>
<td>-0.128715</td>
<td>(0.12526)</td>
<td>[-1.02757]</td>
</tr>
<tr>
<td>D(Lipa(-1))</td>
<td>-0.816395</td>
<td>(0.41002)</td>
<td>[-1.99112]</td>
</tr>
<tr>
<td>D(Lipa(-2))</td>
<td>0.399629</td>
<td>(0.37395)</td>
<td>[1.06868]</td>
</tr>
<tr>
<td>D(Lproindsa(-1))</td>
<td>0.193423</td>
<td>(0.14112)</td>
<td>[1.37065]</td>
</tr>
<tr>
<td>D(Lproindsa(-2))</td>
<td>0.011978</td>
<td>0.011978</td>
<td>[0.08894]</td>
</tr>
<tr>
<td>D(Ltind(-1))</td>
<td>0.089191</td>
<td>(0.09140)</td>
<td>[0.97582]</td>
</tr>
<tr>
<td>D(Ltind(-2))</td>
<td>-0.184482</td>
<td>(0.09156)</td>
<td>[-2.01494]</td>
</tr>
</tbody>
</table>

Adj R-squared 0.059238
Sums q. Resid. 0.096485
Log Likelihood 1313.103
Schwarz IC -3.622567

So, after we have confirmed the existence of a long-run relationship between the variables, we can run the VECM model showed in table 3 and test it for a structural break. Based on the Chow Structural Break Test (as we already know the possible break date) we can verify the hypothesis of structural break.
Due to the limitations of the Chow test, like the exogeneity of the breakpoint, we apply the recursive residuals test and the CUSUM of Squares test in the ECM residential equation.

Recursive residuals test shows a plot of the recursive residuals about the zero line. Plus and minus two standard errors are also shown at each point. Residuals outside the standard error bands suggest instability in the parameters of the equation. We can see that in 2001 we have another evidence of structural break in our electric energy demand equation.

The CUSUM of squares test provides a plot of against and the pair of 5 percent critical lines. Movement outside the critical lines is suggestive of parameter or variance instability. The cumulative sum of squares is generally within the 5% significance lines, but in 2001 once more we have evidence of instability.

Industrial The same procedure is done for Industrial case. The results were less robust, but at 10% level of significance the Chow Test suggested that 2001 crisis represented a change in behaviour of Industrial consumption. This result indicate that elasticities could vary over time and may depend of other determinants. This could be tested as did before, using the State Space Model.
The limitations of Chow Test lead us to the use of CUSUM test. This test suggest strong parameter instability in two periods, in 2001 and 2004. Here, maybe we can have two structural breaks for Industrial demand. Anyway, the test supports that the standard estimation using fixed coefficients are not the best option to estimate the Brazilian Industrial Electric Demand in this period. These results argues in favor of using a time varying VECM to correctly specificate the industrial demand.

**Time-varying elasticities**  After the structural break test in the estimated demand equation we can test the coefficients stability and estimate the time-varying elasticities with the State-Space model where the demand equation is the observable equation and the states equations may include other relevant variables.

An important characteristic of these kind of model, is that state equations may not contain signal equation dependent variables, or leads or lags of these variables; may contain exogenous variables and unknown coefficients, and may be nonlinear in these elements. Each state equation must be linear in the one-period lag of the states.

**Residential**  Table 6 shows our estimated State Space model for Residential consumers. As we can see in the observable equation (our already known ECM residential equation), we tested the dynamics in the GDP and tariff variables, and in the two variables from the cointegrating equations. All the equations (the observable one and the
state equations have an error variance specification, because we assumed that they are not deterministic. And we permit time-variation in variance using a series expression (exponential).

We tested specifications for the four state equations and table 6 have the better fitting for each case. For example, the state equation for the GDP variable (sv1), have a AR(1) format.

