Escola de Pós-Graduação em Economia - EPGE
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Essays on Infrastructure in Brazil

Thesis submitted to the Graduate School
of Economics from
Fundação Getulio Vargas,
as a requirement for the title of
Doutor em Economia

by

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I devote this thesis to my beloved parents, that all my life made the possible and impossible for me. I will never have a way to reward all this love.

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Abstract

This thesis encompasses five papers about two Brazilian infrastructure sectors: energy and road transportation. In the first paper, we model the bid in the Brazilian transmission lines auctions, in order to understand why the winning bids have been lower than one could expect. In the second paper, we estimate the electricity demand and the price and income elasticity of the consumers, using a new technique and including the 2001 Rationing period, which could have changed the consumers' behavior. In the third paper, we study the evolution of the liquefied natural gas (LNG) market worldwide. The LNG could be a link to the natural gas markets and we test this hypothesis using time series and copulas analysis. In the fourth paper, we discuss the entrance of the LNG in the national electricity market. Finally, in the last paper, we analyze the Road concession experience in Brazil. We add new insights about the auction model used in this sector and also about the contract design.

Keywords: Auctions Econometrics, Regulation, Energy, Time Series Analysis, Copula Technique Analysis, Real Options, Infrastructure.

Resumo

A presente tese engloba cinco trabalhos sobre dois setores brasileiros de infraestrutura: setor de energia e de transportes. No primeiro trabalho, modela-se o lance dos leilões de linhas de transmissão de energia, buscando compreender porque os lances ganhadores têm se situado em níveis abaixo do que se espera. No segundo paper, estima-se a demanda de energia do Brasil e as elasticidades preço e renda que os consumidores apresentem em relação a essa demanda, usando uma técnica ainda não aplicada na literatura e incluindo o período da Crise do Racionamento – a qual pode ter mudado o padrão de consumo dos agentes. No terceiro trabalho, estuda-se a evolução do mercado de gás natural liquefeito (GNL) ao redor do mundo. O GNL pode ser o link que faltava entre os mercados de gás natural e essa hipótese é testada por meio de análises de séries de tempo e de cópulas. O quarto paper discute a entrada do GNL no sistema energético brasileiro e suas eventuais consequências. Por fim, o quinto paper analisa a experiência de leilões de rodovias no Brasil. O trabalho levanta relevantes *insights* a respeito do modelo de leilão utilizado e dos detalhes contratuais dessas licitações.

Palavras-Chave: Econometria de Leilões, Regulação, Energia, Análise de Séries de Tempo, Análise de Cópulas, Opções Reais, Infraestrutura.

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Introduction

According to Guasch (2004)[1], infrastructure services - electricity, water and sanitation, telecommunications, roads, railroads, ports, and airports - are critical to the operation and to the efficiency of a modern economy.

The author also points out that infrastructure services begin as critical inputs in the provision of goods and services and significantly affect the productivity, cost, and competitiveness of the economy and the alleviation of poverty. For example, poor infrastructure services limit competitiveness in other markets, and limited coverage and access increase poverty. Policy decisions regarding their provision and sector development have ramifications throughout the economy.

In developing countries, such as Brazil, India and China, among many other challenges that the Public Administration and the population as a whole have to deal with, is the necessity of investments in infrastructure to guarantee the development process.

Turning back the attention to the Brazilian case, the development and the improvement of the current Brazilian infrastructure is crucial for maintaining the country's growth and, because of that, should be a priority to the Public Administration. Nonetheless, there is a consensual idea that the regulatory framework in this sector is still being consolidated, fact that can be seen with constraints by new investors.

In the Brazilian energy sector, there are many key points to be considered when the subject is the infrastructure development. Two of them are the transmission and the generation segments.

The transmission in Brazil is in a positive path. The Brazilian Electricity Regulatory Agency (ANEEL) is following a policy of conduct annual public bids for the transmission lines concession to public and private companies. With this trend, the transmission system is growing in a speed four times superior than it was in the period before the agency starting, in 1999. According to the Brazilian Association of Base Industries (ABDIB), before 1999, the transmission network increased 0.8% per year. After 1999, this annual increment has reached 3.8%.

In the generation topic, the debate concerning a possible unbalance in the electricity supply and demand is permanent in the Brazilian energy sector. In other words, the blackout and rationing occurred in 2001 and the episode of the last November, 2009[2] put in check the system reliability. The lack of investments is understood as the main source of this risk. However, there are many power plants already conceded and waiting for the construction authorization, because of regulatory, environmental and financial constraints existence. At the same time, there is no enough natural gas to fuel the thermo power plants.

In accordance with the energy sector, the transports also need investments in Brazil. The country has more than 60% of the freight transportation carried out by roads, but the road network is lacking of maintenance and the concession program is not dynamic and sufficiently extensive to accomplish the problems (only 5% of the paved network of 217,800 km is on the concessionaires' hands). Another relevant reason to expand the investments in the

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[1] *Granting and Renegotiating Infrastructure Concessions: Doing it Right*. World Bank Development Institute.

[2] In November, 10th, Brazil had the worst power outage in a decade, which left a huge swath of the country in the dark for more than five hours and raised doubts about the reliability of its energy infrastructure. The blackout hit 18 of Brazil's 26 states. Paraguay, which gets about 90 percent of its power from the Itaipu dam, was left entirely in the dark for about 15 minutes. Paraguay's state electricity company said that the problem was originated in Brazil.

transports is the trend of increasing in the Brazilian exports. In this sector, public and private investments can be done in the next years if the rules become more transparent and stable.

In this scenario, we have engineering professionals leading the infrastructure area, with the decisions based on their point-of-view. The present thesis is an attempt to understand and model many Brazilian infrastructure problems in a theoretical economics framework. The possibility to offer new insights and results to help the policy implementation in the infrastructure sector is the first objective to be accomplished by this work.

To exemplify the importance of this category of study in Brazil, we can remember that the auctions topic is constant in the infrastructure sector. According to Dutra and Zugno (2008)[3], Brazilian law requires that a bidding process is conducted for selection of a company that will be responsible for the implementation of a specific infrastructure project. As a result of this law, it is essential to study the auctions used to the concession of harbors, roads, generation plants, transmission lines and other relevant infrastructure projects. The evaluation of the implemented design and the comprehension of the potential competitors' behavior are important questions to the success of these projects and to maintain the incentives for investments.

The present thesis has many contributions in this line, as such:

(i) We model the bid in the Brazilian transmission lines auctions, with the objective to understand why the winning bids have been lower than one could expect. Then, based on the results, we propose a new design to the transmission lines auctions, with neighboring lines put in a same bundle.

(ii) We estimate the electricity demand and the price and income elasticity of the consumers, using a new technique and including the 2001 Rationing period, which could have changed the consumers' behavior. A better estimation of the elasticities is an important task for the regulatory policy. It is also a relevant point to investments incentives in generation and, as a consequence, to the system reliability.

(iii) We study the evolution of the liquefied natural gas (LNG) market. We try to quantify its impact in the world and in Brazil specifically. The LNG expansion worldwide can be the link point to local natural gas market, and we model this possibility; besides that, we discuss the entrance of the LNG in the national electricity market.

(iv) Finally, we analyze the Road concession experience in Brazil. We add new insights about the auction model used in this sector and also about the contract design. Our study is a tool to new policy decisions in the road concession, helping to evaluate if the current model is optimal and if the auction design is choosing the best competitor as concessionaire in moral hazard terms.

In the first chapter of this thesis we utilize a database of the Brazilian Transmission auctions, from 2000 to 2010. We try to explain the traditional aspects of strategic behavior and optimality in auctions, but the main objective is to find out what is behind the very persistent difference between the winning bids and the reserve prices in these

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[3] *Infrastructure opportunities in Brazil*, Latin Counsel. Date: 22/12/2008, Written by: Rafael D´Avila Dutra, Guilherme Ziegler Zugno.

auctions. The winning bids are the revenue of transmission lines companies that win the auction. The higher discounts between this amount and the reserve price (the minimum revenue stipulated by the Regulatory agency) mean something. Our hypothesis is that there is some synergy between the lines. In this way, a company that already had a line in a region goes to the auction looking for win the line close to the old line, to administrate neighboring lines and make profits due to scale and synergy gains. The results show that synergy is very important in Brazilian transmission lines and maybe the auctions should be reorganized in order to the Government profits obtained in the concessions include these synergy gains. A possible solution could be an auction selling neighboring lines in a same "package". To see the robustness of these results, we model an economic experiment, in which we test the auction design already used in the transmission auctions (sequential auctions) with an alternative design (simultaneous auctions).

The current mechanism for the bidding is a sequential auction: the concessions are allocated in a pre-determined order. However, two elements provide uniqueness to the concession environment. Firstly, the bidding involves some segments that are connected or close to others that have already been bid. Furthermore, some involved segments are close to others that were the object of concessions in the past. In this case, there is asymmetry among bidders as such companies already holding concession agreements can operate the segments under more favorable conditions (at lower cost).

Both elements presented herein justify the comparison of the auction format used in the transmission with an alternative: the simultaneous auction. This comparison was carried out in an experimental environment developed to reproduce conditions similar to the background presented. The results confirm a superiority of the simultaneous auction whenever there are positive synergies: it was possible to simplify the bid submission task, thus obtaining higher revenue (in the granting phase) and higher efficiency (choosing the bidder who assigns a higher value to the object).

The second chapter is very important in terms of regulatory policy, once the Brazilian electricity sector is in the middle of the second tariff revision process and the Regulatory Agency is preparing the model for the third revision. After the privatization of the 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 exceeds 100 GW in 2007. Analysts forecast continuity in this expansion, once electricity is a relevant strategic component of an economy, especially in a developing country. An important issue in the electricity sector planning is to understand the electricity demand, its main determinants and its answers to specific shocks on its exogenous variables. There are some estimates for the 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 excluding the severe power rationing crisis, occurred in 2001.

In this paper we search to fill a blank in the economics literature: to our knowledge, there isn't a paper testing the stability of the coefficients for the electricity demand equation. It's necessary to test if the 2001 Crisis changed the Brazilian power consumer behavior, occasioning a shift in the income and in the price elasticities of demand. Furthermore, we include variables commonly used as determinants of the electricity demand in the international literature, such as the 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 consumer classes. The model we use is suitable to catch long run relationship between electricity demand and its determinants and, besides that, it allows dealing with instabilities or dynamics of the short-run adjustment. Our results suggest that Brazilian residential consumers are more sensible to price and to income than the industrial consumers. 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 appears like a structural break to the Brazilian data. This emphasizes that elasticities (the answer of electricity demand to shocks in its determinants) can vary over time and we test this hypothesis for the short run elasticities. With the State Space model, we obtain that income elasticities may stay beyond the unity during the adjustment to the long run (where we found them greater than unity).

The implications of our results are important, because policymakers need to consider the varying responses of elasticities to its determinants. For example, income elasticities correctly estimate are essential to planning need of investments in power generation, while price elasticities are crucial to the electricity sector regulation, in which the incentives are tariff-based.

The third chapter consists in a study about the liquefied natural gas (LNG) and is divided in two parts. The first part is an analysis of the natural gas globalization after the introduction and growth of the liquefied natural gas (LNG). Our hypothesis is that the expansion of LNG could bring the missing mechanism to achieve the integration of the regional markets, or, perhaps, the formation of a unique global market for natural gas. Previous related literature utilizes the Cointegration approach and the Kalman Filter to test the Law of One Price hypothesis within the global natural gas market. In this article, we use a Time Varying Parameter Error Correction Model (TVP-ECM) to examine the convergence between regional markets. Once verified cointegration relationships between the natural gas price series, we estimate, using the Kalman Filter, an Error Correction Model as a way to model the short run dynamics of the prices. We use monthly data of natural gas prices in United States, Europe (United Kingdom, Belgium) and Japan, from 2001 to 2009. Our results show that there is no statistical evidence of cointegration relationship between the Japanese market and the others. Nonetheless, the American and European markets present a relevant price convergence. When analyzing the state estimates we can find out short run dynamics between the markets in the United States and the United Kingdom and also between the United Kingdom and the Continental Europe.

After that, we modeled the short run dependence with the Copula Analysis. This is an innovation of this article: the joint use of the cointegration technique with Copulas. Basically, the Copulas are cumulative distributions functions (CDF) quite suitable to deal with dependence in multivariate data. The application of Copulas was motivated by the fact that neither the VECM nor the TVP-ECM was enough to account for all the dependence of the series in the short run. There is no statistical evidence of cointegration relationship between the Japanese market and the others, while the American and European markets present price convergence in the long run. The Copulas obtained for the pairs Zeebrugge-NBP and NBP-Henry Hub indicate that these markets move together more intensively during extreme periods. Finally, for the pair Zeebrugge-Henry Hub, the Copula fitted shows that there is no dependence at the extremes of the bivariate distribution.

The second part of the third chapter is an attempt to understand the consequences to the Brazilian energy sector of this LNG expansion worldwide. The exercise done in this second part was to calculate the flexibility value of a real option to the national system operator that arises with the entrance of the LNG in the Brazilian market. Petrobras, the Brazilian National Oil Company, is initiating its activities to bring Brazil to the LNG market. The company says that this project is the best technical and economic solution to fulfill the flexible demand for the natural gas in the short and the long-run, ensuring the reliability of the Brazilian thermo power plants.

The Petrobras' project consists in building regasification terminals to import LNG if necessary. The LNG contracts may be adjusted according to the demand dynamics, once the Brazilian natural gas high-demand period, when the thermo power plants are turned on, is concomitant with the global lower-demand period. In this article we search to evaluate, under the real options approach, the investment in the thermo power plants in Brazil as an alternative for expanding electricity generation within this new context of LNG regasification terminals.

The Brazilian dispatch system is highly dependent on hydrological conditions. In this scenario, it is important to the Brazilian energy sector institutions to be able to value all the flexibilities that the system has to operate and to attend the demand, respecting the premises of cost optimization and risk minimization.

Until know, the flexibility in the thermo plants using natural gas was not so relevant, since the only way to have natural gas was by the Brazil-Bolivia pipeline, with "take or pay" contracts. Nowadays, with the introduction of the LNG regas terminals to supply the thermo power plants, the ONS has a new option to consider when calculating the marginal cost of the whole system.

Therefore, the study is a first attempt to identify the importance of the LNG use in the Brazilian electric system. We had applied the Simulations of Monte Carlo in stochastic processes and the Real Options technique to analyze the possible value added by the use of the LNG in the thermo power plants Termoceará (CE), Termofortaleza (CE) and Jesus Soares Pereira (RN). We also have tried to understand the pricing mechanism adopted in the Brazilian electric sector and its consequences to the system operation. The exercise has illustrated how the use of the LNG can be a topic of utmost importance to the Northeast subsystem and to the Brazilian system as a whole, especially when the water reservoirs are in a low level or, other words, when the marginal costs of operation of the hydropower plants are high.

The next step in the paper will be to use the real costs in the integrated Brazilian dispatch system program (NEWAVE) to compare when it is profitable to turn on the thermo power plants using the LNG or when it is better to use the water from the reservoirs to attend the Northeast subsystem demand.

The last chapter of this thesis deals with the Brazilian experience in the Road transportation concessions. According to Guasch (2004), the main challenge of infrastructure concessions is writing time-consistent, enforceable contracts that cover all the contingencies that might arise with such technically complex activities and to signal credible commitment to a policy of not renegotiating opportunistic requests. The task of renegotiation is a concern especially in the Latin American countries, in which we observe the absence of high-quality institutions which could enforce the adherence to contracts.

With this in mind, we want to understand the current scenario in the Brazilian Road Concessions. Firstly we show some historical aspects of Brazilian roads and theoretical topics in concessions, with special attention to the regulatory aspects that a Government needs to take into account when is planning a framework to road concession

programs. Then we detail the Brazilian experience in road concessions, with both stages of the Federal road concession program and one example of a state level program, the São Paulo's state case. We also present some lines about the new concession format that coexists with the road concession program (called in Brazil Public-Private Partnership). Finally we do a theoretical analysis in the Brazilian experience with road concession, showing the main obstacles to be overcome in the Brazilian road sector. As conclusion in our study, we understand that the competitive bidding process applied nowadays in the road concessions in Brazil cannot be used together with the clause of Financial-Economic Equilibrium that rules the road concessions. For reasons broadly discussed, a good regulatory alternative to the Brazilian case would be the use of another auction model: the Present-Value of Revenue (PVR) auction.

As a final point, we have widely presented in this thesis studies and analysis in the infrastructure topic. The theoretical basis connecting the topics herein studied is the mechanism design. Our work contributes to the policymakers and economists in the infrastructure development objective and to the consequent Brazilian sustainable growth that it may cause.

CHAPTER 1

Strategic Behaviour of Winning Bids in the Brazilian Transmission Auctions*

Abstract

This paper investigates the great difference among the maximum reserve price established for the auctions held in the transmission electricity sector in Brazil and the observed winning bids, using a sample of data from 2000 to 2008. We test the hypothesis that the high verified markdown is a consequence of synergies, due to economies of scale in building and operating transmission facilities closely located. To this end, we analyzed reduced-based models, once transmission auctions are hybrids in format, consisting of a First Price Sealed Bid format in the first phase followed by a Descending Open Bid auction in a contingent second phase. The empirical results showed that plenty of factors impact transmission lines winning bids. Among them, one can cite the number of competitors, technology specifics of the undertakings, the maximum reserve price, the required investments, and, mainly, the location of the lines. This last factor indicates that synergies are in fact a relevant constituent of the current Brazilian transmission lines competitive scenario. Finally, we designed an economic experiment in order to test if an alternative design for the Brazilian transmission auctions, with neighbor lines auctioned simultaneously, could improve the rent extraction from the transmission companies.

JEL Codes: D44, Q40, H57.

Keywords: Auctions, Procurement, Econometrics of Auctions, Electric Energy, Strategic Behavior Analysis in Incomplete Information Games.

* Paper co-authored by professor Joisa Dutra Saraiva (EPGE/FGV).

1 Introduction

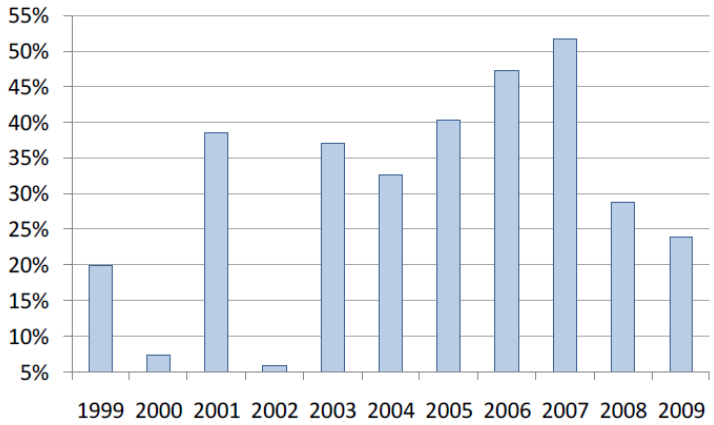
The electricity sector reliability is a determinant question for society and, because of this, it is to Brazilian academy too. The importance of this sector to a sustainable growth is undeniable and the recent experience of the Power Rationing Crisis in 2001 showed how complex can be the planning and execution of policies in this segment.

The electricity transmission lines, specially, are essential to connect distant points to the generation plants - it is a cheap and quick way to attend electricity demand in these places, compared to the construction of new generation plants - and to give support to the demand in the largest consumers locations.

Within this context, and not the least important to Brazilian electricity sector stability, we can insert the transmission lines auctions, that are the current way to guarantee the electric energy transmission construction and service. From 1998 to 2010, the National Electricity Regulatory Agency (ANEEL) auctioned more than 100 transmission lines bundles, that add more than 30,000 kilometers to the system.

In these auctions, agents bid for the right to build and operate transmission lines. The competitor who submits the lowest bid wins the auction. From 2003, there is a marked tendency: discounts in the bids are more and more significant. This can be illustrated by an auction held in December 2006, which involved the offering of six lots, organized by ten lines and three substations, summing 1,033 kilometers. The average discount in this auction reached 49.36%. Yet in the auction that took place in November of the same year, which involved 14 lines and three substations, in a total of approximately 2,250 kilometers of extension, the average discount was of 51.1%.

Figure 1 - Differences Between Winning Bids and Reserve Prices



Brandão & De Castro (2006) present a model to explain these discounts. According to the authors, the higher discounts are related to the lowering of the "Brazil Risk", that is, with the improvement in the risk perception of the national investments to foreigners.

However, both authors understand that only the lowering of the Brazil Risk does not suffice to explain the aggressive bidding behavior observed in these auctions. Part of this new tendency results, according to them, from a higher optimism, mainly due to improved access to capital from BNDES and capital markets.

On the other hand, ANEEL states that the observed discounts demonstrate that the chosen auction design is well succeed, in such a way that competition in the transmission process grants lower rates to consumers.

Despite the high discounts observed, the market does not consider that investors will walk out the transmission sector. On the contrary, they have been more and more numerous.[1] This apparent contradiction - smaller return taxes and longer terms that attract investors - is explained by the sector stability, which presents clear and transparent rules. Regulatory stability is a main driver for investments in this segment.

As presented above, in the auction the winner is the proponent who commits to the lowest Allowed Annual Revenue[2]. Discounts have been higher and higher in the auctions till the present date and analysts cannot explain the extent reached for this difference between the estimated value by ANEEL as ideal to the built, maintenance and operation of the transmission lines as well as the offered value by the transmission companies in the auctions.

According to Brandão and De Castro (2006), the main indicator to evaluate auctions prices is the ratio between the winning Allowed Annual Income (RAP) and the investments necessary to build the facilities (demonstrated in the investment budget provided by the winner of the auction). In the first auctions, the observed ration RAP-Investments is 20%. However in the November 2005 auction, this ratio reached 9.6% for one of the items.

According to the authors, the continuous drop in the return required by the transmission companies can be explained by the following factors: (i) low risks; (ii) the regulatory stability of the electricity sector, mainly in the transmission segment; (iii) the reduction in the debt costs, evidenced by the descending path of the Long Term Interest Rate (TJLP); and (iv) the lowering in equity costs.

Francellino and Polito (2007) argue that the competition with Spanish transmission companies granted higher discounts in the transmission auctions. The reason of such aggressive bidding strategy by the Spanish companies is not simple, but otherwise, it is the result of advantages they could benefit from, ranging from easy credit access to fiscal benefits.

Despite the influence of the mentioned arguments, the aim of this paper is to investigate the behavior of the observed bids in the transmission auctions from the economic perspective, through empirical auction models. We assume that there are economies of scale from a joint management and operation of connected transmission facilities. The analysis of winning bidders' behavior allow us to point out what are the features that affect the winning bid.

In our empirical analysis we found evidence that many factors impact the bidding behavior in the transmission auctions, such as the number of competitors, the extension of the lines, the reserve price, the required investment and, mainly, the lines location. This indicated that synergies are relevant to explain the observed auction results. We also applied Principal Component Analysis to deal with a possible multicollinearity problem and non-linear regression to test a threshold in the bids.

2 Transmission Auctions in Brazil

Following the restructuring of the electricity industry in Brazil, the private sector assumed an important role in the construction, maintenance and operation of the transmission lines. Such services were previously supplied by state owned companies. According to Hirota (2006), the new model encourages the private participation in a sector whose initial investments are high and not recoverable in the short term.

[1] According to Ribeiro (2007), there are around 50 transmission companies in Brazil, and 30 of which, approximately, entered in the segment after the sector restructuring.

[2] The Allowed Annual Income, just to stand out, is obtained by 15 years. After this period, its value falls to the half. The readjustment to this income is annual, based in the IPCA, being the single discount for line unavailability.

The transmission system in Brazil is mainly interconnected in the National Interconnected System (SIN). The SIN comprises two main regions: South-Southeast-Center West subsystem and North-Northeast subsystem. Most of the remaining isolated systems are located in the North Region.

According to ANEEL, with the system expansion it is possible to achieve higher security in the operation of the grid. Each new line constructed in the country contributes to enhance the electricity interchange capacity between regions. Until 2005 almost 83,000 kilometers were in operation in the SIN. The construction of these transmission lines generated nearly 20,000 jobs and attracted national and international investments, mainly from Spain, Italy, Argentina, Swiss and the United States.

The National System Operator (ONS) is in charge of the system operation and administration, and it is regulated and inspected by ANEEL. Besides operating the system, the ONS's role is to propose the necessary short term expansion and reinforcement to the SIN, based on the demand growing projection and systemic risk. The long term planning, for its turn, is attributed to the Planning Company, the Energetic Research Enterprise (EPE).

Hirota (2006) points out that ONS's coordination is essential to optimize SIN, lowering losses and risks. There is energy loss in all transmission and, because of that, the more is the charge in the system, the higher are these losses. This is the reason for the system to be always using its total capacity, in order to serve the demand in the peak hours.

Sector analysts (in Brasil Energia, 2007) state, for example, that in the supply crisis of 2001, a larger interconnection within the SIN could have avoided the consumers' rationing[3]. However, nowadays specialists' claim that, with the actual system configuration the transmission in any hypothesis could replace the generation.

3 The International Experience in Transmission Investments

According to França and Ramos (1998), after the reestructuring process of deregulation that took place in the late 1990s in the electric system around the world, the transmission sector started to pursue new objectives, as such:

(i) neutrality;

(ii) guarantee of open access;

(iii) guarantee of quality and reliability to the market;

(iv) guarantee the integration of all the market agents;

(v) allow the energetic optimization;

(vi) minimize the transport tariff, to facilitate business between generators and consumers.