Another aspect of our state equations is that we added a credit variable to explain the dynamics of GDP ant tariff elasticities.

| TABLE 6 |
| State Space Model Equations - Residential |

| Estimated Observable Equation: |
| dlres = c(1)*ltemp + c(2)*dlpielm(-1) + sv1*dlpib(-1) + c(3)*dlpib(-2) + sv2*dltres(-1) + c(4)*dltres(-2) + sv3*cointe_res1 + sv4*cointe_res2 + c(5)*dlres(-1) + [var = exp(c(6))] |

| Estimated State Equations: |
| sv1 = c(9)+c(18)*sv1(-1) + c(7)*dlcred(-1) + [var = exp(c(8))] |
| sv2 = c(10)*sv2(-1) + c(11)*dlcred(-1) + [var = exp(c(12))] |
| sv3 = c(15)*sv3(-1) + [var = exp(c(14))] |
| sv4 = c(17)*sv4(-1) + [var = exp(c(16))] |

Table 7 emphasizes the final value estimation of the time-varying parameters from residential demand equation. The final value of income elasticity, for example, stayed beyond unity, indicating that, in the short run, until the adjustment for the long run, income elasticity for residential consumers may be inelastic. This is a plausible hypothesis in some situations, depending of economic or the weather conditions.

| TABLE 7 |
| Short-Run Dynamics of Estimation - Residential |

<table>
<thead>
<tr>
<th>Final State</th>
<th>Root MSE</th>
<th>z-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV1</td>
<td>0.90809</td>
<td>1.09E-05</td>
<td>83657.8</td>
</tr>
<tr>
<td>SV2</td>
<td>-0.33184</td>
<td>1.91E-05</td>
<td>-17381.5</td>
</tr>
<tr>
<td>SV3</td>
<td>0.00046</td>
<td>0.162845</td>
<td>0.00287</td>
</tr>
<tr>
<td>SV4</td>
<td>0.00044</td>
<td>0.389678</td>
<td>0.00114</td>
</tr>
</tbody>
</table>

Log Likelihood: 202.0321
Akaike IC: -3.5583
Schwarz IC: -3.1260

In graph 6, we see the plot of smoothed time-varying elasticities along all our sample. The first graph show us the decrease in income elasticity after 2002. The sensitivity of residential demand to income variations is, usually, positive but appears to decrease over time. The tariff-elasticity is more stable after 2002 with a negative growth trend but close to -1.
In Table 8 we present some descriptive statistics for income and tariff-elasticities for residential demand. Comparing these values with its maximum and minimum, we can perceive that the mean value for the short run income elasticity is bigger than unity, but with the maximum and minimum values we see that this elasticity varies significantly in our period sample. At the same way, we see the price elasticity for residential demand, which has mean -0.32 with maximum and minimum with a expressive wideness.

<table>
<thead>
<tr>
<th>TABLE 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential States Estimates - Descriptive Stats</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Median</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Std. Dev.</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Kurtosis</td>
</tr>
<tr>
<td>Jarque-Bera</td>
</tr>
<tr>
<td>Prob.</td>
</tr>
</tbody>
</table>
**Industrial** The State Space model is applied in a similar way to industrial consumers. The measurement equation presents the short run movements in demand but allowing income, tariff-elasticities and error corrections terms to vary over time. These coefficients were modelled by the state equations, with an autoregressive structure using other explanatory variables. These explanatory variables fitting each coefficient dynamics were credit supply and the tariff volatility for the industrial demand case.

<table>
<thead>
<tr>
<th>TABLE 9</th>
<th>State Space Model Equations - Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Observable Equation:</td>
<td>dlind = sv1<em>dlproindsa(-1) + sv2</em>dltind(-1) + c(1)*dltind(-2)+ c(2)*dlproindsa(-2)+ c(3)<em>dlipac(-1)+ c(4)<em>dlipaq(-1)+ sv3</em>cointe_ind1+ sv4</em>cointe_ind2+ [var = exp(c(6))]</td>
</tr>
<tr>
<td>Estimated State Equations:</td>
<td>sv1 = c(11)+c(12)*sv1(-1)+c(21)*garch_ind(-1)+c(14)*dlcredind(-1)+var = exp(c(15))] sv2 = c(7)+c(8)*sv2(-1)+c(9)*garch_ind(-1)+ c(10)*dlcredind(-1)+ [var = exp(c(20))] sv3 = c(16)*sv3(-1)+ [var = exp(c(17))] sv4 = c(18)*sv4(-1)+ [var = exp(c(19))]</td>
</tr>
</tbody>
</table>

The tariff-elasticity for industrial consumers is inelastic on entire period, but described a strong volatility between 2001 and 2002. After the resolution of 2001 crisis, the tariff-elasticity started a strong decrease stabilizing at -0.68 value in 2007.

Income-elasticity described a different pattern, staying between 0.15 and 0.45 during 1999 to 2007. Again, the 2001 crisis generated the most volatile movement of the sensitivity of industrial consumer to income variations. At the same time the Brazilian economy started to recover of this shock, the income-elasticity followed the movement and started to increase. The sensitivity estimated for variations in income today was nearly 40% in our model for industrial consumption.

**GRAPH 7**

<table>
<thead>
<tr>
<th>Smoothed State - SV1 - DLPROINDS(1)</th>
<th>Smoothed State - SV2 - DLTIND(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV1</td>
<td>SV2</td>
</tr>
<tr>
<td>±2 RMS E</td>
<td>±2 RMS E</td>
</tr>
</tbody>
</table>
TABLE 10

<table>
<thead>
<tr>
<th></th>
<th>Final State</th>
<th>Root MSE</th>
<th>z-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV1</td>
<td>-0.68150</td>
<td>8.67e-05</td>
<td>-7857.373</td>
<td>0.000</td>
</tr>
<tr>
<td>SV2</td>
<td>0.40554</td>
<td>3.73E-06</td>
<td>108828.5</td>
<td>0.000</td>
</tr>
<tr>
<td>SV3</td>
<td>-0.00002</td>
<td>0.201752</td>
<td>-0.001416</td>
<td>0.9989</td>
</tr>
<tr>
<td>SV4</td>
<td>2.00E-10</td>
<td>6.61E-05</td>
<td>3.02E-06</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Log Likelihood 199.3253
Akaike IC -3.5101
Schwarz IC -3.3046

For industrial sector we do not report the descriptive statistics of estimated time-varying short-run elasticities. Nonetheless, as in residential case, they also present a significative variation between maximum and minimum values of tariff and income elasticities.

Determinants of the short-run elasticities dynamics

**Residential**  In table 11, we test which determinants affect the dynamics of income and tariff elasticities (with p-values between parentheses). The credit variable is more important to explain price elasticity dynamic, with a negative correlation. Our results suggest that the increase in credit supply can be an explanation for the decrease in price elasticity. How bigger is credit access, higher demand of more efficient electric appliances will be, and the possibility of choosing between more efficient domestic equipments using eletricity can induce a smaller sensitivity of demand to tariff variations.

One explanation for this credit effect is that the increase in consumers loans, in recent years, would augment the financing of electric appliances, which are more energy savers nowadays.

Also the persistence of price elasticity is very significant to explain the sensitivity of consumption to tariffs. The statistically significant and negative coefficient indicates an oscillation movement in elasticity. For income-elasticity, we did not find any significative determinants of its dynamics.

TABLE 11

<table>
<thead>
<tr>
<th></th>
<th>Income Elasticity</th>
<th>Price Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistence</td>
<td>-0.19 (0.36)</td>
<td>-0.48 (0.02)</td>
</tr>
<tr>
<td>Credit</td>
<td>-51.61 (0.12)</td>
<td>-30.47 (0.00)</td>
</tr>
<tr>
<td>Final State</td>
<td>0.91 (0.00)</td>
<td>-0.33 (0.00)</td>
</tr>
</tbody>
</table>
**Industrial** The income-elasticity industrial demand is not statistically dependent of industrial credit market and tariff volatility in Brazil. One potential problem is the difficulty to capture the self production increase in the industrial sector observed during our sample.

For tariff-elasticity, only persistence is significant, meaning that tariff-elasticity for industrial consumption has a high inertia in Brazil. This elasticity has a correlation of 0.85 with one month lagged value, where an exogeneous shock effect over the industrial consumers sensitivity persists for approximately 6 months.