As one can see, these are complex issues and even in the international experience we still do not have a satisfatory solution.

In the Independent System Operator (ISO) of California, United States, for example, they have an indicative planning for the construction of new transmission lines. However, the decision to expand the system is completely in the agents hands. The system operator has the role to administrate the transmission constraints.

In England, the expansion planning is made by the National Grid, which has the function of system operator and electric energy transmission operator. The proposed reinforcement in the transmission are justified to the agents, consolidated in a report directed to the regulatory agency.

[3] Differently from today's situation, in 2001 there was a long term potential gain if the previously described subsystems were interconnected, as they finally were later on. The conclusion is that the created lines after the 2001 crisis added about 2 thousand MW to the SIN, without the necessity to build a single barrier, avoiding an estimated expense of R$2 billion.

Brazil, for its geographic and regulatory features, had in the recent years the need of massive transmission investments. The country had an indicative planning to expand the generation and the transmission, but also have a determinative planning to transmission, elaborated by the national system operator, the ONS, to the horizon of five years. Proposed reinforcements are authorized by the regulatory agency (ANEEL). Finally, the ANEEL runs the auction process to define the transmission concessionaire that will develop the transmission line.

On the other hand, in Argentina there is no planning. The agents in the market have the expansion decision. Projects are discussed in public hearings and the veto of 30% of the agents affectd by the project block the construction. Also, the project needs to be approved by the national regulatory agent.

França and Ramos (1998) affirm that is in process a trend to transfer to the market the responsibility for the improvements in the transmission system. Another characteristic present in many models is the indicative planning development. This planning is a key piece, generally prepared by government institutions, that aims indicate to the market agents the optimal evolution in the generation and the transmission in the long term. With the planning, the agents' decisions are oriented in terms of investments and contractual negotiatitons.

Concerning the tariff regulation, in the transmission systems in the United States it is mainly by rate-of-return or cost of service regulation. Therefore, the transmission investors do not internalize the congestions costs in the system, since these costs are repassed to consumers and, then, there is no incentive to investments in the reduction of the congestion cost[4]. As a consequence, rate-of-return regulation may be inconsistent with newer forms of regulation that seek to emulate the role of competitive market forces in eliciting efficient behavior from regulated firms. A basic tenet of competitive markets is that investors are rewarded based on the value and innovativeness of their actions (not on the cost of their investments, which is the basis for rewards under rate-of-return regulation).

A new class of regulatory approaches, called performance-based regulation (PBR), offer greater promise in incentives toward this end. In England, for example, they have a performance based regulation that gives incentives in the cost reduction and in investments in new transmission lines, with technology innovations. The National Grid Company's (NGC) PBR mechanism employs a profit-sharing approach to reward NGC for reducing the charges that are passed on to consumers for recovery of congestion relief costs incurred by NGC. The profit-sharing scheme is based on NGC's performance relative to a predetermined "yardstick" set by the regulator in view of historical performance and expected efficiency improvements. NGC has reduced the costs of congestion through a combination of operational efficiency improvements, improved forecasting, investment in transmission expansion, and adoption of technologies that improve transmission grid utilization.

An important comparison that can be made in terms of investments in the transmission systems is about the choice between nodal pricing and zonal pricing. In this section we will compare a system that uses the nodal pricing - the PJM system - with another one that uses zonal pricing - the Brazilian system.

Boucher et ali (1999) say that nodal pricing is meant to send generators the right investment and operations signal. In principle, this is achieved when nodal prices properly reflect network congestion. Improving operations by relying on accurate price signals may, by itself, alleviate the need for some construction of new transmission facilities.

[4] In principle, any congestion problem has a "generation solution", which amounts to creating counterflow on the congested interface, and a "wires solution," which requires investment in transmission assets. From an economic perspective, the optimal amount of transmission capacity is achieved when the marginal cost of the generation solution and that of the wire solution are equal. This equality represents the optimum solution from a social perspective, i.e., the total of consumer and producer surplus is maximized; however, there is no guarantee that the consumer surplus increases at this solution. Transmission capacity mitigates market power, so it is possible that additional capacity may benefit consumers by facilitating trading and reducing energy prices although such investment need not be optimal from a total welfare perspective. It is also possible that a transmission expansion that is socially desirable may disadvantage some consumers by increasing their energy costs.

Moreover, when new construction is needed, price signals will help market participants identify opportunities and assess options to address bottlenecks. However, nodal pricing is not always well accepted in practice. It is commonly argued that congestion only occurs infrequently and, hence, that nodal pricing is irrelevant. Furthermore, nodal prices do not ensure the grid operator with sufficient revenues to recover the fixed charges of the network, requiring that additional price components be added for that purpose.

The iconic model of economics-driven capacity expansion using nodal pricing is the PJM[5] Model. In this context, the ISO operates an energy spot market where locational marginal energy prices are based on a security-constrained, bid-based, optimal dispatch. Congestion charges for a point-to-point transaction are priced at the opportunity costs given by the locational price difference between the two points.

Since 1998, a very interesting point in the PJM is the existence of hedge against the congestion costs volatility. This hedge is done by the Financial Transmission Rights (FTRs), which take the form of financial instruments that entitle their holders to the locational price difference times the number of rights (in MW units) over the specified time interval. This instrument is equivalent to a physical right because it enables its holder to execute a point-to-point transaction and offset the congestion charges with the FTR revenues. FTRs are auctioned off by the ISO periodically for different time horizons. The FTRs that are issued must satisfy simultaneous feasibility conditions, which require that if all FTR holders were to use their rights by scheduling corresponding transactions, these transactions would be feasible without impacting the security of the system. This simultaneous feasibility condition guarantees that the congestion revenue collected by the ISO can cover the FTR settlements.

As previously argued, Financial Transmission Rights are financial instruments that entitle to the winners of the FTRs auctions to a stream of revenues (or charges) based on the hourly congestion price differences across a transmission path in the Day-Ahead Energy Market. FTRs allow transmission customers to protect themselves against the risk of congestion cost increases, providing price certainty for transmission customers when receiving electricity across constrained transmission lines. Transmission customers pay the market price to move energy from one point in the transmission system to another. This cost increases when the delivery is across transmission facilities that are constrained. FTRs are a necessary hedging mechanism in the locational pricing market.

Turning attention to zonal pricing in Brazil, Maurer (2005) says that nowadays Brazilian electricity sector is operating in a tight pool model, with a centralized dispatch, looking for the smallest operational cost. This is an international consolidated format, once it allows the best use of the generation and transmission resources. The ONS calculates the spot price (shadow), based in the water value, the declared costs, the offers received and, then, minimizes costs taking into account all the transmission constraints. For contract liquidations, zonal pricing is adopted, with four submarkets. The zonal prices do not take into account the constraints inside the submarkets.

The zonal pricing in Brazil was bring from the British model. In that time, 1997, the zonal pricing was seen as the better solution to the commitment between alocative signs and the necessity to avoid price volatility (vis-a-vis the nodal system). Another reason to the zonal pricing choice is that, in the occasion, the systems had little experience in nodal pricing. Some disadvantages include:

(i) Agents would have too much exposure to price volatility;

(ii) Complexity.

(iii) Questionable value, once in most cases the constraints are not present;

[5] PJM is an American Regional Transmission Organization (RTO) which is part of the Eastern Interconnection grid operating an electric transmission system serving all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. PJM is currently the world's largest competitive wholesale electricity market.

(iv) Make the transactions difficult and give small liquidity;

(v) Concentrate power market by disintegrating zones.

According to Maurer (2005), the recent evolution of the Brazilian electricity regulation in the last 10 years criates a view that the nodal model is the correct technical model. The main counterarguments are:

(i) Risk reduction could be made by congestion contracts, as the FTRs in the PJM model.

(ii) The complexity is intrinsic to the centralized dispactch, which has to calculate the marginal cost by node. The accrual by zone and the arbitrary criteria to make it that bring further complexity to the system.

(iii) The price system need to capture the constraints when they exist. The zonal pricing system can give a reasonable signal most of the time, but it does not work exactly when it is more necessary.

(iv) The liquidity objective can not be reached sharing costs. The international experience has demonstrate that agents learn to deal with FTRs very easily, reaching the necessary liquidity in the market.

(v) Do not increase the market power, even when the plant is beyond transmission constraints.

Finally, the author say that regions where the nodal pricing, or LMP, was applied have a successful market, while which that applied the zonal pricing are in a problematic situation. Among successful markets we can highlight New York, New England, PJM and more recently Texas. On the other hand, among problematic markets is California, whose failure of the system was predicted three years before the crisis, but not much was done to correct it.

This is an important question to Brazil especially to an adequate location of generation plants. If we do not have constraints pricing inside the submarkets, the investor becomes insensible in terms of the plants optimal location. However, we need to understand that the Brazilian model to capture transmission investments, with a guaranteed revenue (regardless the tariff system do not give locational signs as it should be doing) was important in the context of a new regulation in the energy electric sector. The improvements in the transmission was indispensable in a system that present a lack of generation culminating in the 2001 Rationing Crisis.

4 Economics of Transmission

Transmission investments result from processes in which transmission providers analyze (over different time periods) the capabilities of the system to meet the present and future demands of consumers reliably and economically. Prices are essential to reach the correct amount of investments. Actually, transmission prices can perform two key functions:

- Recovering the costs of the existing sunk grid; and
- Signaling the need for new network investment. This in turn can be done in two ways: through modification of the charges meant to recover sunk costs to make them "forward-looking"; or through a separate charging regime for new investment expenditure.

At the most basic level, the fundamental objective of any transmission pricing arrangements should be to encourage efficient use of and investment in the transmission network (and associated electricity industry infrastructure). This overall objective can be separated into shorter- and longer-term operational objectives.

Since transmission is both a substitute for and complement to generation, achieving these objectives requires coordinated action by participants in both the generation and transmission sectors. The principal mechanism for

achieving an efficient level of coordination between transmission and generation in a vertically-separated electricity industry such is through price signals.

In a disaggregated industry in which generators and consumers react to market signals, the level and structure of transmission charges has a potentially significant effect on network use and, to a lesser extent, transmission investment. Transmission charges may also affect the locational choices of new generation and energy intensive users, as well as potentially influencing the bidding conduct of generators.

Implement these charges at the right level is decisive for ensuring the efficient use of and investment in the transmission network. It is also one of the most challenging problems facing regulators. In particular industry and major consumer stakeholders would like to see a transmission pricing methodology that:

- Sends efficient locational signals (assuming these signals are not adequately provided elsewhere);
- Sends capacity signals to encourage, among other things, efficient demand-side response;

In the short-run, physical investment in the transmission network is fixed. Indeed, the majority of Transpower's regulated revenue comprises a return on its existing, sunk network assets. In consequence, the short-run costs of transmission consist of the physical energy losses incurred during transmission and the 'opportunity cost' of any constraints or network congestion.

When a transmission network is congested, the short-run alternative is to deploy more expensive generation from a different location. The short-run marginal cost of transmission is therefore determined by the cost difference between the cheaper generation and that which must be used because of the network constraint. In summary, the short-run costs of transmission are those that vary with respect to the flows of energy over existing facilities, i.e., the scheduling and dispatch of generation and load.

Importantly, these costs include transmission losses and constraints, which each give rise to rentals that must be allocated amongst customers during the settlement process. However, in the long run, all costs are variable. The existing network needs to be maintained, and capacity can be expanded. The long-run costs of transmission are therefore those associated with maintaining and/or expanding the network.

There is a strong link between the short-run costs of transmission, the long-run cost, and efficient investment in both transmission and generation assets. In the first instance, increased transmission demand can be met through increased energy losses across the network. As congestion occurs, alternative (more expensive) generation must be sought. In the long-run, absent generation investment, the cost of losses and constraints might increase until the point where it is cheaper to augment the network. From an economic perspective, therefore, the conditions for optimal expansion of the transmission network are that:

- Additional transmission capacity should be built only if the total savings in the cost of generation (and demand management) exceed the additional transmission costs; and
- Additional capacity should be sized such that the marginal cost of generation savings and loss reductions (indicated by the difference in future spot prices – or generation costs – at different locations) equals the marginal cost of building additional capacity.

In other words, in principle, investment will be efficient up to the point where the cost of one more unit of transmission capacity – the long-run marginal cost (LRMC) – is equal to the avoided cost of future constraints and losses – the short-run marginal cost (SRMC). These economic characteristics of transmission apply irrespective

of the market framework that is put in place: the costs of the costs of transmission and the rules for efficient investment are the same whether or not a competitive energy market exists, whether or not energy markets involve full nodal pricing, and whether or not transmission pricing and investment is planned centrally or determined using 'market-based' incentives.

The difficulties surrounding developing transmission pricing methodologies stem from key economic characteristics of transmission. In particular, transmission involves:

1. Economies of scale (falling average costs) both for individual line developments and for network as a whole. For example, it is cheaper to build a line of a certain capacity than two lines of half that capacity. The consequence is that it is generally cheaper to ostensibly "overbuild" the network. This also means that it is more efficient to have one transmission entity (natural monopoly) than two or more and its pricing and conduct needs to be regulated to protect the interests of customers; and

2. Network externalities, which arise from the physics of electricity networks. A fundamental feature of well functioning markets is the ability of suppliers to identify who is consuming their output and to be able to exact a price from these consumers. In a transmission network, it is not always possible to identify who is consuming a service at a particular time. Electricity does not follow direct routes but follows the path of least resistance. This makes it difficult to attribute use of (or benefit from) a particular asset to particular customer(s).

3. Building any transmission line can actually increase network capacity by more than the capacity of the line because of network effects. It may also decrease capacity in some parts of the system. The net amount of capacity increase associated with a transmission right is a contentious issue that inevitably involves some system operator judgment, and therefore some opaqueness.

4. The theory of market-driven investment remains untested in the real world. Given all the uncertainties, including how long it takes to get the necessary approvals to build transmission lines, to form coalitions, and to wait for long-term market prices to signal the value of new transmission, there is a fear that investment will come too late, and that the reward of transmission rights will not induce enough capacity.

5. Finally, with transmission investment there may be more than private benefits at stake. Increased transmission can reduce market power and increase network reliability. There are also likely to be valid national security interests to 'err on the side of caution' by investing in new capacity before nodal prices increase reflect the costs of congestion. So, even if it was possible to solve all of the other problems of market-based transmission investment, in practice, there will always be a role for centrally planned transmission.

Put simply, an FTR-based framework cannot eliminate the need for regulation to play an important role in ensuring efficient transmission expansion and pricing.

For these reasons, the complexities set out above mean that there will always be a need to recover at least a proportion of the costs associated with the transmission network from users through a regulated transmission pricing framework, where at least some of those prices are levied upon multiple users (or 'socialized'). Also there will continue to be a role for centralized transmission planning, as for example, through the operation of an 'investment test'.

5 Transmission Auction: Contractual Aspects of the Object of the Study

The Government is the granting authority in the transmission system. The regulatory agency, ANEEL, is in charge of running the auctions. After the definition of the objects to be auctioned, the edict is published, which contains information about the auction and the transmission line. For example, the edict describes the basic configuration that the transmission facilities must obey, like origin and ending point, tension and extension, the order in which the objects are to be auctioned, qualification requirements (such as fiscal, financial, technical expertise) for the bidders and the contracts to be celebrated between the winning proponent and the other agents - ANEEL, line users.

According to ANEEL[6], the winner is the qualified bidder who commits to a lower annual revenue. The items are auctioned sequentially. For each item the new concessionary is suppose to build, operate and maintain the transmission plants. The obligations are established in a set of contracts and apply to a period of thirty years from the contracts signature. The submitted proposals must not exceed the maximum annual allowed income.

The transmission companies must also comply to the environmental legislation. Besides the environmental requirements, the transmission company may be requires to adopt compensatory measures.

The building, operation and maintenance of the transmission lines is of exclusive responsibility of the transmission company. Additionally, the transmission company is responsible for the plant integrity, and to attend specific regulatory procedures , as well as the established conditions in the concession contract and in the CPST (Transmission Service Contract).

Regarding the beginning of operations, to take exception from the provided hypotheses in the legislation and in the concession contract, it will not be considered by ANEEL any complaint from the transmission company that is based on, for example:

a) available studies and projects that are inadequate or inaccurate;

b) local conditions that influence direct or indirectly the terms for the delivery of the materials, work force and equipment, as well as the project and construction terms;

c) weather conditions, such as excess of rain, geology, geotechnics, topography, roads, regional infrastructure, communication media, sanitary conditions and environmental pollution.

Besides that, the transmission company, in the same date or until thirty days after the celebration of the concession contract, shall previously sign a contract, the CPST (Transmission Service Contract) with the ONS, that consolidate the technical and commercial conditions committing to the transmission plant availability for the interlinked operation.

It is worth mentioning that there are granted open access to the SIN and this is regulated by ANEEL. To benefit from the access the transmission company shall sign the respective CCT (Transmission System Connection Contract) with users in the limitations of the applicable law.

6 The Auction Rules

The allocation mechanism adopted in the transmission auctions is a hybrid auction. In the first phase a first price sealed bid auction is used, followed by an English auction in a contingent second phase. In the sealed bid auction, if

[6] Edict No 005-2006_1109.

there are no close bids, the competitor is declared as the winner. However, If there is at least one bid close enough to the lowest bid submitted in the first phase, there will be a second stage in which the remaining competitors (the "tied" ones) dispute in an outcry auction, where the lowest bid of the first stage is the reserve price. [7]

Hybrid auctions have become a mechanism more and more used. Besides combining the positive features of both configurations described previously, there is another characteristic of the hybrid auctions very interesting to the granting authority and to the society. Dutra & Menezes (2003) proved that the mentioned hybrid configuration, also used in the telecommunications sector privatization process in Brazil, grants a higher revenue to the auctioneer than any other auction configuration:

> "The first price auction with a Vickrey auction as a second stage when there are bids sufficiently close to the top bid guarantees a higher expected revenue to the seller as compared to standard auction mechanisms."

The auction purpose is to grant the public service concession of these lines by the best possible offer, according to the described proceedings in this chapter. The bids are presented in a closed envelope with an open outcry auction.

The main characteristics of the auction are the following:

(i) only the qualified proponents can participate in the auction; (ii) deposits are required to participate; (iii) one company cannot participate in more than one consortium in the competition for any specific item; (iv) the bids cannot exceed the maximum Annual Allowed Revenue for the item; (vi) there is a preset cutoff value that is calculated over the value of the smallest proposal in the envelopes, according to the following formula:

$$VC = LV \text{ x } 1,05 \tag{1}$$

where VC is the Cutoff Value; and LV represents the lowest bid in the first phase.

The winner is the proponent who the lowest bid if the other bids are higher than the cutoff value. On the contrary, if there are bids with a smaller or equal value than the cutoff value, the auction continues by successive bids in the outcry auction. The proponent that has presented the smallest bid in the envelope and those whose offers in the envelopes are no higher than the cutoff value can participate in the outcry auction. The winner is the competitor who submits the lowest bid in the outcry auction.

7 Literature Review

The empirical study of the auctions is more and more common in the economic science, not only because its political practical appeal, but also because their data are, in many times, better than that typical data of industrial organization. This is due to the following features:

[7] A hybrid auction design was proposed by Paul Klemperer (2002), for the spectrum auction of third generation telecom in England. The advocated auction mechanism, the so-called Anglo-Dutch, combine an Anglo auction followed by a first price sealed bid auction. Klemperer states that the superiority of the model is a result of the combination of positive aspects of the individual mechanisms. The English model is the ideal way to allocate a commodity to someone who values it most, because a competitor can exceed someone's bid in any moment, till the good is acquired by that higher value. However, the English model is subject to the predatory behavior, once the open bid allows retaliation to someone that does not accomplish an agreement previously signed. In the case of the sealed model, its first positive feature is the absence of the retaliation tool and a larger encouragement of the participants' entrance, once the result is less uncertain than that in an open auction. As a negative point, it is pointed out that an auction can be inefficient because it can fail to allocate the commodity to whom that puts more value to it.

(i) the game is relatively simple, with well specific rules;

(ii) the participant's actions are observed directly;

(iii) payoffs can be deduced.

According to Wolfram (1998), the existent empirical literature about auction is extensive, presumably due to the information richness related to the auctions and to the extensive theoretical treatment dedicated to them. Empirical papers analyzed markets like concessions for oil, wood, and aubergine exploration. With the exception of many auction studies for financial instruments and auction analyses of the American radio spectrum (FCC), the great part of the empirical literature takes into consideration the auctions where the participants compete for only one object.

Hendricks & Porter (1988) compare the normative and positive objectives of the auction theory.

Positive and Normative Aspects from Auctions Theory	
Positive Theory of Auctions	Normative Theory of Auctions
It describes how one can offer a bid rationally, which normally comprehends characterizing the Nash Bayesian Equilibrium (BNE) of the game.	*It seeks to characterize the best or efficient sale mechanism.*

In the same way, an empirical study about auction also has its positive and normative objectives, as below:

Positive and Normative Aspects from Empirical Auctions Works	
Positive View - Empirical Studies of Auctions	Normative View - Empirical Studies of Auctions
To answer to the questions about how the agents behave themselves and if the values that they attribute to the object are correlated. If so, what is the source of correlation? The observed distribution of the bids is consistent with the NBE? The aversion to the risk is relevant?	*To answer what is the maximum income or the efficient auction.*

According to Athey & Haile (2001), the standard practice in the empirical literature of auctions is to consider model of strategic demand and information, as the model of independent private values, based on the qualitative evidence, in spite of the application. Once distinct hypothesis can lead to different results and policy implications, a common base is preferred to evaluate alternative models, granting confident empirical results.

Bajari (2000) points a series of difficulties in the econometric analysis of auctions: (i) auctions are games with functions of discontinued utilities; (ii) the existence, uniqueness and characterization of equilibria are established for a restrict set of hypothesis; (iii) even when these basic results are valid, it is difficult to calculate the equilibrium

of the auction models; (iv) if the equilibrium is not unique and if it cannot be calculated efficiently, it is not possible to estimate the parameters using a likelihood function; (v) situations where the equilibrium exists in an auction game and whose equilibrium is unique are limited.

The auction analysis can follow estimation in two configurations: structural and reduced. Bajari (2000) points out that tests of the auction theory using reduced configurations to analyze the implication of the strategic behavior have a poor statistic power. On the contrary, structural models allow to shape the correlation in the informational structure, to compare the alternative auction configurations and can be used to deduce a collusive behavior in bidding.

Bajari & Hortaçsu (2005) states that the structural form is based on three strong hypotheses: (i) the competitor seeks to maximize its expected utility; (ii) competitors are able to calculate the relation between their bids and their probability to win the auction; and (iii) due to their beliefs, competitors are able to properly maximize their expected utility.

To Shum & Hong (2000), the two approaches - structural and reduced forms- are valid to answer different questions. The reduced form is proper to characterize bidding behavior instead of recovering equilibrium bid functions from the observed bids in order to estimate the distribution parameters.

Rezende (2005) points out that the empirical methods created to investigate auction data provide a rich source of information about consumers' preferences or production costs. To this purpose, it would be valid to use a based empirical strategy, robust to misspecification in the environment and also easy to implement. The author suggests the following method.

Studies that usually try to investigate how the covariates affect the demand in the auctions estimate regressions:

$$p = X\beta + \varepsilon \tag{2}$$

where p is the transaction price (or its logarithm). The problem with this analysis does not come from the right side of the equation - covariates can, in fact, impact the demand in a linear way - but are related to the left side. An initial point for a superior empirical analysis would be to use the following specification:

$$V_i = X\beta + \varepsilon$$

where V_i is the value that the $n-th$ consumer attributes to the commodity i, or the disposition to pay by the product that is being auctioned. Differently from the price, this value is a demand concept that reflects consumer's preferences in an isolated way from the supply effects or from the market institutions. A consumer will never choose to pay exactly the real value estimated by him for an object, because in this way he will not take an advantage in participating in the auction. As price and value usually have distinctive magnitudes, the estimation of the first regression is subject to a specification bias.

As it mentioned, reduced form models suffer from poor statistical predictive power. On the other side, Rezende(2005) states that structural methods present two weak points regarding the applicability. The method is designed for a specific type of auction and the estimation may be cumbersome. In this sense, the author proposes a new model that, by being structural, is justified theoretically. Besides that, it is of simple calculation and is robust to misspecification regarding to the auction that is being played. The proposed method comprises a regression of the transaction prices observed (winning bids) by minimum norm least squares in the covariates of interest and in an additional regressor with the number of competitors in each auction. This method is related to the other exercises

yet accomplished in the empirical literature (e.g. Gilley and Karels,1981) either in the reduced configuration, or in the structural (e.g. Paarsch, 1991). The great difference is that the proposed model by Rezende (2005) inserts these competitors in a nonlinear way, in order to justify theoretically the regression method[8].

This model explores two auction desired properties - the Revenue Equivalence Theorem and the equilibrium invariance to the equilibrium set of the related transformations in the value attributed to the object by competitors. Both were approached in other models, but they had not been still considered together and, thus, the previous methods were very demanding in terms of calculation or were restricted to a limited class of auctions.

According to Rezende (2005), the estimation of the proposed model can be made by two ways. In the present paper, we will be restricted to the second mode of estimation - which prevents the researcher from imposing a format for the distribution of the attributed values to the commodity by competitors.

Once we have a well defined institutional environment, it is possible to use the auction theory to get a mapping between the values and the behavior of the observed bids and, from this, to develop a strategy of estimation. Laffont & Vuong (1996) showed that, depending on the auction design, the distribution of the values is readily identified by the observed data. Many structural methods are used to estimate the values from the auction data, but they are made for a specific type of auction, besides being complex in terms of calculation.