<table>
<thead>
<tr>
<th>TABLE 12 Results of State Space Estimation - Industrial*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income Elasticity</td>
</tr>
<tr>
<td>Persistence</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Credit</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Volatility</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Final State</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

*p-value between parentheses

9 **Comparing Results**

Using monthly data, from 1999.1 to 2007.12, we found significant long-run and short-run estimates for residential and industrial elasticities of electricity demand. Our long and short-run residential price-elasticities were -0.96 and -0.46; and the industrial price-elasticities of long and short-run were -0.24 and -0.18. The long and short-run income-elasticities were 1.76 and 1.06 for residential consumers and 1.31 and 0.19 for industrial consumers.

However, estimate the demand without consider the 2001 Crisis can generate problems in the properties of estimatives. Thus a structural break test was made, and we provide evidence that the Rationing Crisis changed the pattern of the electric energy demand in Brazil. The date found in the ECM equations of residential and industrial demand using a structural break test was August 2001, indicating that time-varying elasticities may be a better decision to estimate the Brazilian Eletricity Demand.
<table>
<thead>
<tr>
<th></th>
<th>Y-Long-run</th>
<th>Y-Short-run</th>
<th>P-Long-Run</th>
<th>P-Short-run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential (Fixed)</td>
<td>1.76</td>
<td>1.06</td>
<td>-0.96</td>
<td>-0.46</td>
</tr>
<tr>
<td>Industrial (Fixed)</td>
<td>1.31</td>
<td>0.19</td>
<td>-0.24</td>
<td>-0.18</td>
</tr>
<tr>
<td>Residential (Dynamics - Final State)</td>
<td>0.90</td>
<td>-0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial (Dynamics - Final State)</td>
<td>0.40</td>
<td>-0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chang (2003)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>1.95</td>
<td>-0.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>1.29</td>
<td>-0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Espey &amp; Espey (2004)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0.97</td>
<td>0.28</td>
<td>-0.85</td>
<td>-0.35</td>
</tr>
<tr>
<td>Porter (2004)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
<td>-0.94</td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
<td>-0.55</td>
<td></td>
</tr>
<tr>
<td>Modiano (1984)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>1.13</td>
<td>0.33</td>
<td>-0.40</td>
<td>-0.11</td>
</tr>
<tr>
<td>Industrial</td>
<td>1.36</td>
<td>0.50</td>
<td>-0.45</td>
<td>-0.22</td>
</tr>
</tbody>
</table>

The State Space estimations showed that income and tariff elasticities for residential and industrial consumers really changed over time. The income elasticity stayed beyond unity for many times until describe a decreasing pattern and adjust to long-run inelastic value. Analysing the sensitivity of demand to tariffs, the consumers (mainly industrials) are becoming less sensitive to tariff changes.

For residential consumption, credit supply is negatively associated with tariff-elasticity, explaining part of the decrease of the sensitivity of consumers to tariffs variations. The persistence of tariff-elasticity is statistically important for the specification of state equation for both demands. The consumers demand tariff-elasticity has a negative persistence, generating a sinusoidal behaviour. Although the industrial demand tariff-elasticity has a relevant dependence of past value that implies a half-live of 6 months.

10 Conclusion

This paper update the modelling of Brazilian electricity demand, with a spam of time that includes the power rationing crisis from 2001. In this way it differs from the existing literature, not only in its data set, but also in its empirical method. Due to a possible break, that we confirm to be significative, the estimates from other authors may be desaligned with the current scenario.

Our findings suggest that Brazilian residential consumers are more sensible to price and to income than industrial ones. This result is compatible with conclusions of Chang and Martinez-Chombo (2004) for long-run estimates of Mexican price-elasticities and with Kamerschen and Porter (2004), whose residential price-elasticity stayed in the range -0.85 and -0.94, and industrial between -0.34 and -0.55.
The power Rationing Crisis seems like a structural break to Brazilian data. This emphasizes that elasticities can vary over time and we test this for short-run elasticities. With the State Space model, we obtain that income elasticities may stay beyond the unity during the adjustment to long-run (where we found them bigger than unity).

The implications of our results - consequence of a better specification of electric energy with the TVP-ECM model - are important, because policy-makers need to consider the possibility of varying responses of elasticities to its determinants. For example, income elasticities correctly estimated are essential to planning need of investments in power generation, while price elasticities are indispensable to regulation of electricity sector, where incentives are made within a tariff basis.

References