Rezende (2005), thus, suggests a new method in question which involves the estimation of a regression of minimum ordinary least squares of the transaction prices observed in the covariates of interest and an additional regressor with the number of competitors in each auction.

Many empirical papers apply the auction analysis techniques described above. We will see three of them in a closer way, which are the base for using some variables in the present paper. These papers are: Jofre-Bonet & Pesendorfer (2000), Bajari & Ye (2001) and De Silva (2005).

Jofre-Bonet & Pesendorfer (2000) studied data from highway bidding for the state of California, from December 1994 to October 1998. To this study, it is used a model of dynamic auctions that takes into consideration the existence of intertemporal restrictions as that of capacity. Using nonparametric statistics this model is estimated and reveals the presence of dynamic restrictions in the offers.

Data from highway construction have been studied by many authors. Feinstein et al. (1985) and Porter & Zona (1993) studied aspects related to the collusion. Bajari (1997) focused in the importance of the asymmetry between players.

Jofre-Bonet & Pesendorfer's model has the following description:

- Infinite periods of time. In each period, the buyer offers a unique contract. There are two kinds of competitors: regular and outliers. The first ones remain in the game forever and the others have a short life and abandon the game in a determined period;

- In each period the competitor i learns her cost for the contract. The cost is a private information and is denoted by c_{it}. The beliefs of all competitors about the cost c_{it} from a regular competitor is identical and represented by a distribution function $F(c|s_{it}, s_{ot})$, where s_{it} is the variable that summarizes the available capacity to the competitor i in the time t, and $s_{\sigma t}$ denotes the project characteristics. In the same way, the competitor outlier's cost comes from a distribution function $F(c|s_{ot})$.

[8] The author proves that hypotheses of linearity or in a quadratic fashion for the number of competitors are not correct.

- Agents are risk neutral. The evolution of the state will depend on the amount of projects and on the size of the project won in this period.

- They are considered perfect balances in subgame and Markovian strategies;

A strategy for i is a function of the state vector s and of the cost of the competitor i in the period of time t.

The econometric estimation has the following stages: (i) choice of the state variables; (ii) estimation of the bid distribution function, G, that represents the competitors' belief; and (iii) the costs and the cost distribution function are recovered from G.

At first, the bid log is projected in a vector of the characteristics of the contract and the density and distribution of the residues b are estimated;

In the second place, the bid distribution function is estimated using the following variables:$(a_i, a-i, r, x_i, W_i)$; a_i } is the backlog of i, r and x_i are the indexes that measure the competitor's capacity and localization characteristics (the first one measures the number of competitors who are next in the place of the contract and the second index is a linear projection of the decision about submitting a bid in the period of the maximum capacity of the company. Wi measures the number of contracts won by i before t).

Optimum bids are chosen based on the private costs, in the belief of the bids made by the other competitors and in the effect of all these factors on the future payoffs. The necessary first-order condition for the bid balance summarizes this relation and it is from it that the costs are deduced. They chose a nonparametric method to estimate the model in the paper because the authors did not know about the configuration of the competitors' belief.

In conclusion, the authors state that the behavior of the bids is affected by the restriction of capacity. Competitors with a higher amount of work from old projects have, on average, a higher cost in relation to the competitors with low amount.

Bajari & Ye (2001) develop an auction model where the asymmetry between competitors is introduced. In the paper, the asymmetries can result from siting, capacity restrictions, and collusion between competitors. The authors also demonstrate how to test the conditions that characterize a competitive environment applying the test to a data set of bidding contracts.

In Bajari & Ye's model (2001), competitors provide sealed bids and the contract is given to the agent who has provided the smaller offer. Before starting the game, each company makes a cost estimation for the project, which is a private information. Companies are risk-neutral and have private values.

In the model asymmetries between competitors arise as a result of the location (neighboring companies operating facilities are able to bid aggressively due to smaller costs of transportation) and to higher capacity use (some companies are small regarding to the market and need to take in consideration the fact that they won a project before participating in others). Technological differences can be a source of asymmetry between the companies and their chance to win a contract depends on the State/Country in which they are more active (companies need to be familiar with regulatory framework at a local level).

This can be modeled as follows: (i) firstly, the information structure is described.

N firms compete for a contract to construct a project. An estimate of each firm's cost is a random variable C_i with realization $c_{i.}$ The cumulative distribution function of C_i is given by $F_i(.;\theta_i)$ where θ_i is a parameter vector. The cost's support is $c = (c; \bar{c})$ for all firms.

Consider an example in which each firm faces a location and, therefore, a transportation cost. The specification for firm i private information is given by:

$$c_i = cons\tan t + \beta_1.dis\tan ce_i + \varepsilon_i \tag{3}$$

In the equation, the firm's cost estimate c_i is a function of the constant term – that can reflect attributes of the project that affect all firms identically, as the road-paving needs or how many concrete tons are going to be be used for a building base. The second term is specific to each or each firm, because each one has its own location; the third and last term, a random variable, represent the private information about the firm's cost, such as input or work costs. If ε_i is normally distributed with zero mean and standard-deviation σ, $\theta_i = (constant, \beta_1, distance, \sigma)$.

(ii) Secondly, the Expected Utility Function for the firms is defined;

Let b_i be the firm's i bid. If firm i submits the smallest bid, its utility is given $b_i - c_i$; otherwise, is zero. In the collusion context, it's possible to see that the cartel behavior working efficiently is a simple special case of the model just exposed. Suppose that, before the beginning of the auction, every cartel participant estimates her cost. The cartel members meet before the auction, compare cost draw and the cartel member with the smallest estimate submits an actual bid, while the others choose not to bid or submit higher bids. Let $C \subset \{1, 2, ..., N\}$ be the cartel. The cost to the cartel that we denote by c_c can be written as:

$$c_c = \min_{j \in C} c_j \tag{4}$$

If others competitors know the cartel members, so it is trivial to adopt the precedent model for the cartel case. The cartel is simply modeled as an order statistic of the costs estimates of its members.

(iii) Finally, the equilibrium strategic function is characterized.

In the model of asymmetric auctions, there is a Bayesian-Nash equilibrium in pure strategies. The $i - th$ firm makes a cost estimate c_i , and given this cost, estimates a bid that maximizes its expected profit:

$$\pi_i(b_i, c_i, b_{-i}, \theta) = (b_i - c_i)Q_i(b_i; \theta)$$

where Q_i is the probability that i firm is the lowest bidder.

The equilibrium can be described as a solution to a system of differential equations subject to regularity conditions:

- For each i , the cost distribution function $F_i(c_i; \theta_i)$ has support $[c; \bar{c}]$. The probability density function is continually differentiable in c.
- For each i, both $f_i(c_i; \theta)$ are restricted by zero in $[c; \bar{c}]$.

The model is, therefore, a simple variation of the "Independent-Private Value Model", that allows firms to be asymmetric.

All things considered, it is important, in this literature analysis, to emphasize previous papers that pursued to identify the effects of possible synergies in the strategic behavior of competitors.

De Silva (2005), for instance, investigates the impact of synergies in the competitors behavior in road construction auctions. The article reveals that projects are spatially correlated. Thus, he concludes that when a competitor

with a potential synergy enters into the auction, her winning probability increases, once she bids more aggressively. Finally, the paper also shows that firms without capacity constraints have a more aggressive bidding behavior compared with firms facing such constraint.

According to De Silva (2005), empirical papers about auctions synergies are scarce. For the case of Israel, Gandal (1997) showed that complementarity associated with the achievement of multiple projects in a particular geographic area improved the value of TV cab licenses close to one another. Ausubel et al. (1997) indicated that synergies may exist for adjoining licenses in the American communication auctions. Rusco & Walls (1999) concludes that, in repeated wood auctions in correlated spaces, competitors that face complementarity with more than one project bid more aggressively.

De Silva (2005) highlights that, when we looked for a possible strategic behavior in bids on account of synergies between auctioned objects, if we do not consider in our estimation that bids are different between competitors and projects because of asymmetric costs - transportation or work cost -, only look for synergies, without control for these variables, make the researcher to catch this information in the residuals.

Our results are complimentary to others on Brazilian transmission auctions - Bueno & De Castro (2006a) and Hirota (2006).

8 Model Estimation

The first objective of the present empirical exercise was model the winnig bid of the transmission lines auction in to the factors that the literature considers relevant to the strategic behaviour analysis of multiple-object auctions bids. The line we follow was the one given for the articles we presented in the last section: Rezende (2005), Jofre-Bonet & Pesendorfer (2000), Bajari & Ye (2001) and De Silva (2005), looking for test reduced-based models that includes the variables considered in these papers, that worked with similar auctions.

8.1 Data

We analyze Brazilian data from all auctions that took place from 2000 till the middle of 2010. Effectively 103 transmission facilities were granted (or lots of lines). [9] The source of our data was the Brazilian Electricity Regulatory Agency (ANEEL).

[9] For the G lot of auction n° 005 of 2006, some data were not obtained, so this observation was excluded of our sample.We also excluded the Rio Madeira transmission auction, occurred in November, 2008.

Table 1 - Variables

	Variables	Description of the Variables
Dependent Variables	**BID**	Winning Bid for each transmission line or bundle of lines
	LBID	Log of Winning Bid
	BID / INVEST	Fraction between Winning Bid and Estimate Investment
Independent Variables	**EXT**	Extension of each line
	COMP	Effective number of competitors in each auction
	RAP(0)	Initial Anual Receipt Allowed
	INVEST	Estimate Investment for Construction, Maintenance and Operation
	TRIBUT	Dummy for winning bids bellow R$ 48 millions
	EPC	Dummy for the presence of a "EPC" company in the winner union
	SUL, SE,NE,CENO	Dummies for regional location of the transmission lines
	***Dummies* compet.**	Dummies for number of competitors

The following series are used as dependent variables in our reduced-based models: winning bid in each auction; the log of the winning bid in each auction and the ratio between the winning bid and the estimated investment for the project.

As independent variables, we include the Allowed Initial Annual Revenue (RAP-0), that is equivalent to the reserve price determined by the regulator agency; the number of competitors in each auction - a standard control in the empirical auction literature; the estimated investment by ANEEL for building and maintenance of the lines[10]; the extension of each line (as a control for the characteristics of the project); a dummy variable for a consortium that is integrated also by an "EPC" (Engineering, project and construction); a dummy variable a winning bid lower than R$ 48 million.[11]

Besides the variables mentioned, we also include the initial hypothesis that competitors already operating a transmission line will compete more to operate another transmission line close to the first one, that is, this company will offer a smaller annual revenue to win the second line because of the economies of scale of operating lines close one to another. In order to pursue this objective, we include dummy variables for siting, as in De Silva (2005). We segment the auctioned transmission lines into four macro-regions (figure 2).[12]

[10] The estimated investment for each project will be used as a proxy to the companies costs, in the lack of other variables.

[11] In his work, Hirota (2006) differentiated the state owned companies from the private companies, due to the hypothesis that the first group has a specific behaviour in the transmission auctions. We choose not to include this distinction in our models.

[12] It was not possible to obtain property data of the transmission lines already operating before the implementation of the auctions analyzed. It would be a way to observe case-by-case which lines each company would seek in an evident way or if there is some intertemporal strategy for some groups of companies.

Figure 2 - Brazilian Regions Specification to Capture Synergies

According to Francellino & Polito (2007), in each transmission auction, agents were surprised with the markdown offered by Spanish transmission companies - Abengoa, Cymi, Isolux, Cobra e Elecnor. In a specific event, the markdown offered by these companies was higher than 50% of the maximum reserve price. After this auction, many hypothesis have been formulated to explain the success of these firms. The authors say that there are two key aspects in the composition of this scenario:

(i) The fact of a competitor have or not have an "EPC" firm[13] in his group (with no exception, every Spanish firm that participated in the Brazilian transmission auctions have a company specialized in the EPC in their group). In the bidding time, the EPC firm profit margin get in the bid composition, making it more competitive than the bids of other companies that don't have an EPC. So, a dummy variable will be included to discriminate when competitors include a construction firm.

(ii) Many firms offer a bid below R$ 48 millions. As a consequence, we observe great differences between the winning bids and reserve price - to benefit from a differentiated tax system (the companies that register an annual revenue below R$ 48 millions use a assumed profit income tax system). Thus, we include a dummy variable for bids below this monetary value.

[13] EPC - Engineering Procurement and Construction.

Table 2 - Descriptive Statistics from the Auctions Results

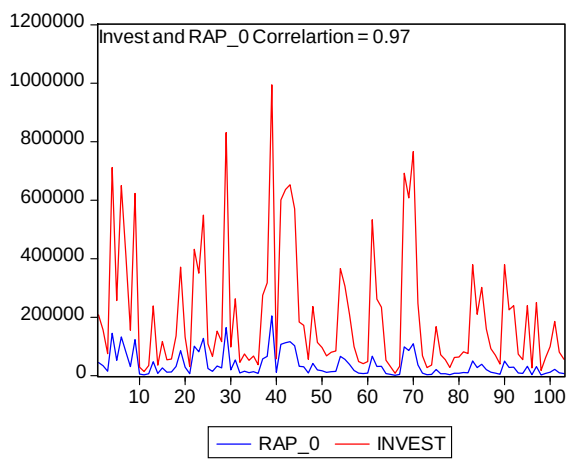
	BID	INVEST	EXTENSAO	COMPET	RAP_0	BID/INVEST
Mean	25970.50	208991.3	287.1179	5.495146	36996.19	0.123786
Median	12882.79	113651.3	188.0000	5.000000	20648.34	0.110000
Maximum	140950.0	994581.7	1278.000	14.00000	204902.1	0.230000
Minimum	665.0000	8540.000	1.500000	1.000000	1410.320	0.050000
Std. Dev.	30211.68	215456.5	269.3937	3.441026	40839.37	0.048246
Skewness	1.918072	1.533621	1.455061	0.598323	1.756849	0.645361
Kurtosis	6.281790	4.665006	4.711143	2.478328	5.821113	2.279103
Observations	103	103	103	103	103	103

8.2 Reduced-Based Models Results

In this section we seek to explain winning bids in the Brazilian transmission auctions. As a first step of a multivariate method, we test if all the potential explanative variables have the desirable characteristics for a linear model. We conclude that the Estimated Investment and the Reserve Price are strongly correlated. This correlation between independent variables leads to a multicollinearity problem. According to Hair (2005), besides the effects in the explanation of our dependent variable, the multicollinearity can seriously impact the coefficients' regression and the usefulness of the estimated model.

Many possibilities are proposed to deal with if multicollinearity (Hair, 2005). The most common approach is the exclusion of one of the involved variables. For us, a more relevant information is the estimate of the relationship between the winning bid and the investment variable (that will be our cost proxy), so we will drop out the reserve price from these first reduced-based models.[14]

Figure 3 - Investment and Reserve Price Correlation



[14] However, in the next subsection we will present an alternative solution to deal with multicollinearity without exclude any of our informative variables. It is the Principal Component Analysis.

Following we present the results from the four reduced-based models estimated for the winning bid transmission auctions. At this stage, one can say that this empirical exercise could be unnecessary if one prove that the high markdown observed was just a consequence of a change in the Regulatory Agency reserve price formulation pattern. This was not the case. We tested the stability in the reserve price per kilometer and a same pattern was found in our auction's sample. So the pattern change in the winning bid level may be due to something else that we want to explain quantitatively by applying our models.

The first reduced-based model has the following specification[15]:

$$BID_i = \beta_1 EXT_i + \beta_2 COMP_i + \beta_3 INVEST_i + \beta_5 TAX + \beta_6 SOUTH + \beta_7 SE + \beta_8 NO + \beta_9 CWNO, \quad (5)$$

in which,

BID_i: Winning bid in each auction i of transmission lines or bundle of lines;

EXT_i: Extension of each line or bundle of lines;

$COMP_i$: Number of competitors in each auction i of transmission lines;

$INVEST_i$: Estimate Investment to building and maintenance of transmission lines;

TAX: Dummy variable that indicates if the concessaionaire win the auction with a bid below R$ 48 millions;

$SOUTH$: Dummy variable indicating if the transmission line auctioned is mainly locate at South region;

SE: Dummy variable indicating if the transmission line auctioned is mainly locate at Southeast region;

NE: Dummy variable indicating if the transmission line auctioned is mainly locate at Northeasth region;

$CWNO$: Dummy variable indicating if the transmission line auctioned is mainly locate at Center-West or North regions.;

In this first model, with the winning bid as dependent variable, as we can see in table 3, we have:

- The bigger the auctioned transmission line extension, bigger the winning bid;
- The bigger the proxy to the line cost, given by the Estimated Investiment, bigger the winning bid;
- The bigger the competitors number in the auction, smaller the winning bid;
- The dummy variable that indicates that firms gave bids below R$ 48 millions is significative at 1% significance level, with a negative coefficient, as we could expect;
- Dummies indicating geographic location of auctioned transmission lines are significatives at 1% significance level.

The second estimate follows this specification:

$$LBID_i = \beta_1 LCOMP_i + \beta_2 LINVEST_i + \beta_3 LEXT_i + \beta_4 TAX + \beta_5 SOUTH + \beta_6 SE + \beta_7 NE + \beta_8 CWNO \quad (6)$$

In this regression, we have the logarithm of winning bid as dependent variable. We can conclude that:

- The bigger the logarithm of competitors number, smaller the logarithm of the winning bid;

[15] In this regression and in the next ones, we do not include the statistically non-significant variables.

- The bigger the logarithm of the line extension, bigger the logarithm of the winning bid;
- The bigger the logarithm of the estimated investment, bigger the logarithm of the winning bid;
- The TAX dummy variable was significative in this model, with a negative sign;
- All geographic dummies for transmission lines location are significative at 1% significance level, except the Northeast region that is significative at 5% significance level.

The third estimate, according to Bajari & Ye (2001), presents the following specification, with the fraction winning bid per estimate investment as dependent variable,

$$\frac{BID}{INVEST_i} = \beta_1 COMPET_i + \beta_2 SOUTH + \beta_3 SE + \beta_4 NE + \beta_5 CWNO \tag{7}$$

The results from this regression show these relations:

- The bigger the competitors number in the auction, smaller the ratio winning bid per estimated investment;
- All geographic dummies for transmission lines location are significative at 1% significance level.

Table 3 - Results of Estimated Reduced-Based Models

Variables[1]	Model 1		Model 2		Model 3		Model 4	
	Coefficient	t-Stats	Coefficient	t-Stats	Coefficient	t-Stats	Coefficient	t-Stats
Number of Competitors	-1303.3***	-5.11			-0.01**	-2.15		
Extension	36.25***	3.24					36.57***	3.03
Tax Dummy	-27636.7***	-4.70	-0.51***	-4.12			-28219***	-4.27
Estimated Investment	0.05***	4.11					0.05***	3.45
South Region	37671.3***	5.82	2.49***	2.61	0.25***	3.21		
Southeast Region	35797.5***	5.44	2.56***	2.59	0.21***	6.96		
Northeast Region	34498.5***	5.46	2.18**	2.28	0.20***	5.05		
North and Center-West Regions	32413.7***	5.18	2.45***	2.42	0.21***	4.77		
Log Number of Competitors			-0.24***	-3.97				
Log Estimated Investment			0.59***	6.28				
Log Extension			0.20***	3.47				
Dummy 1 competitor							34421.1***	4.36
Dummy 2 competitors							33116.6***	4.26
Dummy 3 competitors							32853.8***	4.34
Dummy 4 competitors							31617.5***	4.41
Dummy 5 competitors							29609.4***	3.06
Dummy 6 competitors							30754.7***	3.66
Dummy 7 competitors							24966.9***	3.17
Dummy 8 competitors							19783.6**	2.32
Dummy 9 competitors							24196.6***	2.69
Dummy 10 competitors							22925.3***	2.87
Dummy 11 competitors							25798.0***	3.70
Dummy 12 competitors							13724.8	1.26
Dummy 13 competitors							26872.9***	3.78
Dummy 14 competitors							23395.3***	3.15
Adjusted R^2	0.91		0.88		0.05		0.92	
SQR	7.84E+09		14.63		2.98		7.47E+09	
Schwarz Inf. Criterion	21.4		1.04		-0.61		21.3	

Models 1 and 4 have the winning bid as dependent variable; model 2 has the log of the winning bid; Model 3 has the fraction winning bid per estimated investment.
Significance Levels: * 0.10 **0.05 ***0.01.

At last, we estimate the regression:

$$BID_i = \beta_1 EXT_i + \beta_2 INVEST_i + \beta_3 TAX + \beta_4 d1 + \beta_5 d2 + ... + \beta_{17} d14 \quad (8)$$

In which the dependent variable is the winning bid either, as in the first regression, but with the Rezende (2005) approach. As we showed before, the author says that this estimation is a way to capture structural analysis into the auctions econometrics. What Rezende does is a regression of the price - in our case, the winning bid - with the covariables that affect the mean price and with the combinations of the covariables affecting the variance with the dummies for the number of competitors.

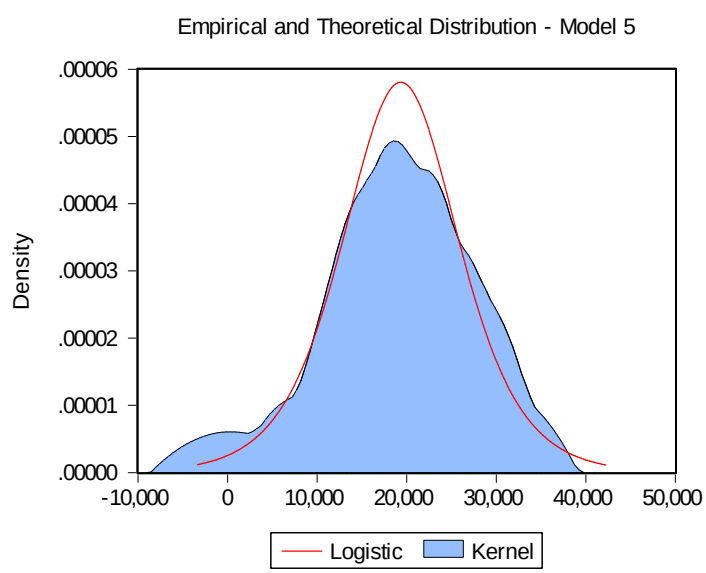
Then, in the specification above, besides the already presented variables, we have the dummies with the number of competitors in the auctions - d_1 to d_{14}, once 1 to 14 are the possible values that the number of competitors can assume in this analysis.

From the results of this exercise we can say that:

- The bigger the line extension, bigger the winning bid;
- The bigger the estimated investment, bigger the winning bid;
- The dummy variable indicating that companies presented a bid below R$ 48 millions is significative at 1% of significance level, with negative coefficient, as we could expect;
- Almost all the dummies for the number of competitors are significative - eleven of these fourteen dummies variables.

According to Rezende (2005), once we have estimated the regression above, we can use the parameters from the dummies to find the competitors' valuation distribution function. Our estimation, presented in figure 4, suggests that a better specification for the competitors' valuation is given by the logistic distribution function.

Figure 4 - Competitors' Valuation Distribution Function



The logistic function resembles the normal distribution in shape but has heavier tails (higher kurtosis, that means that more of the variance is the result of infrequent extreme deviations, as opposed to frequent modestly

sized deviations).

Another characteristic of the four reduced-based presented is that no one of them has the variable "EPC" - the dummy for a construction firm in the auction's winning group - statistically significative.

Graphs 5 to 8 show the estimated regressions, with the residuals of each one. We have some evidence, with the fitting, that specifications with winning bid as dependent variable are more appropriate in the analysis. Then we have first and fourth models explaining in a better way the bidding process in the transmission auctions.

Fig. 5 - Winning Bid Regression*

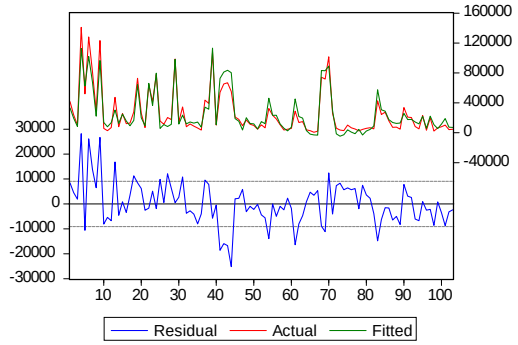


Fig. 6 - Log(winning bid) Regression

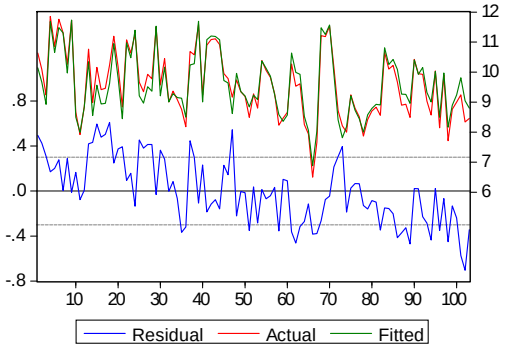


Fig. 7 - Winning Bid/ Investment Regression

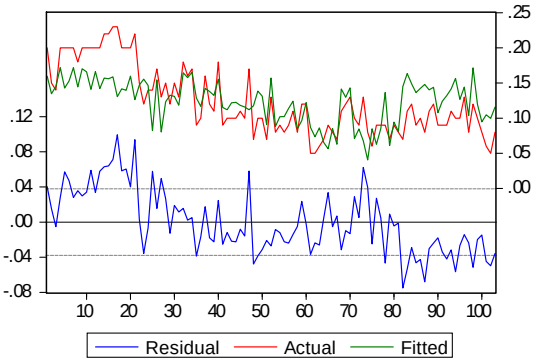
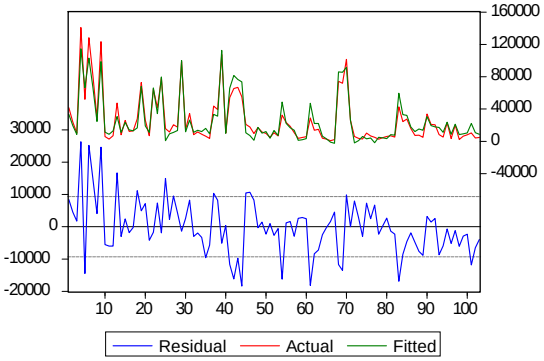


Fig. 8 - Winning Bid Regression



* We used in this section the EViews 5.0 package.

8.3 Principal Components Analysis

In this section, we ran a principal component analysis to deal with the multicollinearity between the investment and the reserve price in the Brazilian transmission auctions.

Principal components analysis (PCA) models the variance structure of a set of observed variables using linear combinations of the variables. These linear combinations, or components, may be used in subsequent analysis, and the combination coefficients, or loadings, may be used in interpreting the components. While we generally require as many components as variables to reproduce the original variance structure, we usually expect to account for most of the original variability using a relatively small number of components.

PCA is mathematically defined as an orthogonal linear modification that transforms the data to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on. PCA is theoretically the optimum transform for given data in least square terms. Because of these transformations, PCA deals with the multicollinearity problem.

The principal components of a set of variables are obtained by computing the eigenvalue decomposition of the observed variance matrix. The first principal component is the unit-length linear combination of the original variables with maximum variance. Subsequent principal components maximize variance among unit-length linear combinations that are orthogonal to the previous components. For more details see Johnson and Wichtern (1992).

Table 4 - Cumulative Proportion of Principal Components Analysis

Computed using: Ordinary correlations
Extracting 11 of 11 possible components
Eigenvalues: (Sum = 11, Average = 1)

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	4.971766	3.489233	0.4520	4.971766	0.4520
2	1.482532	0.113159	0.1348	6.454298	0.5868
3	1.369373	0.210619	0.1245	7.823671	0.7112
4	1.158753	0.269116	0.1053	8.982425	0.8166
5	0.889638	0.207807	0.0809	9.872062	0.8975
6	0.681831	0.416297	0.0620	10.55389	0.9594
7	0.265534	0.158334	0.0241	10.81943	0.9836
8	0.107199	0.050267	0.0097	10.92663	0.9933
9	0.056932	0.040491	0.0052	10.98356	0.9985
10	0.016441	0.016441	0.0015	11.00000	1.0000
11	9.61E-17	---	0.0000	11.00000	1.0000

The table 4 summarizes the eigenvalues, showing the values, the forward difference in the eigenvalues, the proportion of total variance explained, etc. Since we are performing principal components on a correlation matrix, the sum of the scaled variances for the eleven variables is equal to 11. The first principal component accounts for 45.2% of the total variance ($4.9718/11.00 = 0.4520$), while the second accounts for 13.5% ($1.4825/11.00 = 0.1348$) of the total. Doing the same with the third and fourth components, we see that the first four components account for over 81% of the total variation.

Table 5 - Linear Combination Coefficients and Correlations

Eigenvectors (loadings):

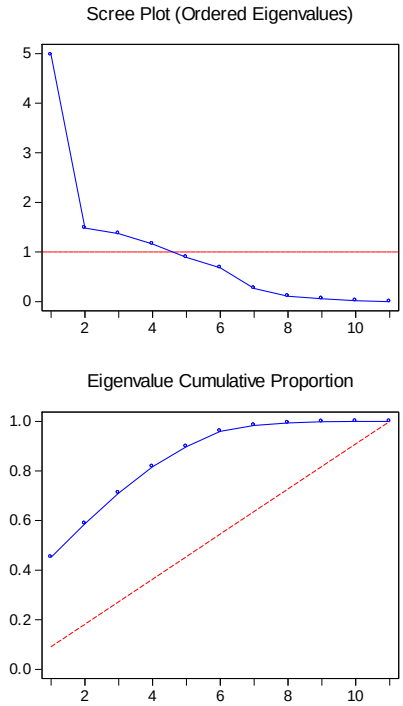
Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11
BID	0.431807	-0.010649	-0.022650	-0.090791	0.102375	-0.102668	0.036244	-0.218857	0.838758	0.175854	-2.30E-16
EPC	0.094776	0.222400	-0.486674	-0.399158	-0.116554	0.727243	-0.026334	0.038775	0.006772	0.025808	-5.03E-17
INVEST	0.428454	-0.033723	0.063173	0.042591	0.205159	0.004924	0.031436	0.529200	-0.239702	0.654884	-1.45E-15
EXT	0.406032	0.073345	0.086098	0.089422	0.054752	0.095386	0.637168	-0.523101	-0.348953	-0.029458	4.43E-16
RAP_0	0.429030	-0.024950	-0.006446	-0.019523	0.235097	-0.022110	0.076973	0.469060	0.017238	-0.729993	1.20E-15
REGFOUR	0.252089	0.106279	0.379784	0.159599	-0.685764	0.158654	-0.119453	0.088098	0.039555	-0.043809	0.484243
REGONE	-0.153776	0.424043	0.342498	-0.516692	0.395282	-0.098687	0.009677	-0.034268	-0.034833	0.014394	0.493548
REGTWO	-0.075471	-0.779041	-0.141749	-0.085837	0.152139	0.136068	0.095566	-0.046248	-0.004563	0.010946	0.553954
REGTHREE	-0.009422	0.368316	-0.591765	0.485785	0.113657	-0.223176	0.000278	-0.000278	0.001218	0.017351	0.463739
TAX	-0.400293	0.072223	0.038906	0.043749	-0.154295	0.055876	0.739654	0.404652	0.300655	0.054477	-8.78E-17
COMPET	-0.137272	0.066330	0.343303	0.533412	0.434954	0.587035	-0.120471	-0.045559	0.154021	-0.016283	1.34E-17

Ordinary correlations:

	BID	EPC	INVEST	EXT	RAP_0	REG4	REG1	REG2	REG3	TAX	COMPET
BID	1.000000										
EPC	0.194756	1.000000									
INVEST	0.910590	0.112302	1.000000								
EXT	0.858417	0.151611	0.863513	1.000000							
RAP_0	0.935116	0.173027	0.975626	0.857330	1.000000						
REG4	0.435932	-0.022119	0.450769	0.532762	0.383555	1.000000					
REG1	-0.250908	-0.012056	-0.274059	-0.260396	-0.252600	-0.295901	1.000000				
REG2	-0.130147	-0.107418	-0.111736	-0.227561	-0.099712	-0.388514	-0.402367	1.000000			
REG3	-0.032704	0.164243	-0.045551	-0.007353	-0.012567	-0.265197	-0.274653	-0.360616	1.000000		
TAX	-0.872141	-0.170615	-0.853139	-0.698527	-0.855852	-0.380820	0.285309	0.055876	0.027263	1.000000	
COMPET	-0.356776	-0.271630	-0.164215	-0.135665	-0.232643	-0.082514	0.101300	-0.034335	0.019365	0.265272	1.000000

Table 5 describes the linear combination coefficients. We see that the first principal component (labeled "PC1") is a roughly-equal linear combination of EXTENSION, INVESTMENT, RESERVE PRICE, TAX and BID variables; The PC2, for its turn, is a combination of the dummies variables for the South, Southeast and Northeast regions. The PC3 is a combination of the EPC dummy, the dummies for the South, Northeast and Center West- North regions and the variable of competitors number. We see that the regions are relevant for this group of variables, which constitute our models to explain the transmission winning bids.

Figure 9 - Scree Plot and Cumulative Proportion



The scree plot in the upper portion of the figure 9 presents the sharp decline between the first and the second eigenvalues. Also depicted in the graph is a horizontal line with the average value of the eigenvalues (which is always 1 for eigenvalue analysis conducted on correlation matrices, as we had done).

The lower portion of the graph shows the cumulative proportion of the total variance. As we saw in the table, the first four components account for about 81% of the total variation. The diagonal reference line offers an alternative method of evaluating the size of the eigenvalues. The slope of the reference line may be compared with the slope of the cumulative proportion; segments of the latter that are steeper than the reference line have eigenvalues that exceed the mean.

8.4 Non-Linearity test

A possible difference in the competitors behaviour can arise when we consider bids below or up R$ 48 millions. As we already mentioned, companies with annual revenue below this value have an assumed profit income tax system and, if they can, they will do the option to stay in this beneficial tax system. Then we can expect a distinct behaviour, more agressive for bids below this value, comparative to other bids. This is the hypothesis we will test in this non-linearity exercise. For this test, we choosed the first reduced-based model showed, once the TAX variable appears more statistically significant in this model.

Besides our sample being cross-section data, the test is based in Threshold Autoregressive (TAR) models, which, according to Enders (2007), are a straighforward way to extend models to a non-linear format, with the possibility to observe two regimes acting in the data.

The results of this test are in table 6. We can see that the exogenously determined limit, R$ 48 millions, is relevant for the winning bid magnitude, or in other words, this amount is in fact a threshold for the behaviour of the winner in the transmission auction.

Table 6 - Regression with Exogenous Threshold

Dependent Variable:	Winning Bid
Adjusted R^2:	0.978
Residual Sums of Squares:	1439.82
F test:	119.12
Significance level of F test:	0.0000
Durbin-Watson Statistics:	2.26

Table 7 - Estimation Results of Exogenous Threshold - R$ 48 millions as limit to Winning Bid

Variable	Coeff	Std Error	T-Stat	Signif
1. DEP	2.15863608	7.36863847	0.29295	0.77100359
2. INVEST_DEP	-0.02857833	0.03640533	-0.78500	0.43685700
3. RECEITA_DEP	0.85265220	0.20610147	4.13705	0.00016513
4. EXT_DEP	1.21964029	1.33801049	0.91153	0.36721717
5. EPC_DEP	1.66403127	6.33795434	0.26255	0.79418086
6. COMP_DEP	-1.14889582	0.39975157	-2.87402	0.00633377
7. SUL_DEP	0.20312681	4.15545083	0.04888	0.96124504
8. SE_DEP	-0.63975014	4.05168852	-0.15790	0.87529454
9. NE_DEP	-0.76403728	4.11475059	-0.18568	0.85358760
10. CO_DEP	0.00000000	0.00000000	0.00000	0.00000000
11. AP	31.96028507	5.92386481	5.39517	0.00000293
12. INVEST_AP	0.05598604	0.02327946	2.40495	0.02065946
13. RECEITA_AP	0.15103367	0.10176345	1.48416	0.14523210
14. EXT_AP	5.05224044	0.77498263	6.51917	0.00000007
15. EPC_AP	0.00000000	0.00000000	0.00000	0.00000000
16. COMP_AP	-7.76259619	0.66181614	-11.72923	0.00000000
17. SUL_AP	0.69804042	5.28644914	0.13204	0.89558056
18. SE_AP	8.41913521	3.77329123	2.23124	0.03105960
19. NE_AP	-4.90301495	4.67004663	-1.04989	0.29977448
20. CO_AP	0.00000000	0.00000000	0.00000	0.00000000

Notwithstanding, to verify if the better winning bid level that separate the agents behaviour is, in fact, R$ 48 millions, we also tested the existence of an endogenous threshold. Tables 8 and 9 show that this endogenous threshold is statistically significative and even more expressive than the exogenous limit (the comparison was made with the Residual sums of Squares, that is lower in the second exercise). In this case, the estimated value for our sample of the threshold was R$ 66.49 millions.

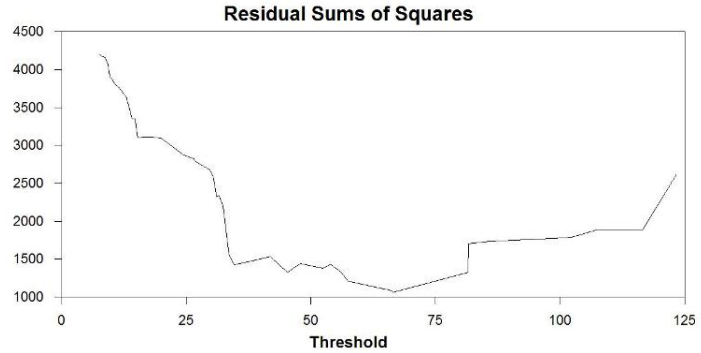
Table 8 - Regression with Endogenous Threshold	
Dependent Variable:	Winning Bid
Adjusted R^2:	0.984
Residual Sums of Squares:	1058.15
F test:	163.03
Significance level of F test:	0.0000
Durbin-Watson Statistics:	1.528

Table 9 - Estimation Results of Endogenous Threshold

Variable	Coeff	Std Error	T-Stat	Signif
1. DEP	2.24793058	6.04106271	0.37211	0.71168308
2. INVEST_DEP	-0.04666323	0.02895996	-1.61130	0.11460470
3. RECEITA_DEP	0.85466818	0.14430785	5.92253	0.00000051
4. EXT_DEP	1.18092056	0.86814054	1.36029	0.18099562
5. EPC_DEP	3.83210549	5.36791228	0.71389	0.47924313
6. COMP_DEP	-1.43262037	0.32577989	-4.39751	0.00007327
7. SUL_DEP	0.79221775	2.93061312	0.27032	0.78823426
8. SE_DEP	0.24099320	2.85863878	0.08430	0.93321571
9. NE_DEP	-0.38623135	3.00286949	-0.12862	0.89827168
10. CO_DEP	0.00000000	0.00000000	0.00000	0.00000000
11. AP	44.20804816	7.62859470	5.79504	0.00000078
12. INVEST_AP	0.05073948	0.02125697	2.38696	0.02156798
13. RECEITA_AP	-0.01982717	0.09852866	-0.20123	0.84148819
14. EXT_AP	6.71997004	0.79200104	8.48480	0.00000000
15. EPC_AP	0.00000000	0.00000000	0.00000	0.00000000
16. COMP_AP	-7.36748303	0.78442292	-9.39223	0.00000000
17. SUL_AP	-11.65150500	6.70619023	-1.73743	0.08964110
18. SE_AP	5.21958773	4.26121127	1.22491	0.22743585
19. NE_AP	-2.53538717	4.22522867	-0.60006	0.55169087
20. CO_AP	0.00000000	0.00000000	0.00000	0.00000000

Figure 10 shows the value that minimizes the residual sums of squares between all the possible thresholds. As we already showed, this value was R$ 66.49 millions.

Figure 10 - Residual Sums of Squares in Function of the Thresholds*



* We used in this section the Rats 6.0 package.

Then, with this exercise, we can conclude that the tax system is relevant for the winning bid behaviour, but not the determinant variable, as we test the amount that separates one system of the other as a threshold (R$ 48 millions) but we find R$ 66.49 millions as the optimal one.

9 Modelling an Economic Experiment to Capture the Synergy Gains

The econometric analysis with a reduced-based models approach, as presented before in this article, is a first attempt to investigate the mechanism design applied in the Brazilian transmission lines auctions. It's important to rebound that structural econometrics is still in development, with models that do not include heterogeneous multiple-objects auctions, like the transmission auction.

With this in mind, was necessary, as a way to complement this study, model an economic experiment to compare the performance of this current auction design - a sequential auction of multiple objects - with another design, in wich objects are offer in a simultaneous way, with some combination between them. This alternative design could capture the revenue that competitors have in reason of the synergies between transmission lines contiguous or close one another.

The winner is chosen in two phases. In the first phase, qualified bidders make sealed bids (an annual revenue to construct and mantain the service) for the transmission lines. In this one, the bidder submitting the lowest value is ranked as the best. In case there are bidders whose bid proposals were sufficiently close to the best ranked bidder's (in this case, higher by up to 10%), they shall be entitled to take part in the second phase as long as they accept the revenue proposed by the best ranked bidder.

In the second phase, qualified bidders would compete in Descending open auctions for the concession through annual revenue proposals to obtain the concession granting. The winner would be the one who, upon accepting the lowest revenue proposed in the first phase, makes a smaller bid in this phase. The Resolution that determines the bidding mode states that in the second phase the granting proposals should be presented in successive bids.

A key point in establishing the bidding environment is that in some cases the segments to be auctioned are adjacent or contiguous; i.e. connected segments shall be assigned. Furthermore, some of these concessions refer to

segments connected to others operated by utilities whose shareholders are companies that may take part in current biddings. This means that such environment is made up by both synergies among the objects to bid or between these and others whose operation has already been assigned in the past. In this case, there is asymmetry among bidders.

The concession bidding of transmission lines segments is an example of multiple heterogeneous objects auctions. A key element to increase the complexity in this environment is the fact that more than one object can be assigned to each bidder (in this case, the concession agreement). Furthermore, the environment is asymmetric since there are players operating licenses connected to others that shall be bid. In the presence of synergies, the winner of a component making up a certain basket of goods obtains advantages vis-à-vis the others. Such asymmetry may lead to revenue loss for the auctioneer if objects are sequentially auctioned, because disadvantaged bidders may refrain from bidding, what reduces the competition. In this case, there is an income transfer from society, in general terms, to a private player thus impairing the reputation of the policy maker[16].

In the existence of complementarities among objects, i.e. if the items are not independent, the task of bids submission becomes difficult as a result of concession assignment by means of a sequence of auctions. Therefore, it is worth investigating auction formats that allow players to submit bids that not only embody such synergies, but also attract bidders.

It is a fact known in the auction literature[17] that the auction format affects the result both in terms of efficiency (capacity of assigning the object to the player who best values it) and revenue collection or cost reduction (in case of descending auctions). Therefore, the environment configuration allows recommendations regarding auction formats that best fit a specific context.

This section reports the experimental analysis of alternative auction mechanisms to the transmission lines, which means the electronic implementation of alternative formats of multiple objects auctions. The group of implemented auctions is the result of theoretical studies as well as the assessment of auction experience.

9.1 The Model

The experiment carries out the comparative investigation of two mechanisms subject to use in the allocation of multiple heterogeneous objects: a hybrid auction of a single object used sequentially implemented and a simultaneous auction of multiple rounds. The performance of the said mechanisms is described below.

In each session, a group of I players, $i = 1, ..., I$, competes for a group of K heterogeneous goods. The objects are auctioned either sequentially or simultaneously. As an example of the Brazilian transmission lines concessions, the number of objects to be auctioned equals eight. For each license taken individually, each bidder attributes a private value independently distributed as follows:

$$v_i\left(l_k\right) \sim U\left[\underline{v}_k, \overline{v}_k\right].$$

This piece of information is common knowledge at the beginning of the experimental session.

[16] Paul Kemplerer reports examples of flaws in auction design harming the reputation of economic policy makers. For further references, see Paul Kemplerer, "Auction: Theory and Practice", Princeton University Press, 2003.

[17] For further references, see Paul Milgrom, "Putting Auction Theory to Work", Cambridge University Press, 2003 and Flavio M. Menezes and Paulo K. Monteiro, "An Introduction to Auction Theory", Oxford University Press, 2004.

The design envisages the existence of scope economies or synergies between subsets of objects. The existence of positive synergies for a given subset of commodities means that to some pre-defined baskets the value of the joint possession of objects is higher than the sum of values separately assigned to the objects. Let $S \subseteq K$ be a subset of licenses presenting positive synergies. Without loss of generality, assume that for the entire subset $s \in S$,

$$v_i\left(\left(\underset{k\in s}{\cup} l_k\right)\right) = \alpha_s\left(\sum_{k\in s} v_i\left(l_k\right)\right) \geq \sum_{j=1}^{k} v_i\left(l_j\right) \quad \forall l_k \in s \tag{9}$$

where $v_i(l_1, .., l_j)$ is bidder $\acute{i}s$ value for the basket $(l_1, .., l_j)$ and $\alpha_s > 1$.

9.1.1 Treatments

The study tests two alternative mechanisms: a sequential auction and a simultaneous ascending auction.

Sequential Auction (Sequence of hybrid auctions for a single object) In this treatment, the objects are sequentially auctioned through an auction format similar to the one used in the Brazilian privatization process[18]. This is a sequential auction where one object is assigned in each auction. One can think of the object either as a license for the concession of a transmission line or as the right to explore a power generation development.

All players (potential buyers) submit sealed bids for a given object. After the opening of bids, if there are players whose bids are sufficiently close to the highest bid, the ones qualified to take part in the second phase will be the bidder with the highest bid and those bidders whose bids are higher than or equal to τ times the value of the highest bid. In the experiment $\tau = 0,9$. Thus, if there are bids that differ from the winning bid by less than 10%, the qualified bidders compete for the object in an ascending auction. In this auction, the reserve price, or the lowest admissible bid, is the highest bid submitted in the first phase. In order to take part in the second phase, qualified bidders should be willing to honor the payment represented by the highest bid of the first phase.

The second phase consists of an ascending auction[19]. In this auction, at each period the current price is equal to the current price of the preceding period plus a minimum amount denoted by $\delta^{\min}$. Bidders may accept or reject the current price; if they reject it, they will be out of the bidding. The default situation is to accept the bid. The auction ends with one remaining player who is then declared the winner. The "price" to be paid is the price to which the next-to-last player leaves the auction.

Simultaneous Ascending Auction Besides the sequential auction, in a second treament the K licenses are allocated through a simultaneous ascending auction.

Simultaneous auctions have been championed and extensively used to assign commodities in cases where the values assigned by bidders are not independent. Although they might be susceptible to exposure problems, the relative simplicity of the bids formulation process makes this auction format proper for scenarios where it is desirable that players have an opportunity to reach a desired object aggregation.

[18] For further references, see Dutra, J. and F.M. Menezes, "Hybrid Auctions", Economics Letters 77, 301-307, 2002.

[19] For references on auctions, see F.M. Menezes and P.K. Monteiro "An Introduction to Auction Theory", Oxford University Press, 2004.

In the auction[20], the bids by players at each period must meet the budget constraint, i.e. the sum of their bids for the set of commodities they are competing for, $\sum_{k=1}^{K} b^t_{i(l_k)}$, cannot exceed the initially assigned income. Denote by $\overline{w}^0_i$ s the initial endowment of the i-th player. Its budget constraint is given by:

$$\sum_{k=1}^{K} b^t_{i(l_k)} \leq \overline{w}^0_i, \quad i = 1, ..., I; \ \forall t \tag{10}$$

In order to avoid demand reduction, it is common practice to adopt an activity rule. In this case, the rule is a monotonicity requirement in the number of objects for which the bidder competes. Let N^t_i be the number of elements in the set of objects for which the $i - th$ player submitted a bid in period t. Then the monotonicity rule requires that

$$N^t_i \leq N^{t-1}_i \quad \forall t \tag{11}$$

an i player who is said to be active for a set of licenses cannot increase the number of licenses to which the bid is submitted. Furthermore, at each new period only the bids meeting the following condition shall be accepted

$$b^t_{i,k} \geqslant \max\left\{b^{t-1}_{i,k}\right\} + \delta^{\min}_k, \quad k = 1, ..., K; \quad i = 1, ..., I \tag{12}$$

i.e. price bids (in this case, granting value) must be non-descending. However, the bidder submitting the highest bid in a t round does not have to propose a higher bid in the subsequent round. In this case, at the beginning of the $(t + 1) - th$ round this one should be considered as active.

Conditions $(10) - (12)$ must be met at each round so that player i may continue taking part in the auction.

The end of the auction is simultaneous; i.e. the auction continues as long as bids are still being submitted by at least one player for at least one object. That means the auction goes on while there is a price change for at least one product. For each object, the winner would be the bidder who would have submitted the highest bid at the moment the auction is over; prices to be paid will be the ones in force.

9.1.2 Auction Rules

Before the beginning of the auction, each bidder is informed of:

- the values assigned to each commodity;
- the values associated with pre-established combinations for which there are positive synergies (transmission lines close one to another).

Private Values The first set of auctions is characterized by private values: for each object bidder $i's$ value is a number extracted with equal probability of a distribution that is of common knowledge.

In the case of the experimental design, it was established the existence of synergies for licenses 3, 4 and 5 as well as for the 7 and 8 combination; the following valuations - just a possibility of gains - for commodities were

[20] This restriction applies to the sequential auction as well.

experimentally implemented,[21]

$$v_i\left(\bigcup_{k=3}^{5} l_k\right) = 1.44 \cdot \sum_{k=3}^{5} v_i\left(l_k\right)$$

$$v_i\left(\bigcup_{k=7}^{8} l_k\right) = 1.2 \cdot \sum_{k=7}^{8} v_i\left(l_k\right) \tag{13}$$

In 11 auctions the values assigned to the objects by bidders were private ones. In this case, all values were extracted with equal probability from the [30, 80] interval and such fact was common knowledge.

Almost-Common Values In this second set of experimental sessions, a different form of assigning value to commodities was implemented. This structure describes the case where the value of the object has a common component for all bidders and this value is not known at the moment bids are submitted. The auctions motivating the current analysis are part of this group; i.e. there is a common component associated with the value of the object that is being sold.

For sessions numbered 12 to 17, players' values for the objects by were made up of two parts. In each auction, the value that participant i assigns to the $k-th$ commodity, $V_{i,k}$, is equal to the sum of a common value component (c_k), which is equal to all bidders, and of a private value ($x_{i,k}$), as follows:

$$V_{i,k} = x_{i,k} + c_k$$

The value of the common component of each commodity, c_k, $k = 1, ..., 8$, is a number extracted with equal probability from the interval $[\underline{c}_k, \overline{c}_k]$; however, such value is not known until the end of the auction. The bidder observes only a signal, s_k, which can be understood as an estimate of the value of this common component; for each commodity, this signal $s_{i,k}$ is uniformly distributed in the interval $[c_k - z, c_k + z]$ and this is common knowledge The private signal $x_{i,k}$ is a number uniformly distributed in the $[\underline{x}_k, \overline{x}_k]$ interval. Note that positive synergies for referred sets are still valid.

TESTABLE HYPOTHESIS: In the presence of positive synergies, the simultaneous auction allows bidders with a higher probability to benefit from such synergies, thus assuring higher efficiency at the auction and higher revenue for the auctioneer.

9.1.3 Payoffs

Besides observing the information concerning values for the goods, at the beginning of the auction each bidder observes the initial prices of each object. Upon such information, the auction gets started.

In each experimental session, the players' earnings are made up of a participation fee, in the form of a fixed rate, plus their decision gains throughout the session. For each acquired commodity, the winner's gain is given by:

$$v_i\left(l_k\right) - p_k = v_i\left(l_k\right) - \max\left\{b_{i,k}^t\right\}$$

[21] An extension of the study leads to the analysis of the case of a group of players who hold a D license previously assigned to a $\widehat{i}$ participant in the auction so that $v_{\widehat{i}}(C+D) > v_{\widehat{i}}(C) + v_{\widehat{i}}(D)$. This example characterizes the presence of asymmetries among players.

where $b_{i,k}^t = b_i^t(l_k)$. The non-winning bidders earn nothing. Total gains in the session are equal to gains for the sum of obtained licenses, net of paid prices.

If the bidder managed to add the corresponding licenses to pre-established synergies, his gain for said combination is equal to the value for the combination, which is given by (9), net of the price paid for the combination, which is equal to the sum of paid prices. By way of illustration, if participant 1 won licenses 3, 4 and 5 his gain, π_1, would be equal to:

$$\begin{aligned} \pi_1(l_3, l_4, l_5) &= v_1(l_3, l_4, l_5) - (p_3 + p_4 + p_5) \\ &= 1.44(v_{3,1} + v_{4,1} + v_{5,1}) - (p_3 + p_4 + p_5) \end{aligned}$$

At the end of the experimental session, the payment is made in cash.

9.2 Experiments Results

9.2.1 Aggregated Results

Seventeen experimental sessions have been carried out. Out of these, 8 sessions consist of sequential auctions while the remaining ones are simultaneous auctions. In each auction, a group of bidders ranging from six to eight competes for the ownership of eight commodities. As a whole, 136 commodities were auctioned, which stood for licenses.

The values assigned by bidders to the objects were private ones in 88 auctions. In this case, all values were extracted with equal probability from the $[30, 80]$ interval and such fact was of common knowledge.

For auctions numbered 89 to 136, in turn, the values assigned by players to the objects were made up of two parts (almost-common values); in each auction, the value that bidder i assigns to the $k-th$ commodity, $V_{i,k}$, is equal to the sum of a common value component (c_k) and a private value ($x_{i,k}$) as follows:

$$V_{i,k} = x_{i,k} + c_k$$

The common value component of each commodity,c_k, $i = 1, ..., 8$, is a number between 30 and 80, drawn with equal probability; however, this value is not observed by i. The bidder knows only a signal, $s_{i,k}$, which can be understood as a value estimate of this common component. For each commodity, this signal, $s_{i,k}$, is uniformly distributed in the $[c_k - 10, c_k + 10]$ interval. On the other hand, the private signal $x_{i,k}$ is a uniformly distributed number in the $[0, 30]$ interval.

Table 10 summarizes the results of the experimental design. The following conclusions can be drawn from said data:

- The mean efficiency of the simultaneous auction is relatively higher than that of the sequential auction;
- The revenue obtained with the implementation of the simultaneous auction is higher;
- The number of inefficient assignments (number of times in which the winner of the auction was a player who would not present the highest value for the commodity) is lower in the simultaneous auction;

- Mean gains of bidders in the simultaneous auction are comparatively higher than those in the sequential auction.

Table 10 - Experimental Results (Mean per Treatment)

Mechanism	Values	Profit/Potential Value[1]	Value Appropriation[2]
Sequential	Private	− 4%	92%
Sequential	Almost Common	8%	97%
Simultaneous	Private	3%	97%
Simultaneous	Almost Common	2%	99%

Notes: (1) Bidders' mean profit as proportion of the maximum possible value;
(2) Value realized as proportion of the maximum possible value.

According to results, the simultaneous auction is higher both in terms of efficiency and revenue guarantee (without necessarily resulting in losses to bidders).

This is the conclusion of the experimental study carried out in an environment meant to reproduce characteristics that possible exists in transmission lines scenario auctions.

9.2.2 Individual Behavior

Analysis results of bidders' individual behavior are presented below. Table 11 shows data on the bids as proportion of players' values in the auction. It is inferred that players are more aggressive in the case of simultaneous auctions and such behavior is more intense the higher the synergy degree among goods. As described in the experimental design, the absence of synergy refers to goods 1, 2 and 6; while the weak and strong synergies refer to baskets (l_7, l_8) and (l_3, l_4, l_5) respectively.

Table 11 - Bid Behavior (Bid as value proportion)

Mechanism	Private Values		Almost-Common Values		General Mean	
Sinergy	Sequential	Simultaneous	Sequential	Simultaneous	Sequential	Simultaneous
Absent	0.93	0.84	0.91	0.74	0.93	0.81
Weak	0.88	0.97	0.95	1.03	0.94	0.99
High	1.02	1.21	1.00	1.23	1.03	1.22

A more aggressive bidding behavior is favored by the auctioneer's once it allows a higher appropriation of the value bidders assign to the objects. In the case of transmission line concessions this means a higher rent extraction in the form of a decrease in the revenue they accept to construct and administrate the transmission lines. Table 12 shows the percentage variation of bids as value proportion relatively to the case in which goods do not present synergy. Data denote an advantage of the simultaneous auction over the sequential one; an advantage that is even more stressed in the case of almost-common values.

Table 12 - Bid as value proportion (% Variation)

Mechanism	Private Values		Almost-Common Values		General Mean	
Sinergy	Sequential	Simultaneous	Sequential	Simultaneous	Sequential	Simultaneous
Weak	−5.00	13.00	4.00	29.00	1.00	18.00
High	9.68	44.05	9.89	66.22	10.75	50.62

Base: Absence of synergy

Mean equality tests for the case of private values are shown in Table 13. At a 5% level, means are statistically different for goods 1 and 2 (absence of synergy) and for good 4.

Table 13 - Means Difference Test – Private Values

	Mean per Mechanism		
Good	Sequential	Simultaneous	p- value
Good 1	0.978	0.836	0.03
Good 2	0.980	0.841	0.00
Good 3	1.194	1.251	0.61
Good 4	1.009	1.279	0.02
Good 5	0.954	1.113	0.16
Good 6	0.871	0.833	0.65
Good 7	0.990	0.992	0.98
Good 8	0.875	0.955	0.34

In the case of almost-common values, data reported in Table 14 show an advantage of the sequential auction in the case of no synergy (Goods 1 and 6). On its turn, at the 5% significance level, the simultaneous auction reveals a more aggressive bidding behavior under strong synergy. Note that in the case of Good 3, said means do not differ under the statistical viewpoint. Such behavior is expected considering that in the sequential auction players show more aggressiveness in the auction of the first object of the basket. This strategy ends up by reducing the participation of other players in subsequent auctions (of basket objects) since only the winner of commodity 3 may then carry out the involved synergies. Figure 2 of Appendix A2 shows these arguments.

Table 14 - Means Difference Test – Almost-Common Values

	Mean per Mechanism		
Good	Sequential	Simultaneous	p- value
Good 1	0.894	0.658	0.00
Good 2	0.878	0.799	0.33
Good 3	1.109	1.202	0.56
Good 4	0.949	1.232	0.02
Good 5	0.950	1.262	0.01
Good 6	0.935	0.734	0.00
Good 7	0.996	1.018	0.77
Good 8	0.947	1.087	0.19

The analysis of individual data reveals a comparative edge of the simultaneous auction format vis-à-vis the sequential one. In the presence of positive synergies, bids by players in the simultaneous auction reflect the increase of the value associated with the ownership of pre-established combinations of commodities. In the sequential auction, in turn, the uncertainty as to the capacity of reaching the desired aggregation of commodities compel players to adopt a more conservative behavior in which joint ownership is not priced. Figures 1 and 2 of appendix A2 show these observations.

Finally, a regression analysis of bids is shown in Tables A5, A6 and A7. The inclusion of several interaction dummies between the simultaneous mechanism and goods confirm the presented arguments especially in the case of almost-common values (Table A6 attached).

10 Conclusions

Our empirical exercises suggest that many factors affect, in the direction of economic intuition, the winning bid in transmission auctions. We estimated four reduced-based models and conclude that a better specification is to use the winning bid in level against the logarithm and a ratio of the bid with investments need.

With these models, it seems that the number of competitors in the auctions, in all reduced-based models, negatively impact the level of the winning bid. The location of the transmission undertaking is also relevant to explain the winning bid. Hence the hypothesis that a company operating a line in a determined region will bid more aggressively in auctions for facilities closer to existing ones under their operation is confirmed. Additionally, the dummy variable for a bid no higher than R$ 48 millions is significant in the estimation. As a consequence, we argue that firms benefit from the differentiated tax system, what is embodied in their bids. The projects' specifics, such as the extension of the lines and the estimated investment to the building and maintenance also explain the winning bid level, as expected.

The reduced-based model following Rezende (2005) allows us to estimate the distribution function of the competitors' valuation. The results indicate a logistic distribution to the competitors valuation. The logistic distribution has a shape very similar to that of the Normal distribution, with the mean as one of its parameters. Since the logistic distribution is symmetrical, the median and the mode are always equal to the mean.

In our Principal Component Analysis, we found that the main variables responsible for the winning bid are the extension, the investment, the reserve price of the auction, the dummy relative to the tax system. However, we also see that the regions are relevant in the group of variables which are used in our models to explain the transmission winning bids.

For its turn, the non-linearity analysis, which was applied with the objective to test if our model has two regimes, identifies that both exogenous (R$ 48 millions) and endogenous thresholds for the winning bids are valid to our analysis. As a consequence, we can say that competitors have a different behavior in each sample of our data. The endogenous threshold was the best specification for this non-linear analysis, indicating that bids are different beyond and up R$ 66 millions. Then, we can say, with the non-linearity exercise, that the tax system is a relevant component of the winning bid, but is not the determinant one.

Finally, we model an economic experiment testing that an alternative design for the Brazilian transmission auctions, with neighboring lines auctioned simultaneously, would improve the rent extraction from the transmission companies.

The current mechanism for the bidding is a sequential auction: the concessions are allocated in a pre-determined order. However, two elements provide uniqueness to the concession environment. Firstly, the bidding involves some segments that are connected or close to others that have already been allocated. Furthermore, some involved segments are close to others that were the object of concessions in the past. In this case, there is asymmetry among bidders as such companies already holding concession agreements can operate the segments under more favorable conditions (at lower cost).

Both elements presented herein justify the comparison of the auction format already used in the transmission (a sequential auction) with an alternative: the simultaneous auction. This comparison was carried out in an experimental environment developed to reproduce conditions similar to the background presented. The results confirm a superiority of the simultaneous auction whenever there are positive synergies: it was possible to simplify the bid submission task, thus obtaining higher revenue (in the granting phase) and higher efficiency (choosing the bidder who assigns a higher value to the object).

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11 Appendix - Econometyric Analysis - A1

Outcomes from estimated regressions trying to model the winning bids in the actual transmission auctions are present below.

Table A1- Winning Bid as Dependent Variable

Dependent Variable: BID
Method: Least Squares
Date: 10/02/10 Time: 21:16
Sample: 1 103
Included observations: 103
White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COMPET	-1303.285	255.2355	-5.106204	0.0000
INVEST	0.051416	0.012506	4.111426	0.0001
REGONE	37671.31	6469.037	5.823325	0.0000
REGTWO	35797.51	6579.237	5.440983	0.0000
REGTHREE	34498.55	6317.253	5.461004	0.0000
REGFOUR	32413.68	6260.224	5.177719	0.0000
TRIBUTACAO	-27636.67	5877.355	-4.702230	0.0000
EXTENSAO	36.25182	11.19593	3.237947	0.0017

R-squared	0.915748	Mean dependent var	25970.50
Adjusted R-squared	0.909540	S.D. dependent var	30211.68
S.E. of regression	9086.619	Akaike info criterion	21.14148
Sum squared resid	7.84E+09	Schwarz criterion	21.34612
Log likelihood	-1080.786	Durbin-Watson stat	1.545353

Table A2 - Logarithm of Winning Bid as Dependent Variable

Dependent Variable: LBID
Method: Least Squares
Date: 10/02/10 Time: 20:15
Sample: 1 103
Included observations: 103

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TRIBUTACAO	-0.513908	0.137117	-3.747948	0.0003
LINVEST	0.591193	0.050076	11.80596	0.0000
LEXTENSAO	0.203443	0.042325	4.806688	0.0000
LCOMPET	-0.242908	0.054773	-4.434808	0.0000
REGONE	2.499994	0.574486	4.351709	0.0000
REGTWO	2.561137	0.584944	4.378433	0.0000
REGTHREE	2.185807	0.573439	3.811749	0.0002
REGFOUR	2.454267	0.594414	4.128887	0.0001

R-squared	0.882296	Mean dependent var	9.582932
Adjusted R-squared	0.873623	S.D. dependent var	1.104216
S.E. of regression	0.392543	Akaike info criterion	1.042148
Sum squared resid	14.63858	Schwarz criterion	1.246787
Log likelihood	-45.67063	Durbin-Watson stat	1.162331

Table A3 - Winning Bid/Estimated Investiment as Dependent Variable

Dependent Variable: BIDPERINVEST
Method: Least Squares
Date: 10/03/10 Time: 16:54
Sample: 1 103
Included observations: 103

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COMPET	-0.011097	0.005087	-2.181304	0.0316
REGONE	0.250369	0.048551	5.156792	0.0000
REGTWO	0.214190	0.042720	5.013812	0.0000
REGTHREE	0.200746	0.045684	4.394246	0.0000
REGFOUR	0.214295	0.041488	5.165205	0.0000

R-squared	0.053252	Mean dependent var	0.157961
Adjusted R-squared	0.014609	S.D. dependent var	0.175697
S.E. of regression	0.174409	Akaike info criterion	-0.607506
Sum squared resid	2.981000	Schwarz criterion	-0.479606
Log likelihood	36.28655	Durbin-Watson stat	0.490948

Table A4 - Winning Bid as Dependent Variable

Dependent Variable: BID
Method: Least Squares
Date: 10/03/10 Time: 16:54
Sample: 1 103
Included observations: 103
White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COMP1	34421.11	7895.033	4.359844	0.0000
COMP2	33116.57	7765.713	4.264459	0.0001
COMP3	32853.75	7569.961	4.340016	0.0000
COMP4	31617.48	7165.437	4.412499	0.0000
COMP5	29609.43	9659.533	3.065307	0.0029
COMP6	30754.66	8401.164	3.660762	0.0004
COMP7	24966.86	7867.478	3.173426	0.0021
COMP8	19783.62	8525.860	2.320426	0.0227
COMP9	24196.58	9008.437	2.685991	0.0087
COMP10	22925.27	7999.571	2.865813	0.0052
COMP11	25798.00	6964.069	3.704443	0.0004
COMP12	13724.83	10874.95	1.262059	0.2103
COMP13	26872.99	7105.228	3.782143	0.0003
COMP14	23395.26	7434.190	3.146981	0.0023
EXTENSAO	36.56487	12.05197	3.033933	0.0032
TRIBUTACAO	-28219.92	6604.712	-4.272694	0.0000
INVEST	0.048899	0.014164	3.452324	0.0009

R-squared	0.919729	Mean dependent var	25970.50
Adjusted R-squared	0.904794	S.D. dependent var	30211.68
S.E. of regression	9321.935	Akaike info criterion	21.26784
Sum squared resid	7.47E+09	Schwarz criterion	21.70270
Log likelihood	-1078.294	Durbin-Watson stat	1.760425

12 Apppendix - Experiments - A2

Outcomes from estimated regressions aiming to assess the determinants of players' bids in the auction are presented below.

Table A5 - Bid Determinants – Private Values

Variables	Coefficient	p- value
Private Value	0.96	0.00
Mechanism	−5.72	0.03
Good 2	−0.10	0.93
Good 3	12.73*	0.00
Good 4	3.07	0.39
Good 5	−0.87	0.87
Good 6	−4.64*	0.03
Good 7	1.83	0.64
Good 8	−4.05	0.13
Mechanism *Good 2	−2.17	0.49
Mechanism *Good 3	5.32	0.35
Mechanism *Good 4	14.70*	0.01
Mechanism *Good 5	13.84*	0.04
Mechanism *Good 6	1.51	0.73
Mechanism *Good 7	3.96	0.47
Mechanism *Good 8	9.03*	0.04
Constant	1.10	0.73
Number of Observations	624	
F$(16, 607)$	32.34	
Prob > F	0.00	
R^2	0.41	

Notes: (1) Mechanism is a dummy with value 1 if the auction is simultaneous;
(2) bem_i is a dummy variable with value 1 for the $i-th$ good, $i = 2, ..., 8$;
(3) $Mechanism \ * good_i$ is the interaction of the i-th good with the mechanism.

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Table A6 - Bid Determinants – Almost-Common Values

Variables	Coefficient	p- value
Private Value	1.30*	0.00
Mechanism	−24.62*	0.00
Good 2	0.37	0.92
Good 3	18.92*	0.00
Good 4	7.04	0.14
Good 5	7.92	0.06
Good 6	8.87*	0.03
Good 7	6.05	0.31
Good 8	3.66	0.50
Mechanism *Good 2	6.19	0.40
Mechanism *Good 3	18.51*	0.05
Mechanism *Good 4	30.76*	0.00
Mechanism *Good 5	30.32*	0.00
Mechanism *Good 6	−2.74	0.65
Mechanism *Good 7	14.98	0.06
Mechanism *Good 8	18.11*	0.02
Constant	49.96*	0.00
Number of Observations	288	
F$(16, 271)$	17	
Prob > F	0.00	
R^2	0.44	

Notes: (1) Mechanism is a dummy with value 1 if the auction is simultaneous;
(2) bem_i is a dummy variable with value 1 for the $i-th$ good, $i = 2, ..., 8$;
(3) $Mechanism \ * good_i$ is the interaction of the i-th good with the mechanism.

Tabela A7. Bidding Determinants

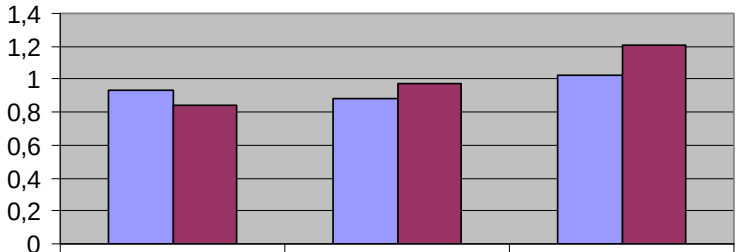
Variables	Coefficient	p- value
Private Value	0.05	0.10
Mechanism	-15.74^*	0.00
Good 2	-1.77	0.58
Good 3	12.72^*	0.01
Good 4	5.90	0.15
Good 5	-1.86	0.70
Good 6	-2.21	0.55
Good 7	0.50	0.91
Good 8	-5.83	0.13
Mechanism *Good 2	5.03	0.31
Mechanism *Good 3	12.89^*	0.04
Mechanism *Good 4	18.43^*	0.00
Mechanism *Good 5	26.87^*	0.00
Mechanism *Good 6	3.42	0.53
Mechanism *Good 7	12.16^*	0.04
Mechanism *Good 8	18.18^*	0.00
Constant	58.60^*	0.00
Number of Observations	912	
$F(16, 895)$	7.97	
Prob > F	0.00	
R^2	0.12	

Notes: (1) Mechanism is a dummy with value 1 if the auction is simultaneous;
(2) bem_i is a dummy variable with value 1 for the $i-th$ good, $i = 2, ..., 8$;
(3) $Mechanism \ * good_i$ is the interaction of the i-th good with the mechanism.

The results of Table A.3 show that, in the presence of synergies the mechanism-good interaction presents a significant positive effect from a statistical viewpoint. Asterisks indicate statistically significant parameters at 5% level.

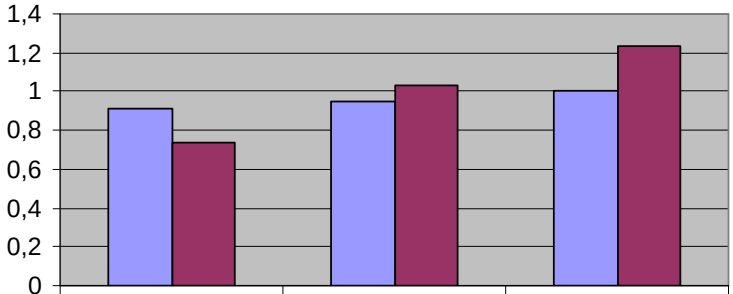
Figures 1 and 2 from this appendix present bid data as a proportion of the value the bidders assign to the objects in cases of private and almost-common values respectively.

Figure 1. Bid Behavior
Private Values



	No Synergy	Weak	Strong
Sequential	0,93	0,88	1,02
Simultaneous	0,84	0,97	1,21

Figure 2 - Bid Behavior
Almost-Common Values



	No Synergy	Weak	Strong
Sequential	0,91	0,95	1,00
Simultaneous	0,74	1,03	1,23

CHAPTER 2

Brazilian Electricity Demand Estimation: What Has Changed After the Rationing in 2001? An Application of Time Varying Parameter Error Correction Model*

Abstract

In this article we search to fill a blank in the Brazilian Energy Economics literature. To our knowledge, there isn't an article estimating the Brazilian electric energy demand testing structural break and also the constancy of the 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 the industrial consumers and the Rationing Crisis as being a structural break in Brazilian demand. Finally, our State Space estimates do not rule out the hypothesis that coefficients vary over time. Besides that, the expansion of credit in Brazil could be a major factor to explain the decline in the level of residential demand elasticities.

JEL Codes: C22, C51, Q41

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

*Paper co-authored by Hilton Notini (ANAC - EPGE/FGV) and Luiz Maciel (IBRE - EPGE/FGV).

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 it already exceeded 100 GW in 2007. Analysts forecast continuity in this expansion, once electric energy is a relevant strategic component of an 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 the 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.[1]

In this contex, another relevant fact is pointed out by Castro and Rosental (2008). They quote that residential and industrial consumers are saving more electricity in the recent years and that is possible to observe a change in the consumption trend. If this happen, new studies to forecast the electric energy supply will be necessary, including a smaller consumption at the same GDP levels.

With the present paper we search to fill a blank in the economics literature: to 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[2], leading to a shift in the demand income and price-elasticity. We test which economic factors explain the long run elasticities and the short run varying elasticities of the energy eletric demand. Furthermore, we include other determinants of this demand present in the international literature, as such temperature, for example.

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 confirming that the variables are non-stationary; First, we estimate the cointegration equation with the variables of any sector, what gives 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 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 the 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 show that 2001 Crisis is as a structural break in electricity demand and our State Space estimates don't rule out the hypothesis that short run elasticities vary over time.

[1] This Rationing episode will be detailed in the section "Brazilian Electricity Sector".

[2] 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, such as the crisis occurred in 2001.

2 Brazilian Electricity Sector

Brazilian electricity sector has changed severely in the recent years. The first fact in the reestructuring process was the extinction of garanteed rat-of-return regulation in 1993. After that, the reform encompasses institutional changes and large privatization. Around 60% of distribution market and 20% of generation market was privatized between 1995 and 2000.

Besides common sense, the Brazilian electricity sector wasn't always close to the idea of investments made by the State. In the beginning of 20th century, the State role in energy supply was very small. Private companies were responsible for energy generation, distribution and comercialization in the sub-national states with limited interconnection. Lima (1995) characterizes this context:

> "In 1930, electricity sector that showed 780MW of installed generation potency and production of 1.483GWh , already had a strategic position, from natural resources use point of view ... It was a sector composed by large multinational firms, like Brazilian Traction, Light and Power - Light and American & Foreign Power Company - Amforp (North-American) groups, that in 1920 decade have taked the virtual monopoly of Brazilian electricity industry, with a quick concentration process and capital centralization..."

After de 1930 world crisis, some realize a structural weakness in the economic liberalism, what made the States change their role, like North-American with the New-Deal.

Moving within this trend, the Brazilian government took a more active position in public utilities provision and the "Código das Águas" draft-law content indicates this change. Lima (1995) says that the main influence of this project, from the institutional point of view, was the North-American legislation, that highlights hydro-power as a special privilege of the water use.

With the institution of the "Código das Águas", from 1934, the regulation of the private sector became more effective, [3]in fact it gave a regulatory benchmark for the sector until 1993. As an overview, it was determined in this document that all public use of hydro resources, independently of the land property rights, would be conditional to the Federal government concessions.

Besides that, the Code establishes the tariff principles, which was based on historical investment costs. Notwithstanding, with the inflation increases, starting at 1960 decade, a new tariff regulation was implemented. The decree 54.936 of 1964 still had a tariff regulation investment cost-based, but with an inflation adjustment.

According to Branco (1975), the Code was the great target of the agents who were against the state intervention on the electric energy sector, to make it responsible for the fall of the investments in the sector. Among these agents were not only foreign concessionaries, but also electric energy national companies, and the industry representatives in the country, who claimed a total reformulation on the actual principles in the document. It stands out that the main point in common in the criticism was the historical cost which, for them, was unacceptable in a country with a remarkable monetary instability.

Thus, till the beginning of the 50's, direct public investment was not the most important in the sector. Nevertheless, from that date, to ensure the offering capacity, the public sector started building its own generating

[3]Código das Águas is the way the law n° 24.643/34 became known. Such name refers to the predominance of hydro power in Brazilian electricity generation process. In 1934, the hydro-power installed capacity proportion related to total capacity was 80%, says Lima (1995). In 2001, hydro-power represented 87.3% from total installed capacity and 88. 7% from total produced.

plants.[4]

State expansion in the sector consolidated during the Military Regime, when private companies were incorporated into the state's power. In a detailed manner, about 50% of the generation and transmission was slowly incorporated by the state companies and the other half was incorporated by the federation states. However, the distribution and commercialization sectors became concentrated in a state level.

It's worth noticing why this centralized and concentrated structure in the electric energy sector kept itself for very long period. We know that the sector development in Brazil was based on the continental dimensions of the country and its great hydroelectric potential. In this way, scale economies, because of the construction of great plants, originated a transmission interlinked system, with public service companies, sharing the costs related to transmission lines. In that context, the best alternative was, in fact, the cooperation among the electric energy companies, and the creation of regional/state monopolies of distribution was the first step to the implementation of such centralized model.

Ferreira (2000) says that one problem in this centralized context was, in the presence of guaranteed returns, a considerable efficiency loss:

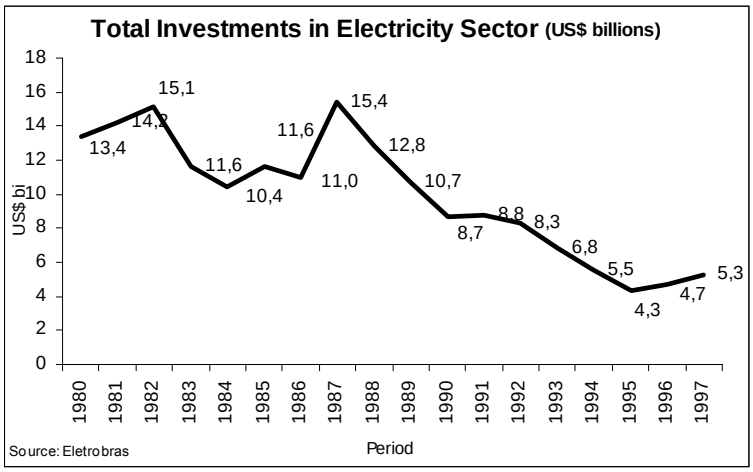
> "In a problem shared by other state companies of other sectors, public service of electricity companies didn't have the control over the operational costs, basically because they didn't have motivation to understand (and, thus, they didn't have knowledge) about operational cash flows even in the more basic levels. Such ignorance was specially harmful if we consider the distinctive nature of the investments, of the maintenance costs, and of the returns involved in the different generation activities, transmission, and electric energy distribution".

Just before starting the privatization process, in 1995, distribution and commercialization by the state companies represented 90% of the total electric energy consumed in Brazil. Each state had its own distribution and dealer company that distributed and negotiated and, some states, had more than one.

The restructuring of the electric sector began in the 90's. A collapse of the international financing and fiscal crisis that took place in the 80's only pronounced the need of changing. The graph below shows the detailed report of the sum of the total investments in the sector from the 80's. From 1995, a reversion took place in the reduction tendency of the investments.

[4] In the beginning of the 50's, because of the lack of private investment conditions to cover the accumulated necessity of expansion of the electric sector, political and economic tendency in that time was the governmental effort concentration. With the creation of Eletrobrás (Brazilian Electric Centrals), in 1961, there was a developmental process (in the 60's and 70's) based on state initiatives under financing of national and international organizations.

GRAPH 1



In that way, from the beginning of the 90's, there was a search for another operational model for the electric sector. In 1993, as mentioned before, the first step for the sector reform was made, with the approval of the Law 8631 which eliminated the geographical equalization of the taxes and 10% of minimum return over assets. The restructuring, in fact, took place from 1995, with the beginning of the privatization of the electric energy companies.[5]

According to Laffont (2005), the reference point of any theory about privatization must be the Sappington-Stiglitz's irrelevance result, which shows that, even with the asymmetrical information, the company property is not relevant, when it has to do with a benevolent government and without restrictions to contract. Thus, any result obtained by a private company could be replicated by a properly designed public company. To consolidate the privatization, the hypothesis of complete contracts and/or benevolence must be loosen.

An example of a model that accepts that privatization can be useful to the society is the Schmidt's (1996). The author considers that privatization is an agreement to amplify the company information and, with that, giving to it an informational income in the future. In this way, having the correct incentives to the investment through potential informational income, privatization can increase efficiency.

Beyond that theory prediction, privatization in Brazil reflected the substitution of a development model based on the substitution of importation, guided by state investment, by a model of market orientation with emphasis on the efficiency. In the 80's and 90's, other Latin America countries, such as Chile, Argentina and Mexico went through a similar process of privatization. However, it was the economic crisis of the 80's that made privatization possible in Brazil. Such crisis also determined the establishment of the privatization process in the country while other aspects of the reform were more gradual, specially the competition implementation. For example, the ANEEL establishment took place only one year after the first auction.

Coppers & Lybrand[6], the American Consulting that helped the government in the reform planning stated that,

[5] Nevertheless, it's important to point out that the restructuring processes of the economic sectors and privatization must not be confusing. Restructurating changes commercial arrangement of the sector, agent's number, performed functions and the relationship between them. In its turn, privatization changed the control from the governmental scope to the private area. Both processes didn't need to happen simultaneously.

[6] Consulting that won the bidding process opened by Mines and Energy Ministry in 1996, for the realization of the restructuring project of the electric energy sector in Brazil.

one of the main objectives, was to ensure the expansion of the generation capacity, attracting investments from the private sector, in order to increase the efficiency and reduce the expenses and the national debt. Besides that, the new model should be decentralized, functional and effective.

The paradigm followed by the consulting mentioned before in its reform proposal was that of England, which established principles that seek to ensure and encourage competition in the generation and commercialization sectors, fulfilling the following features:

(i) Deverticalization - separation between generation, transmission, distribution in the production chain and introduction of a fourth sector, the commercialization;

(ii) Creation of a spot market to trade the generated energy;

(iii) Open access to the transmission network for generators and consumers;

(iv) Creation of an independent operator to administrate the generation and transmission system in large scale;

(v) Energy negotiation made through the offer of prices - auctions;

(vi) Freedom of choice to the final consumers; and

(vii) Creation of a regulatory agency.

From 1991 to 1994, 33 companies were privatized in Brazil, in many economic sectors.[7]

Thus, with the good performance of these privatized companies and the program of inflationary stabilization of 1994, there was support to the expansion of the privatization and it, then, came to the electric energy sector. We can count four factors that contributed to the public utility companies, as the electric energy ones, to make part of the agenda, which are:

(i) The constitutional public monopoly over the infrastructure was abolished by a constitutional amendment;

(ii) A constitutional amendment eliminated the differentiation between domestic and foreign capital. This allowed the foreign companies to compete for public concessions;[8]

(iii) According to the article 175 of the Federal Constitution of 1988, the public authority is responsible for providing the public services, directly or indirectly under the regime of concessions or permissions. The fundamental conditions of the concession regime of the public services would be established by the Law No. 8987/95 (Concession Law). Such legislation, by defining the basic conditions of entry, exit and operation in the infrastructure sector, contributed to the reduction of the private agents' uncertainties;

(iv) States got the financing of their debts by the Union, conditioned to a certain level of amortization. For many states, the only way to amortize one fraction of their debts was the sale of assets. Besides that, Brazilian National Bank of Economic and Social Development (BNDES) launched a special program to promote the state privatization, stipulating loans to the sale of the parts of their state companies.

[7] Many of those companies were from the metallurgic, petrochemical and fertilizing sectors.

[8] Constitutional Amendment No. 6/95 eliminated the article 171 of the Federal Constitution, which allowed a special treatment to the Brazilian companies of national capital.

TABLE 1					
Privatized Generation Companies					
Company	State	Year Privatization	Auction Revenue U$MM	Transfered Debt	Result
Cachoeira Dourada	GO	1997	714	140	854
Gerasul	RS	1998	883.5	-	883.5
Tietê	SP	1999	472	668	1,140
Paranapanema	SP	1999	682	482	1,164
Total of Auctions Revenues			2,751.5		
TOTAL Revenues Generation+Distribution			21,869.2		

Source: BNDES

TABLE 2					
Privatized Distribution Companies					
Company	State	Year Privatization	Auction Revenue US$MM	Transfered Debt	Result
Escelsa	ES	1995	385.7	-	385.7
Light (Federal)	RJ	1995	2,270	-	2,270
CERJ	RJ	1996	587	364	951
COELBA	BA	1997	1,598	213	1,811
RGE	RS	1997	1,486	149	1,635
AES SUL	RS	1997	1,372	64	1,436
CPFL	SP	1997	2,731	102	2,833
Enersul	MS	1997	565	218	783
Cemat	MT	1997	353	461	814
Energipe	SE	1997	520	40	560
Cosern	RN	1997	606	112	718
Coelce	CE	1998	868	378	1,246
Metropolitana	SP	1998	1,777	1,241	3,018
Bandeirantes	SP	1998	860	375	1,235
Elektro	SP	1998	1,273	428	1,701
Celpa	PA	1998	388	116	504
Celpe	PE	2000	1,004	131	1,135
Cemar	MA	2000	289	158	447
Saelpa	PA	2000	185	-	185
Total of Auctions Revenues			19,117.7		

Source: BNDES

The first privatizations were accomplished in an 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 institution,

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.[9]

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 demand 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 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.

[9] 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.

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.

After the 2001 Crisis, in 2004, Brazil started with a new model in the electric energy sector. The basis of this new model, as pointed by the Brazilian Ministry of Mines and Energy, was the four topics:

(i) Reasonability of tariffs, that is a very important factor in the social inclusion of the electricity;

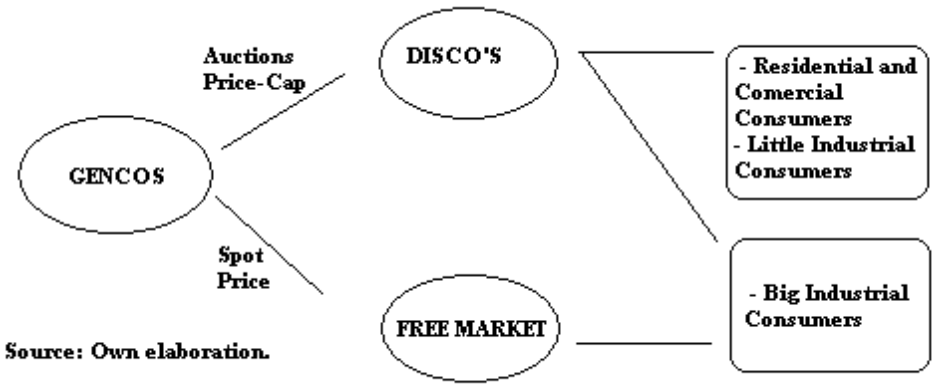
(ii) Guarantee the supply adequacy in the system;

(iii) Ensure the stability of the regulation law in the system, to attract more investments to the sector;

(iv) Promote the social inclusion through the energy sector, specially by the implementation of universalization programs.

Electric energy supply is made by generators. In the Brazilian new 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.

GRAPH 2



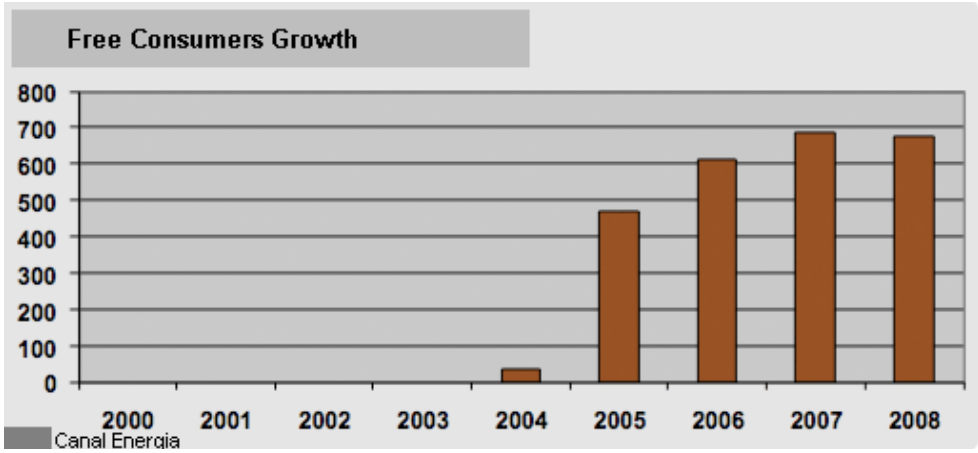
Source: Own elaboration.

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" electricity, 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.

GRAPH 3



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 – Conexion cost: rates that seek to cover expenses with conexion and establishment of measuring systems;

(iv) Technical losses: loss calculation in the energy transmission.

However, there are 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[10], in general great industrial consumers of the intensive sectors in the use of electric energy, invest,

[10]Presently, companies that invest in energy generation for its own consumption have 31 hydro power plants, 9 thermo power plants

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 uncertainness 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 hydro power plant 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 on 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 authors estimated price elasticity and long term income with fixed coefficients to the industrial and residential sectors. As results, they found, for the residential sector, -0.44 and 1.95 to the elasticities price and income, respectively. And for the industrial sector, 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

and 9 small hydro power centrals (PCHs). Abiape has great Brazilian companies as partners, like Vale, CSN Energy, Gerdau and Votorantim.

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 time 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 distributer 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 asymmetry 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 electricity 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 Electric 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 allows a flexible way to model their short-run dynamics.[11] 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:

$$d_t = \alpha_0 + \alpha_1 z_t + \epsilon_t, \quad \epsilon_t \sim NID\ (0, \sigma_\epsilon^2) \tag{1}$$

where d_t and z_t are respectively electricity demand and its determinants, t $(t = 1, ..., n,)$, α_0 are α_1 fixed scalars and ϵ_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 ϵ_{t-1} by its estimate, $\hat{\epsilon}_{t-1}$, we run the second equation, the TVP-ECM *measurement equation*, which is given by:

[11] 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 ECM reflects a dynamic self-correcting process of demand behavior towards its long-run steady state. In addition, ECMs can avoid the occurrence of spurious regression and multicollinearity problems, which may otherwise affect the reliability and accuracy of the econometric analyses. Our model allows a flexible way to deal with this ECM model, trying to get some dynamics in their coefficients with the State Space model.

$$\Delta d_t = \beta_{1t}\epsilon_{t-1} + \sum_{i=1}^{p}\gamma_{it}\Delta d_{t-i} + \sum_{i=1}^{p}\lambda_{it}\Delta z_{t-i} + \ e_t, \quad e_t \ \sim NID\ (0, \sigma_e^2) \tag{2}$$

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

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

$$\beta_t = \phi + \Phi\beta_{t-1} + u_t, \quad u_t \ \sim NID\ (0, \Sigma) \tag{3}$$

where $\beta_t = (\beta_{1t}, \gamma_{1,t}, ..., \gamma_{p,t}, \lambda_{1,t}, ..., \lambda_{p,t})\prime$ is the $2p + 1 \times 1$ state vector in time t ϕ is a $2p \times 1$ vector, Φ 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, Σ.

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), which 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[12]. Basically, there are three alternative procedures 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 used 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 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 the estimation, we perform a Kalman filter (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.[13]

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

1. Johansen VECM-Cointegration approach:

[12] This is the best way to incorporate all the necessary information about the data in a specification.

[13] Durbin and Koopman (2001) have a very good presentation of state space models setting and estimation.

(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.

Our steps will culminate in the following estimate pair of equations:

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

$$lres_t = \alpha_0 + \ \alpha_1 ltres_t + \ \alpha_2 lpib_t + \ \alpha_3 lipaelm_t + \alpha_4 \lg lp_t + \epsilon_t, \tag{4}$$

where *Lres* is the log of residential electric energy demand, *Ltres* is the log of residential tariff, *Lpib* is the log of GDP, *Lipaelm* is the log of appliances price index, *Lglp* is the log of liquefied petroleum gas (LPG) barrels and ϵ_t is an error.

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

$$\Delta lres_t = \beta_{1t} \ \epsilon_{t-1} + \sum_{i=1}^{p} \gamma_{it} \Delta lres_{t-i} + \sum_{i=1}^{p} \lambda_{it} \Delta ltres_{t-i} + \sum_{i=1}^{p} \phi_{it} \Delta lpib_{t-i} + \sum_{i=1}^{p} \varphi_{it} \Delta lipaelm_{t-i} + \sum_{i=1}^{p} \eta_{it} \Delta glp_{t-i} + \ e_t, \tag{5}$$

where $\Delta Lres$ is the first difference of log of residential electric energy demand, $\Delta Ltres$ is the first difference of log of residential tariff, $\Delta Lpib$ is the first difference of log of GDP, $\Delta Lipaelm$ is the first difference of log of appliances price index, $\Delta Lglp$ is the first difference of log of liquefied petroleum gas (LPG) barrels and ϵ_{t-1} is the lag of the 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.

$$lind_t = \alpha_0 + \ \alpha_1 ltind_t + \ \alpha_2 lproindsa_t + \ \alpha_3 lipaq_t + \alpha_4 lipac_t + \epsilon_t, \tag{6}$$

where *Lind* is the log of the industrial electricity demand, *Ltind* is the log of the industrial tariff, *Lproindsa* is the log of Industrial Production, *Lipaq* is the log of Machines and Equipments price index, *Lipac* is the log of Oil price index and ϵ_t is an error.

$$\Delta lind_t = \beta_{1t} \ \epsilon_{t-1} + \sum_{i=1}^{p} \gamma_{it} \Delta lind_{t-i} + \sum_{i=1}^{p} \lambda_{it} \Delta ltind_{t-i} + \sum_{i=1}^{p} \phi_{it} \Delta lproindsa_{t-i} + \sum_{i=1}^{p} \varphi_{it} \Delta lipaq_{t-i} + \sum_{i=1}^{p} \eta_{it} \Delta lipac_{t-i} + \ e_t, \tag{7}$$

where $\Delta Lind$ is the first difference of the log of industrial electric energy demand, $\Delta Ltind$ is the first difference of log of industrial tariff, $\Delta Lproindsa$ is the first difference of log of Industrial Production, $\Delta Lipaq$ is the first

difference of log of Machines and Equipments price index, $\Delta Lipac$ is the first difference of log of Oil price index and ϵ_{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, in observations, at least double of others Brazilian applications. But previous articles for Brazilian electricity 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 3, firstly, we have the variables for the residential demand and below, the variables for industrial demand estimation.

TABLE 3

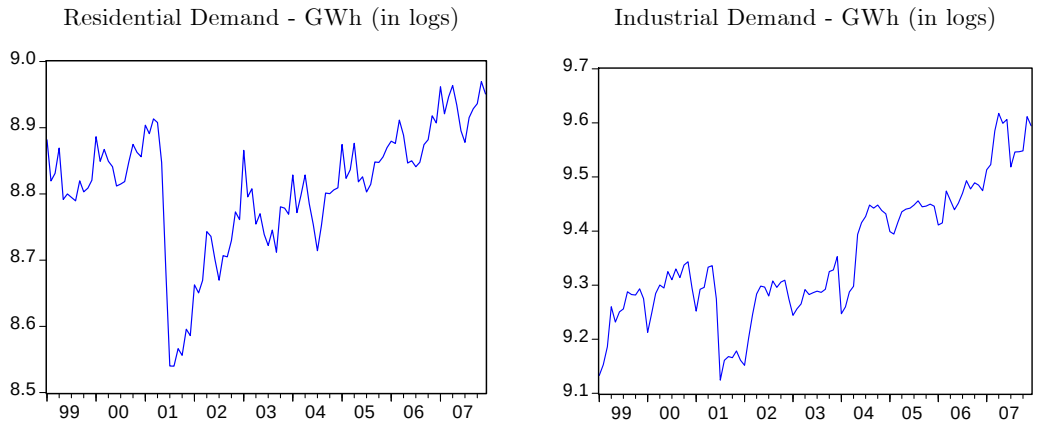
Variables and Sources

Variable	Name	Source
Residential Demand (MWh)	Lres	ANEEL
Residential Tariff (R$/MWh)	Ltres	ANEEL
GDP (R$)	Lpib	Notini & Issler (2008)
PPI - Appliances	Lipaelm	Ipeadata
LPG gas (Thousands of barrels)[14]	Lglp	Banco Central
Consumer Loan Operations (R$)	Lcredfis	Ipeadata
Median Temperature (^{o}C)	Ltemp	INMET
Industrial Demand (MWh)	Lind	ANEEL
Industrial Tariff (R$/MWh)	Ltind	ANEEL
Industrial Production (R$)	Lproind	IBGE
PPI - Machines and Equipments	Lipaq	Ipeadata
PPI - Oil	Lipac	Ipeadata
Corporate Loan Operations (R$)	Lcredind	Ipeadata

Graph 4 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.

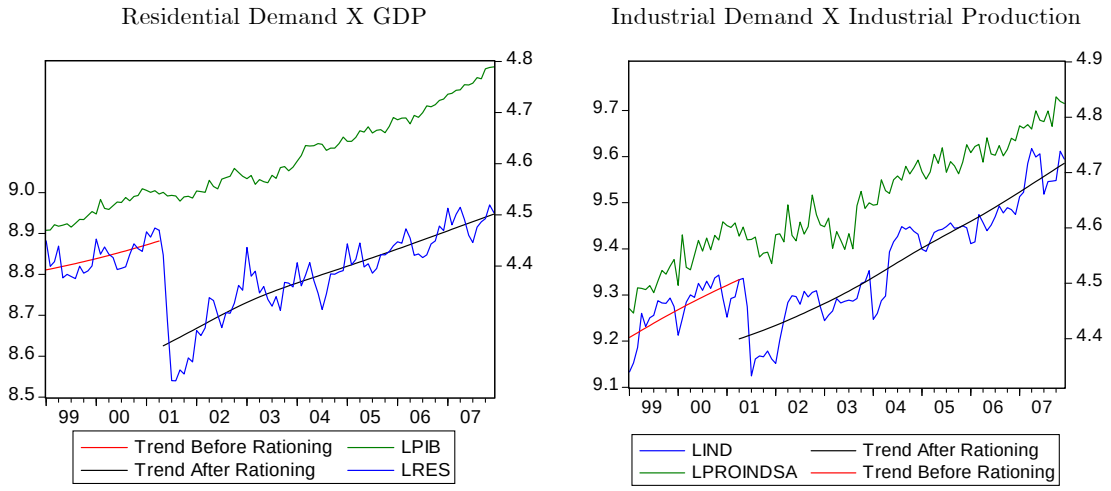
[14] In spite of the knowledge that the LGP data series that we have captures all the demanded LGP in Brazil, not only in domestic use, we choose to continue with the inclusion of this variable in our model as a substitute for electricity in residential class. We did it for two main reasons: firstly, National Agency of Petroleum (ANP) says that residential use corresponds for the biggest portion of LGP sales in Brazil at the resale points. The second reason is that we estimate our model without the series and we didn't find a significant difference in our results.

GRAPH 4



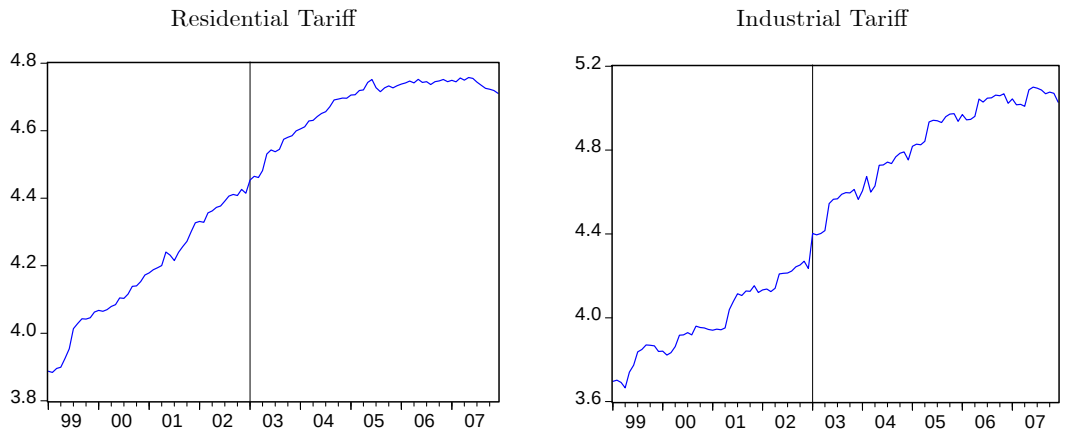
In Graph 5 we try to see if there is a same trend between the income series and the electricity consumption series in Brazil. For residential and industrial cases, as we expect, income and electricity demand have a strong correlation.

GRAPH 5



Another variable that is very important for the electricity demand is the electricity price, or the tariff. Brazilian electricity tariff had a characteristic that residential consumers usually pay more than industrial consumers. Graph 6 shows the log of tariff for these 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.

GRAPH 6



Unit root tests[15] 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, in other words, if the 2001 crisis was a structural break in the Brazilian demand. After testing this behaviour change, we can allow income and tariff elasticities to 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[16]. 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[17] indicates the existence of two common stochastic trends between residential demand and its determinants. The estimated long run relationship was significant for all coefficients

[15] The unit root tests are in the appendix section.

[16] Espey & Espey (2004) say that postulate some lag structure in electricity demand estimation has been a common practice in the literature, to reflect the fact that some adjustments in the usage take time.

[17] 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. Complete results for cointegration tests are in the appendix section.

but the constant (standard errors in brackets):

$$lres_t = \underset{(3.233)}{0.95} - \underset{(0.267)}{0.97}\, ltres_t + \underset{(0.710)}{1.76}\, lpib_t + \underset{(0.298)}{0.93}\, lipaelm_t + \epsilon_t \tag{8}$$

These coefficient estimates suggest that:

- the long run elasticities of the residential electric demand with respect to PPI and the GDP 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 the quantity consumed. The residential consumption is elastic to income: 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 prices.

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.

TABLE 4

Error Correction Model for Residential Demand

Variables	Coefficients	Standard-Errors	T-Stats
CointEq1	-0.098	(0.04307)	[-2.28099]
CointEq2	0.400	(0.06807)	[5.87778]
D(Lres(-1))	0.038	(0.10181)	[0.37639]
D(Lres(-2))	0.206	(0.09952)	[2.07067]
D(Lglp(-1))	-0.073	(0.07954)	[-0.92254]
D(Lglp(-2))	0.072	(0.08350)	[0.87284]
D(Lipaelm(-1))	-0.165	(0.24092)	[-0.68685]
D(Lipaelm(-2))	-0.245	(0.19979)	[-1.22924]
D(Lpib(-1))	1.068	(0.45802)	[2.33226]
D(Lpib(-2))	-0.970	(0.47686)	[-2.03594]
D(Ltres(-1))	-0.210	(0.27831)	[-0.75576]
D(Ltres(-2))	-0.461	(0.27751)	[-1.66156]
Ltemp	0.147	(0.02425)	[6.08996]
Adj R-squared	0.352707		
Sums q. Resid.	0.095892		
Log Likelihood	1448.23		
Schwarz IC	-3.584414		

Table 4 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%;

$$\begin{aligned} lind_t &= \underset{(1.307)}{1.93} - \underset{(0.133)}{0.24}\ ltind_t + \underset{(0.309)}{1.32}\ lproindsa_t + \underset{(0.333)}{0.51}\ lipaq_t + \epsilon_t \end{aligned} \tag{9}$$

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 the consumed quantity. It is important to note that industrial consumers are less sensitive to tariff variations compared to the residential consumers. This result is expected because the industrial consumers can use self production plants and have different access to energy market than residential consumers, independently of the tariffs.

The industrial consumption is elastic to income, with a 1% variation of the income causing 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 5 shows the estimated Error Correction Model for the industrial sector. With the optimal lags, we can see that the cointegrating regressions terms (CointEq1 and CointEq2) don't 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 energy consumption. Income does not seem to affect the consumption in the short run, but tariff-elasticity is significantly negative in the short term.[18]

[18] The less robust results of the industrial electric energy modelling related to the residential demand may be explained by several reasons. First, in the last decade, industrial demand have had many changes, as such the rise of the free market. Then, its behaviour may be explained more by the trends in factors affecting intensity than by how consumers react to changes in price or income. Another possible reason is industrial production being a poor proxy to the sector income. However, the Brazilian previous studies also used this variable and we maintain to allow some comparison between our results and the related literature.

TABLE 5

Error Correction Model for Industrial Demand

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

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

Residential 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 6.

The classic test of structural break is attributed to Chow (1960). This test consists into 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, which can be seen as a consequence of Rationing Crisis occurred that year.

TABLE 6

Chow Structural Break Test - Residential

H0: there's no break /at specific breakpoints

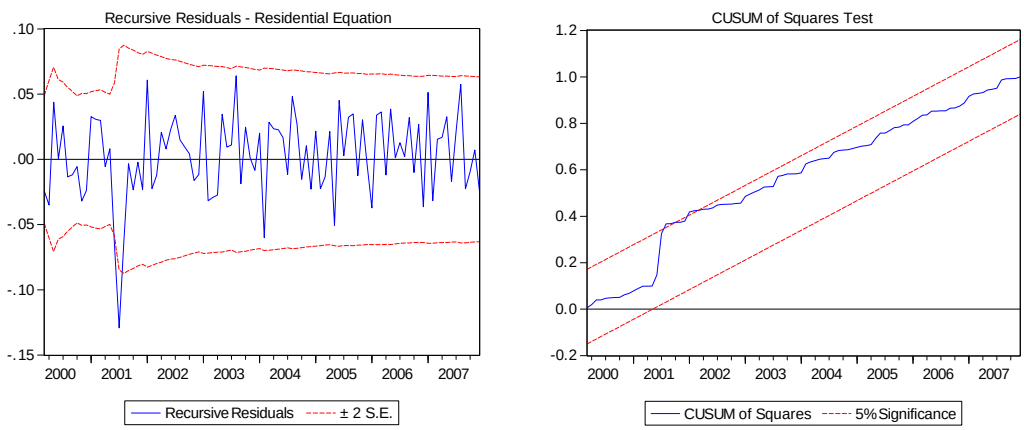
Statistics	Value	Prob.	P-value
F-Statistic (2001 M08)	2.6611	Prob. F(11,82)	0.0057
Log Likelihood ratio	31.7470	Prob. Chi-Square (11)	0.0008
Wald Statistic	29.2721	Prob. Chi-square (11)	0.0021

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, in graph 7, 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.

Also in graph 7, 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.

GRAPH 7



Industrial The same procedure is done for the 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 indicates that elasticities could vary over time and may depend of other determinants. This could be tested as did before, using the State Space Model.

TABLE 7

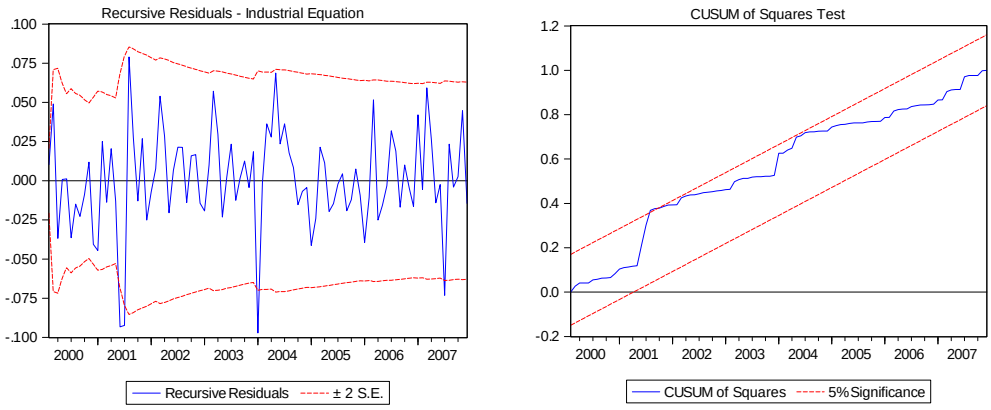
Chow Structural Break Test - Industrial

H0: there's no break /at specific breakpoints

Statistics	Value	Prob.	P-value
F-Statistic (2001 M08)	1.8773	Prob. F(11,82)	0.0661
Log Likelihood ratio	18.6551	Prob. Chi-Square (11)	0.0283
Wald Statistic	16.8964	Prob. Chi-square (11)	0.0504

The limitations of Chow Test lead us to the use of CUSUM test. This test suggests 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 energy demand in this period. These results argue in favor of using a time varying VECM to do a correct specification of the industrial demand.

GRAPH 8



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 this 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 8 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 equation and

the state equation have an error variance specification, because we assumed that they are not deterministic. And we allow 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 an 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 8

State Space Model Equations - Residential

Estimated Observable Equation:

dlres = c(1)*ltemp + c(2)*dlipaelm(-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)*dlcredfis(-1) + [var = exp(c(8))]

sv2 =c(10)*sv2(-1)+c(11)*dlcredfis(-1) + [var = exp(c(12))]

sv3 = c(15)*sv3(-1) + [var = exp(c(14))]

sv4 = c(17)*sv4(-1) + [var = exp(c(16))]

Table 9 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.

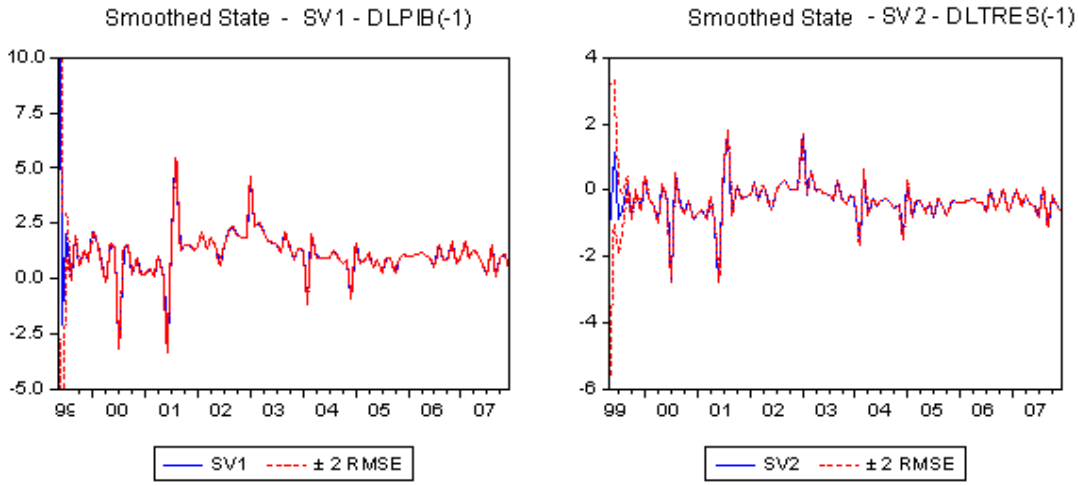
TABLE 9

Short-Run Dynamics of Estimation - Residential

	Final State	Root MSE	z-Statistic	Prob.
SV1	0.90809	1.09E-05	83657.8	0.000
SV2	-0.33184	1.91E-05	-17381.5	0.000
SV3	0.00046	0.162845	0.00287	0.9977
SV4	0.00044	0.389678	0.00114	0.9991
Log Likelihood	202.0321			
Akaike IC	-3.5583			
Schwarz IC	-3.1260			

In graph 9, we see the plot of smoothed time-varying elasticities along our entire sample. The first graph shows 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.

GRAPH 9



In table 11 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 an expressive wideness.

TABLE 11

Residential States Estimates - Descriptive Stats

	SV1 - Dlpib(-1)	SV2 - Dltres(-1)
Mean	1.082922	-0.324919
Median	1.043494	-0.330754
Maximum	5.478506	1.813328
Mininum	-3.398079	-2.797540
Std. Dev.	1.063266	0.613259
Skewness	-0.423118	-0.532405
Kurtosis	10.56099	8.697300
Jarque-Bera	243.5981	141.3708
Prob.	0.000000	0.000000

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 correction terms to vary over time. These coefficients were modeled 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 12

State Space Model Equations - Industrial

Estimated Observable Equation:
dlind = sv1*dlproindsa(-1) + sv2*dltind(-1) + c(1)*dltind(-2)+ c(2)*dlproindsa(-2)+
c(3)*dlipac(-1)+ c(4)*dlipaq(-1)+ sv3*cointe_ind1+ sv4*cointe_ind2+ [var = exp(c(6))]
Estimated State Equations:
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))]

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 10

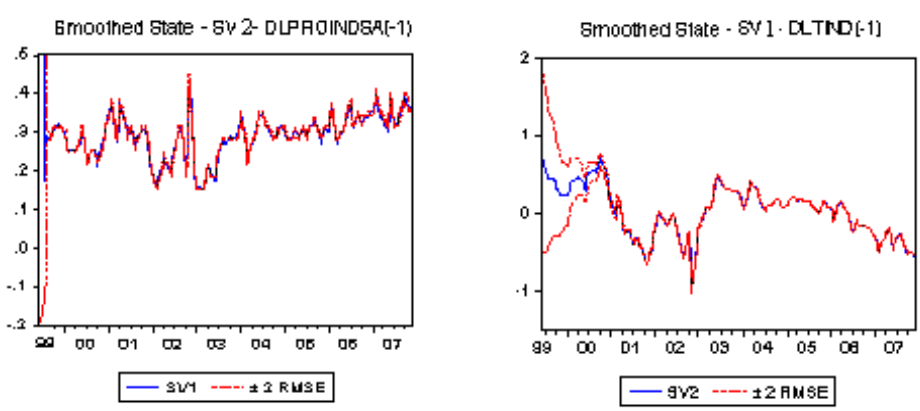


TABLE 13

Short-Run Dynamics of Estimation - Industrial

	Final State	Root MSE	z-Statistic	Prob.
SV1	0.40554	3.73E-06	108828.5	0.000
SV2	-0.68150	8.67e-05	-7857.373	0.000
SV3	-0.00002	0.201752	-0.001416	0.9989
SV4	2.00E-10	6.61E-05	3.02E-06	1.000
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 14, we test which determinants affect the dynamics of income and tariff elasticities (with p-values between brackets). 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 electricity 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 14

Results of State Space Estimation - Residential

	Income Elasticity	Price Elasticity
Persistence	-0.19	-0.48
	(0.36)	(0.02)
Credit	-51.61	-30.47
	(0.12)	(0.00)
Final State	0.91	-0.33
	(0.00)	(0.00)

Industrial The income-elasticity industrial demand is not statistically dependent on 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 exogenous shock effect over the industrial consumers' sensitivity persists for approximately 6 months.

TABLE 15

Results of State Space Estimation - Industrial*

	Income Elasticity	Price Elasticity
Persistence	-0.0027	0.85
	(0.99)	(0.02)
Credit	0.75	-8.52
	(0.95)	(0.24)
Volatility	-205.49	-8.52
	(0.82)	(0.64)
Final State	0.41	-0.68
	(0.00)	(0.00)

*p-value between brackets

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.

Our results are in line with Abrate et. al (2005) conclusions. The authors say that there is a substantial difference between short run and long run elasticity. In the short run, given the lack of good substitutes for electricity, consumers have limited options for responding to changes in price, and elasticity is usually assumed to be relatively low. In the long run, progress in technology and the possibility of switching to other kinds of energy will offer more opportunities for price responsiveness, and elasticity is usually estimated in a more elastic range.

However, estimating the demand without considering the 2001 Crisis can generate problems in the properties of estimative. Thus, a structural break test was made and we provided 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 Electricity Demand.

TABLE 16

Elasticities Estimates and Comparisons

	Y-Long-run	Y-Short-run	P-Long-Run	P-Short-run
Residential (Fixed)	1.76	1.06	-0.96	-0.46
Industrial (Fixed)	1.31	0.19	-0.24	-0.18
Residential (Dynamics -Final State)		0.90		-0.33
Industrial (Dynamics - Final State)		0.40		-0.68
Chang (2003)				
Residential	1.95		-0.44	
Industrial	1.29		-0.25	
Espey & Espey (2004)				
Residential	0.97	0.28	-0.85	-0.35
Porter (2004)				
Residential			-0.94	
Industrial			-0.55	
Modiano (1984)				
Residential	1.13	0.33	-0.40	-0.11
Industrial	1.36	0.50	-0.45	-0.22

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 it described a decreasing pattern and adjust to long-run inelastic value. Analyzing the sensivity 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 in the sensivity 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, even though the industrial demand tariff-elasticity has a relevant dependence of past value that implies a half-live of 6 months.

10 Conclusion

This paper updates the modeling 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 misaligned with the current scenario.

Our findings suggest that Brazilian residential consumers are more sensible to price and to income than the 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.

Also, it's important to note that the result of smaller short run elasticities (elasticities more inelastics) in the industrial sector compared to the long run may be a consequence of the huge increase in the self-production that occurred recently in the Brazilian industrial sector, because the companies that are still in the system probably have a smaller capability in switch the fuel or option to turn off the electricity. On the other hand, the result of smaller elasticities in the residential sector in the short run compared to long run may be a consequence of the substitution of old appliances for new energy efficient products.

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 then unity).

The implications of our results - consequence of a better specification of electric energy with the TVP-ECM model - are important, because policy-makers should consider the possibility of varying responses of elasticities to its determinants. For example, income elasticities correctly estimated are essential to planning needs investments in power generation, while price elasticities are very important to regulation of electricity sector, where incentives are made within a tariff basis. Policy-makers should attempt to the varying price elasticities in the implementation of energy efficiency programs. If increasing prices motivate investments in energy efficiency, then the impact of energy efficiency might be greater in periods most elastic (i.e., those with the lowest negative price elasticities). In these moments, changes in price could lead to greater changes in energy efficiency. Any estimates of the effect of energy-efficiency programs will be impacted by price elasticity, and if the elasticity varies significantly over time, the estimates of the impacts will differ accordingly. These are only a few examples of the importance of considering this electricity demand behaviour, which we have observed in the Brazilian market in this paper.

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11 Appendix

In this section we present complete results (tables and graphs) that are ommited in the results section without losses.

TABLE 17

Unit Root Test (ADF)

Variable	Terms Included	T Stats*	p-value
Residential Demand (MWh)	Constant	-2.08 (-2.89)	0.250
Residential Tariff (R$/MWh)	Constant and Trend	1.10 (-3.45)	0.999
GDP (R$)	Constant and Trend	-2.09 (-3.45)	0.543
PPI - Appliances	Constant	-1.15 (-2.89)	0.690
LPG gas (Thousands of barrels)	Constant	-1.10 (-2.89)	0.711
Consumer Loan Operations (R$)	Constant and Trend	-1.65 (-3.45)	0.765
Median Temperature (^{o}C)	Constant	-7.64 (-2.89)	0.000
Industrial Demand (MWh)	Constant and Trend	-2.73 (-3.45)	0.226
Industrial Tariff (R$/MWh)	Constant	-1.16 (-2.89)	0.685
Industrial Production (R$)	Constant	-0.86 (-2.89)	0.806
PPI - Machines and Equipments	Constant and Trend	-1.02 (-3.45)	0.934
PPI - Oil	Constant and Trend	-2.50 (-3.45)	0.325
Corporate Loan Operations (R$)	Constant	-1.58 (-2.89)	0.999

*Rejection of hypothesis at 5% of significance.

Residential The estimation method presented in Section 6, was applied to the data. Following the estimation procedure described earlier, first we applied the Johansen cointegration test. The results are in Table 18. The optimal number of lags was selected by the Bayesian Information Criteria (BIC), for a matter of parsimoniousness: 3 lags were selected for the estimated residential VAR.

TABLE 18

Johansen Cointegration Test - Residential

Series: Lres, Lglp, Lipaelm, Lpib,Ltres

Possibles CE's	Eigenvalue	Trace Stats	5% Critical Value	Prob. **
None*	0.401391	125.3693	76.97277	0.0000
At most 1*	0.299604	72.00204	54.07904	0.0006
At most 2	0.193875	34.96663	35.19275	0.0529
At most 3	0.088648	12.55290	20.26184	0.4006

Tests indicates 2 cointegrating vectors at 5% of significance.

* rejection of hypothesis at 5% of significance.

** MacKinnon-Haug-Michelis (1999) p-values.

Based on these tests, therefore, it is not possible to reject the existence of a long-run relationship (cointegration) between the residential electricity demand and the gas consumption, the electric appliances PPI, the GNP and the residential tariff.

All long-run coefficients reported in Table 19 present the *a priori* expected signs and are statistically significant at the 5% level.

TABLE 19

Cointegrating Equations - Residential

Normalized Coefficients (Standard-errors) Log Likelihood:1247.96

LRES	LGLP	LIPAELM	LPIB	LTRES	C
1.0000	0.0000	-0.9287	-1.7657	0.9660	-0.9481
		(0.298)	(0.710)	(0.267)	(3.232)
0.0000	1.0000	0.13807	-0.4020	0.1865	-4.9432
		(0.105)	(0.251)	(0.094)	(1.145)

In order to investigate the adequacy of the estimated empirical model, we used a Potmanteu test of residual serial correlation, in table 20 and found that the null of residual autocorrelation was rejected at the usual significance levels. In the same way, a normality test showed that the functional form of our model is correct. Finally, the results of a White test allowed us to reject the hypothesis of heteroscedastic residuals.

TABLE 20

Autocorrelation Test (Potmanteau) for Residential VECM

H0: no redisual autocorrelations up to lag h

Lags	Q - Stat	Prob.	Adj Q-Stat	Prob.	df
1	7.629	NA*	7.703	NA*	NA*
2	14.065	NA*	14.263	NA*	NA*
3	39.502	0.032	40.448	0.026	25
4	63.761	0.091	65.668	0.067	50

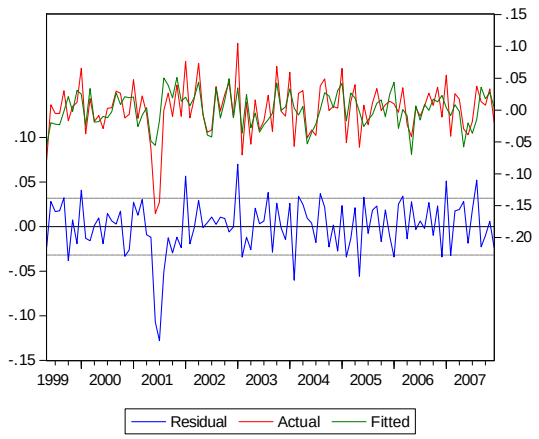
* The test is valid only for lags larger than the VAR lag order.

df is degrees of freedom for Chi-square distribution.

Graph 11 plots the residential demand equation which was used to run the State space model, that is, the observable equation in the TVP-ECM.

GRAPH 11

Residential ECM Equation Fitting



Industrial For industrial case, the first step was to apply the Johansen cointegration test to the industrial demand equation. The main results are in Table 21. We could not reject the hypothesis of the two cointegration vectors. Table 19 shows the two cointegration relationship between the variables.

TABLE 21

Johansen Cointegration Test - Industrial

Series: Lin, Lipac, Lipaq, Lproindsa,Ltind

Possibles CE's	Eigenvalue	Trace Stats	5% Critical Value	Prob. **
None*	0.228542	81.17640	76.97277	0.0230
At most 1*	0.191144	54.19117	54.07904	0.0489
At most 2	0.140716	32.12924	35.19275	0.1032
At most 3	0.089141	16.35707	20.26184	0.1584

Tests indicates 2 cointegrating vectors at 5% of significance.

* rejection of hypothesis at 5% of significance.

** MacKinnon-Haug-Michelis (1999) p-values.

TABLE 22

Cointegrating Equations - Industrial

Normalized Coefficients (Standard-errors) Log Likelihood:1321.25

LIND	LIPCA	LIPAQ	LPROINDSA	LTIND	C
1.0000	0.0000	-0.505696	-1.318462	0.241006	-1.931026
		(0.33278)	(0.30941)	(0.15338)	(1.30734)
0.0000	1.0000	-18.11590	22.54728	4.431007	-48.77769
		(8.60524)	(8.00093)	(3.96616)	(33.8060)

To test the adequacy of the estimated industrial model, we used a Potmanteu test of residual serial correlation, in table 23, and found that the null of residual autocorrelation was rejected at the usual significance levels.

TABLE 23

Autocorrelation Test (Potmanteau) for Industrial VECM

H0: no redisual autocorrelations up to lag h

Lags	Q -Stat	Prob.	Adj Q-Stat	Prob.	df
1	4.5293	NA*	4.57292	NA*	NA*
2	12.7373	NA*	12.9402	NA*	NA*
3	32.9989	0.131	33.7978	0.112	25
4	72.3295	0.021	74.6861	0.013	50

* The test is valid only for lags larger than the VAR lag order.

df is degrees of freedom for Chi-square distribution.

GRAPH 12

Industrial Equation Fitting

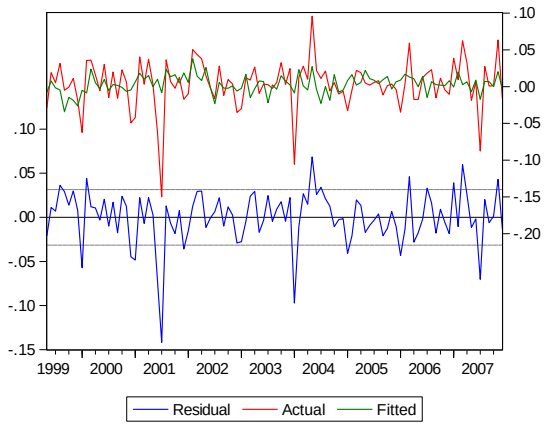


TABLE 24		
Industrial States Estimates - Descriptive Stats		
	SV1 - Dlproind(-1)	SV2 - Dltind(-1)
Mean	0.696184	0.029341
Median	0.297529	0.081067
Maximum	42.18019	0.752631
Mininum	0.152150	-1.020283
Std. Dev.	4.128030	0.341179
Skewness	9.997413	-0.343345
Kurtosis	100.9692	2.783040
Jarque-Bera	42907.03	2.225728
Prob.	0.000000	0.328617

CHAPTER 3

LNG Market Growth Worldwide and its Consequence to the Brazilian Energy System

PART 1

Price Convergence in the Global Natural Gas Market: The LNG Expansion*

Abstract

The natural gas market all over the world has been suffering tremendous changes for the past decades, not only because of market liberalization, but also due to industry restructuring and the strong expansion of the liquefied natural gas (LNG) market which brought the missing mechanism to achieve the integration of the regional markets or perhaps, the formation of a unique global market for natural gas. Previous related literature utilizes the Cointegration approach and the Kalman Filter to test the Law of One Price hypothesis within the global natural gas market. In this article, we use the Error Correction Model (ECM), the Time Varying Parameters Error Correction Model (TVP-ECM) and the Copula Analysis to examine the dependence between regional markets. Once cointegration relationship between the natural gas price series was verified, we estimated an ECM for each pair of prices and we ran a TVP-ECM using the Kalman Filter approach, as a way to model the short run dynamics of the pair of prices that presented some structural break. Afterwards, we modeled the short run dependence with the Copula Analysis. The joint use of Cointegration Technique with Copulas is the innovation of this article. Basically, the Copulas are cumulative distributions functions (CDF) quite suitable to deal with dependence in multivariate data. The application of Copulas was motivated by the fact that neither the VECM nor the TVP-ECM was enough to account for all the dependencies of the series in the short run. We use monthly data of natural gas prices in United States, Europe (United Kigdom, Belgium) and Japan, from 2001 to 2009. There is no statistical evidence of cointegration relationship between the Japanese market and the others, while the American and European markets present price convergence in the long run. The Copulas obtained for the pairs Zeebrugge-NBP and NBP-Henry Hub indicate that these markets move together more intensively during extreme periods. Finally, for the pair Zeebrugge-Henry Hub, the Copula fitted shows that there is no dependence at the extremes of the bivariate distribution. The natural gas relationships observed in our results are important to the public and private sectors optimal planning.

JEL Codes: L9, Q4, C22

Keywords: Natural Gas, Cointegration, Kalman Filter, Error Correction Model, Copula Analysis.

*Paper co-authored by Marcela Ferreira (Petrobras and EPGE/FGV) and Rafael Souza (ENCE).

1 Introduction

The natural gas is playing more and more an important role in the global energy scenario, and the LNG is a key factor in this growth trend. In this context, it is important to understand the price movements and relationships between natural gas regional markets to seek an optimal public and private sectors planning. The present paper is an attempt to model the behaviour of these prices in the main global markets, using time series analysis and the conditional copula approach to explain the dependence between them.[1]

Actually, the global natural gas market has been suffering a series of changes over the past decades, both institutional and economical. We can divide the world market into three large regional markets: North America, Europe and Asia/Pacific. Liberalization in the American market occurred during the 1970's, but deregulation only occurred in the second half of the 1980's, thereby allowing free access to the natural gas transportation network. In Continental Europe the opening of the market only occurred in 2003, almost 20 years after the breake up of the market monopoly. In Asia/Pacific the natural gas market is still regulated. Regulation is specifically related to oil prices through long term contracts.

The observed changes in the American and European markets allowed the development of spot markets on the two continents and also the surge of short term negotiation and non-dedicated contracts, which provoked the restructurization of the regional markets. Henry Hub in the United States, National Balancing Point (NBP) in the United Kingdom and Zeebrugge Hub in Belgium have become reference points in their respective markets, which have allowed total transparency.

International natural gas trade has increased a lot, mainly because of the development of the liquefied natural gas market (LNG). The LNG provides the missing link among regional markets as it makes it possible to have arbitrage between them. It results in the markets becoming more and more integrated.

During the past few years, because of the main changes in the natural gas industry, natural gas markets have been constantly the focus of study in literature. L'Hegaret, Siliverstovs and Hirschhausen (2005) utilize cointegration analysis to evaluate integration between markets in Europe, North America and Japan and conclude that the American market is not fully integrated whereas the European and Japanese markets are integrated, but are still indexed to oil prices. Within the three markets, the authors demonstrated that in the long run the American market will still be disconnected from the others.

Neumann and Hirschhausen (2006) analyze the convergence between North American and European markets using the Kalman Filter technique. Using daily data for the Henry Hub in the United States, and the NBP in the United Kingdom, the authors achieve empirical evidence that natural gas spot prices in the Atlantic Basin are converging towards the Law of One Price.

Other articles investigate convergence inside each specific market. For example, the American market has been analyzed in King and Cuc (1996), Serletis (1997) and Cuddington and Wang (2006). The European market was the subject of analysis in Asche, Osmundsen and Tveteras (2002) and Neumann, Siliverstovs and Hirschhausen (2005).

In this article, we start by making a quick analysis of the characteristics among each regional market (North America, Europe and Japan) and the LNG market. Next, we use the Cointegration technique to investigate price convergence between the three markets and once the long run convergence is verified, we estimate the Error Correction Models (ECM) for each pair of prices. For the prices which present a sign of some structural break, we apply the Kalman Filter to the Error Correction Model to analyze the price behavior in the short run. It is important to note that related studies on natural gas market integration have only used the Cointegration Technique

[1] With the time series analysis we seek to understand which markets have a relationship and if this dependence is constant over time. In turn, we apply the copula approach searching for how these prices move together in extreme periods. Both analysis together give a comprehension of the natural gas prices movement in the main global markets.

or the Kalman Filter Approach. This is the first paper to use a Time Varying Parameter Error Correction Model (TVP-ECM) to investigate this relation.

Another innovation of this paper is the joint use of Cointegration Technique with Copulas. Basically, as we will introduce in the upcoming sections, the Copulas are cumulative distributions functions (CDF) quite suitable to deal with dependence in multivariate data. Embrechts, Lindskog and McNeil (2001), Bouyé, Durrleman, Nikeghbali, Riboulet and Roncalli (2000), Embrechts, McNeil, Straumann (1999a), Embrechts, McNeil, Straumann (1999b), Mendes and Souza (2004) are good examples of applications in the financial literature. Its use in the financial literature has been growing since the late 1990's, mainly because of the perception that the framework widely used to deal with dependence relies on the Gaussian assumption. The decision to use Copulas was motivated by the fact that neither the VECM nor the TVP-ECM were enough to account for all the dependencies of the series in the short run, which will be explained in this paper. Besides that, more than quantifying correctly, the Copula Technique is suitable to model the "dependence structure" of the series.

The remainder of the article is structured as follows: in the next section we characterize each market. In section 3 we present the related literature. In section 4 we specify our model. Section 5 presents the estimation procedure and data details. Section 6 presents the results and section 7 presents the conclusion.

2 Regional Market Characteristics

2.1 The North American Market

The North American natural gas market deregulation occurred in the mid 1980's in Canada and the United States. It had great impact on the natural gas market once it provided the development of a spot market, hubs, a future market, a secondary market for transport capacity, etc. All these changes generated a huge increase not only in natural gas production, but also in its consumption within the region.

Due to competition that took place in the market, natural gas prices are now determined simply by supply and demand. In this new scenario, the main factors that can cause volatility in North American prices are: inventory fluctuation; abrupt demand variation and physical infrastructure damages due to climate (hurricanes, extreme weather, etc.), market expectations, and lack of flexibility in market balance (supply inline with demand).

However, we can verify the fast development of a short run market and, also, a spot market for natural gas in the Atlantic Basin because of LNG. It provides more flexibility to natural gas supply and makes the interconnection easier between North American and other markets, primarily the European market, thereby increasing the possibility of arbitrage between them.

2.2 The European Market

The United Kingdom is a unique market compared to other European countries because is a hugley important competitive market and spot market. In Continental Europe, this is not true: prices are still linked to oil prices through long term contracts. However, over the past few years this situation has been progressively changing and, nowadays, in the European continent, one can find contracts indexing the natural gas price to the spot price in the United Kingdom market (NBP). This link between the English and the continental markets is due to the openness of the "Interconnector", a pipeline which connects the United Kingdom to Zeebrugge in Belgium, that was constructed at the end of the 1990's. Zeebrugge is directly connected to the pipelines in Netherlands, Germany and France.

2.3 The Japanese Market

The Asian market is almost completely functioning on LNG. Japan alone imports approximately 50% of the whole world's production of LNG (L'Hegaret et al. 2004). Even so, the country does not have a vast pipeline network; on the other hand, it has the largest number of regasification terminals in the world. However, natural gas plays only minor role in the Japanese energy matrix (13% of total energy consumption), while oil represents 50% of it. Because of the great concern regarding supply warranty, this market is characterized by long term contracts in which prices are indexed to oil prices, thereby establishing a weak dependence on the spot market.

2.4 The LNG Market

The three markets that we have just analyzed are the main LNG consumers in the world nowadays: 70% of trade occurs on the Asia/Pacific region and the other 30% in the Atlantic Basin. The volume of LNG traded has increased considerably during the last decade, going from 108MMtpa in 2000 to an estimated 247MMtpa in 2010 (Wood Mackenzie, 2008).

Spot market transactions of LNG suffered a huge boom in the early 2000's. This growth brought the missing link to integration between the regions, mainly in the Atlantic Basin where arbitrage practices could already be seen (Neumann et Hirschhausen, 2006). Despite the global recession, the outlook for longterm gas demand remains high. So a huge expansion in import capacity in the United States and also in Europe is expected during the next few years, which will provide an even stronger interaction between the two regions. Nowadays, LNG trade represents 20% of the world's natural gas trade and it is expected that over the next few years, due to the development of new liquefaction and regasification plants, this will achieve 30%. The LNG supply of new projects will allow even greater gains in flexible supply .

3 Related Literature

There are some related articles that analyze the integration of natural gas regional markets and the price convergence between them. Now, we are going to review some of the main studies which utilized similar techniques to make these analysis.

Neumann and Hirschhausen (2006) use the Kalman Filter approach to investigate price dynamics between Europe and United States from 1999 to 2006. When utilizing daily spot prices for both natural gas and oil in their respective markets, they found clear evidence that prices are converging in the direction of the Law of One Price. However, when they deduce the effect of oil spot prices on natural gas prices and apply the Kalman Filter to the new series again, it seems that prices do not interact much.

L'Hegaret, Siliverstovs and Hirschhausen (2004) tests the degree of natural gas integration throughout Europe, North America and Japan, between the period of mid 1990's to 2002. The Principal Component Analysis and Cointegration procedures show a "high level of integration within the European/Japanese and North American markets and that the European/Japanese and the North American markets are connected to a much lesser extent" (L'Hegaret et al., 2004).

Neumann, Siliverstovs and Hirschhausen (2005) test whether the prices of natural gas in major European trading spots – United Kingdom (NBP), Belgium (Zeebrugge) and Germany (Bunde) – are converging. They use daily prices from March 2000 to February 2005 and applied the time-varying Kalman Filter analysis to each pair of prices. They find evidence of full convergence between UK and Belgium. On the other hand, it clearly states that there is no single Continental European natural gas market as prices at Zeebrugge and Bunde are not converging, even though

these two locations are also connected by a pipeline.

Asche, Osmundsen and Tveteras (2002) examine whether or not there is integration within the German market by using time series analysis of Norwegian, Dutch and Russian gas export prices to Germany between 1990 and 1998. Results from cointegration tests show that "the different border prices for gas to Germany move proportionally over time, indicating an integrated gas market"(Asche et al., 2002). However, the Russian gas had been sold at lower prices than Dutch and Norwegian gas.

King and Cuc (1996) used Kalman Filter to measure the degree of price convergence in North American natural gas spot markets from mid 1980's to mid 1990's. The results indicate that price convergence in natural gas spot markets had increased significantly since the price deregulation of the mid 1980's, but a split between prices in the east and west coasts of the United States still existed.

4 The Model

In this section we are going to describe our model, specifically focusing on the use of copulas. We also will describe our estimation methodology.

4.1 Copulas

The copula concept was first used in the statistics literature in 1959 with the seminal work by Sklar (1959). At the end of the 1990's there was an increasing interest in copula models applied to multivariate finance data. One main reason for this recent interest is the increased understanding that the traditional framework used to deal with dependence strongly relies on the Gaussian hypothesis, which has shown to be inadequate in delaing with the stylized facts of financial data. There is plenty of work on copulas applied to financial data. Some good examples are: Embrechts, Lindskog and McNeil (2001), Bouyé, Durrleman, Nikeghbali, Riboulet and Roncalli (2000), Embrechts, McNeil, Straumann (1999a), Embrechts, McNeil, Straumann (1999b), Mendes and Souza (2004), among others. In this section we present a very short introduction to Copulas.[2]

Definition 1 *A copula is a cumulative distribution function of a random vector in $\Re^p$ with $U \sim (0,1)$ marginal distributions. Equivalently, a copula is any function $C : [0,1]^p \rightarrow [0,1]$ with three properties:*

1. *$C(x_1, ..., x_p)$ is increasing in each one of its components $x_i, i = 1, ..., p$;*
2. *$C(1, ..., 1, x_i, ..., 1, ..., 1) = x_i \ \forall \ i \in \{1, ..., p\}, x_i \in [0,1]$;*
3. *For all $(a_1, ..., a_p), (b_1, ..., b_p) \in [0,1]^p$ with $a_i \leq b_i$, we have:*

$$\sum_{i_1=1}^{2} ... \sum_{i_p=1}^{2} (-1)^{i_1+...+i_p} C(x_{1i_1}, ..., x_{pi_p}) \geq 0, \tag{1}$$

in which $x_{j1} = a_j$ e $x_{j2} = b_j$ for all $j \in \{1, ..., p\}$.

As the definition tells by states, a copula is a cumulative distribution function (CDF) in which each univariate marginal have the uniform distribution in $(0,1)$. The Sklar(1959) theorem is one of the most important results about copulas, as follows:

[2] Some very good introductory references are Nelsen (1999) and Joe (1997).

Theorem 2 *Let F be a p-dimensional cumulative distribution function with marginais $F_1, \ldots, F_p$. Then there exist a copula C such that $\in \bar{\Re}$, where $\bar{\Re} = \Re \cup \{\pm\infty\}$,*

$$F(x_1, \ldots, x_p) = C(F_1(x_1), \ldots, F_p(x_p)) \tag{2}$$

If $F_1, \ldots, F_p$ are all continuous, then C is unique; i.e., C is determinated in $\mathrm{Im}F_1 \times \ldots \times \mathrm{Im}F_p$. Reversely, for a copula C in continuous marginals $F_1, \ldots, F_p$ a distribution function F is a p-dimensional distribution function with marginals $F_1, \ldots, F_p$.

Thus, this important theorem states that vector $(X_1, \ldots, X_p)$ of random variables with CDF F has a copula C and that if $(X_1, \ldots, X_p)$ is a vector of continuous random variables, this copula is unique. The following Proposition states about another important property of the copula function:

Proposition 3 *If $(X_1, ..., X_p)^t$ has copula C and $T_1, ..., T_p$ are increasing functions, therefore $(T_1(X_1), ..., T_p(X_p))^t$ also has copula C.*

Then, when working with a pair of continuous random variables and applying over them an increasing function, the new transformed variables will have the same copula. This result lead us to think about the copula function as the "dependence function" of the variables in the random vector.

As C is a continuous CDF, we can get its probability density function. Taking its total derivate, we have:

$$c(u_1, ..., u_p) = \frac{\partial^p C(u_1, ..., u_p)}{\partial u_1 ... \partial u_2 ... \partial u_p}.$$

$c(u_1, ..., u_p)$ is very usefully when we need to write random vector $(X_1, \ldots, X_p)$ pdf as follows:

$$f(x_1, ..., x_p; (\theta_c, \theta_1, \ldots, \theta_p)) = c(F_1(x_1), ..., F_n(x_p); \theta_c) \prod_{i=1}^{p} f_i(x_i; \theta_p). \tag{3}$$

If we consider the log likelihood for the vector θ of parameters constructed based on the pdf above, we get:

$$\begin{array}{rcl} \log L\left(\theta_c, \theta_1, \ldots, \theta_p; x_1, ..., x_p\right) & = & \log\left(f(x_1, ..., x_p; \theta_c, \theta_1, \ldots, \theta_p)\right) \\ \log\left(c(F_1(x_1), ..., F_n(x_p); \theta_c) \prod_{i=1}^{p} f_i(x_i; \theta_p)\right) & = & \log(c(F_1(x_1), ..., F_n(x_p); \theta_c) + \sum_{i=1}^{p} \log(f_i(x_i; \theta_p)). \end{array} \tag{4}$$

Therefore, when working with copulas, the multivariate probability model can be seen as the one that clearly describes the marginal behavior of each of the univariate random variables in the random vector and the joint behavior of them separately. Statistically, the following result may help to state these ideas:

Proposition 4 *Let X be a random variable with cumulative distribution function F e let F^{-1} be its inverse, i.e., $F^{-1}(\alpha) = \inf\{x | F(x) \geq \alpha\}, \alpha \in (0, 1)$. If F is a continuous function i.e., then the random variable $F(X)$ has uniform distribution on the $(0, 1)$, i.e., $F(X) \sim U(0, 1)$.*

This result is very important because it opens two streams of estimations for equation 3: full estimation and two step estimation. The full estimation consists on the joint estimation of all the parameters of equation 3 in one step. The two-step estimation first consists of estimates of the parameters of the marginal models and, second, uses the uniform observations to estimate the copula function. Here, by uniform observation we mean the original observation transformed by the application of estimated CDF, i.e., $u_{j,t} = \hat{F}(x_{j,t}), j = 1, \ldots, p$ and $t = 1, \ldots, n$. We will discuss estimations in the upcoming section Model Estimation. Following, we present the copulas functions

that we work on in this paper. An important feature of the copula is that it allows for different degrees of tail dependence: Upper tail dependence exists when there is a positive probability of positive outliers occurring jointly, while lower tail dependence is symmetrically defined as the probability of negative outliers occurring jointly.

4.1.1 Some Copulas Functions

We also introduce some important copulas families that are going to be used in this work. Each of these families have particular characteristics. Although we are not able to go into further detail about all their properties, the reader is encouraged to search for additional information on the mentioned references.

Elliptical Copulas These copulas are characterized to have their dependence given by elliptical forms. The first elliptical form is the Gaussian or Normal Copula. This copula is associated with the multivariate normal distribution. Since we are going to only deal with bivariate data in this paper, we write its bivariate version:

$$C_\rho = \Phi_\rho \left(\Phi^{-1}(u), \Phi^{-1}(v)\right) \tag{5}$$

where u and $v \in [0,1]$ and Φ denotes the Normal cumulative distribution function.

Another very important elliptical copula is the t-Student Copula, which form is given by:

$$C^t_{\nu,R}() = t^n_{\nu,R}(t^{-1}_\nu(u_1), \ldots, t^{-1}_\nu(u_n)), \tag{6}$$

where $R_{ij} = \Sigma_{ij}/\sqrt{\Sigma_{ii}\Sigma_{jj}}$ for $i,j \in \{1,\ldots,n\}$ and where $t^n_{\nu,R}$ denotes the distribution function of multivariate $t-student$ distribution with n t_ν marginals.

A relevant difference between the Gaussian and the t-Student Copula is their upper tail dependence,

$$\lambda_U = 2 \lim_{x\to\infty} P\left(X_2 > x | X_1 = x\right), \tag{7}$$

and their lower tail dependence

$$\lambda_L = 2 \lim_{x\to-\infty} P\left(X_2 < x | X_1 = x\right). \tag{8}$$

λ_U and λ_L are important measures. They measure, as their own names suggest, dependence at the extremes of the distribution supports. Theses measures are constants given one copula function, i.e., given a copula function, these values are given independently of the marginals distributions. One of the most important properties of the elliptical copulas is that their structure of dependence is symmetric. This implies that $\lambda_U = \lambda_L$.

A difference emerges when we use Gaussian and t-Student Copulas: the Normal Copula has $\lambda_L = \lambda_U = 0$, which implies independence at the extremes of the bivariate distribution. However, the t-Student Copula usually has $\lambda_L > 0$, where λ_L increases with ρ and decreases with ν.

Archimedean Copulas Archimedean copulas is an important copulas family. It has simple properties such as associativity and a variety of dependence structures. They have closed-form solutions and are not derived from the multivariate functions using Sklar's Theorem. One particularity of a n-dimensional Archemedean copula is

$$C^A(u_1,\ldots,u_n) = \Psi^{-1}\left(\sum_{i=1}^n \Psi(u_i)\right) \tag{9}$$

Ψ is known as generator function. A generator satisfies the following properties:

$$\Psi(1) = 0; \quad \lim_{x \longrightarrow 0} = \infty; \quad \Psi'(x) < 0; \quad \Psi''(0) > 0. \tag{10}$$

Some Archimedean copulas are used in this paper. One of them is the Product Copula, which is the independent copula between the variables. Its density function integrates to unity on its support, and its generator function are given as follows:

$$C(u, v) = uv, \quad \Psi(x) = -\ln(x); \tag{11}$$

Among the Archemedean copulas, we are going to use three models considering different structures of dependence. First is the Gumbel Copula, given by:

$$C_\theta^G(u, v) = \exp\left(-\left[(-\ln u)^\theta + (-\ln v)^\theta\right]^{1/\theta}\right), \quad \Psi = (-\ln(x))^\alpha; \tag{12}$$

The Gumbel Copula is such that for $\theta > 0$, $\lambda_U^G = 2 - 2^{1/\theta}$, i. e., it has upper tail dependence. Its $\lambda_L^G = 0$. The Clayton Copula is the second density we are going to study:

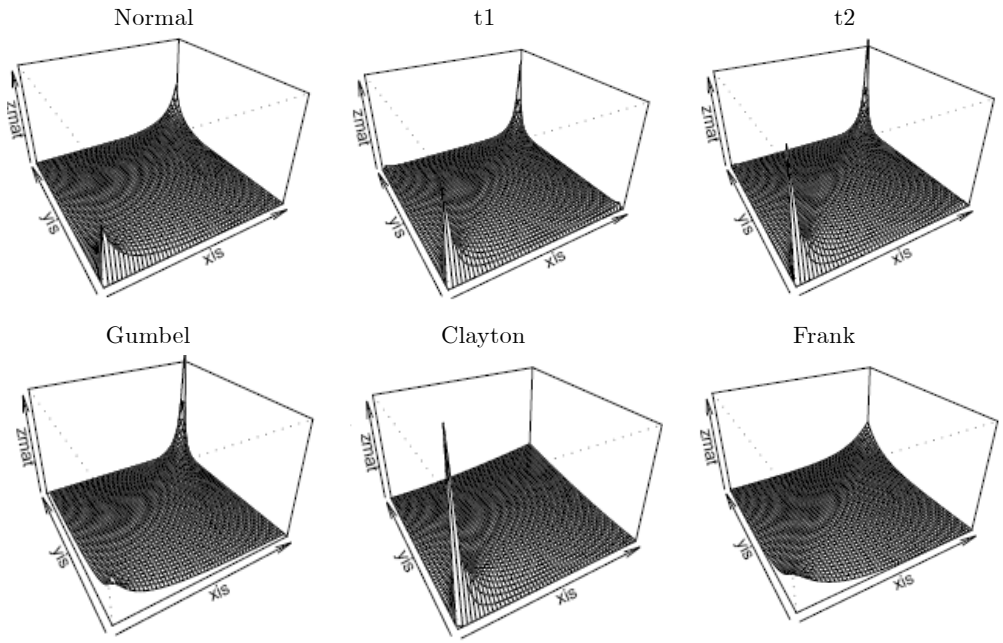
$$C_\theta^C = (u^\theta + v^\theta - 1)^{1/\theta}, \quad \Psi = x^\theta - 1; \quad \theta \leq 0; \tag{13}$$

It is contrary to the Gumbel Copula because it has $\lambda_U^C = 0$ and $\lambda_L^C > 0$. The third Archemedean copula is the Frank Copula.

$$C_\theta^F(u, v) = (u^\theta + v^\theta - 1)^{1/\theta}, \quad \Psi = \ln\left(\frac{e^{\alpha x} - 1}{e^\alpha - 1}\right) \tag{14}$$

The Frank copula also satisfies $\lambda_U^F = \lambda_L^F = 0$.

Figure 1 presents some plots of the copulas for a better understanding of the models used in this paper. Comparing the graphs on the first row, it is possible to notice that the edges of the t-Student Copula are sharper than those in the Gaussian Copula. This feature helps to understand the difference in the tail dependence in these two families. In the second row, we present the Archimedean copulas. Gumbel Copula has an edge in the upper corner, Clayton Copula, in the lower and the Frank Copula has no sharp edges.



4.2 Model Specification

As stated before, the cointegration technique has been widely applied to study the link of the different global natural gas markets. In these works, the underling VECM model for the cointegrated series is built and estimated using the Gaussian framework. But, natural gas prices are essentially financial data. One of the most important stylized facts about financial data is their non-Gaussian distributions. In the univariate case, this non-normal behavior is mainly linked to excess of kurtosis. In the multivariate case, the lack of normality is associated to different structures of dependence those generated by multivariate normal distribution. Besides these important stylized facts, most of the work on cointegration relies on the traditional Gaussian framework, ignoring the important aspect of gas prices.

Therefore, in order to build a VECM to investigate the existence of a global natural gas market, we are going to adapt this technique to identify and model the possible non-normality that natural gas price data may have. To clarify our idea, consider the conditional joint probability density function (pdf) of the series of log returns of natural gas prices, namely $f(\Delta \ln p_{1,t}, \Delta \ln p_{2,t}; \theta | I_{t-1})$. As presented in the previous section, the copula approach is going to have an important role in dealing with the dependence structure of the error terms. Using the proposed factorization, we can write our probability model as follows:

$$f(\Delta \ln p_{1,t}, \Delta \ln p_{2,t}; \theta | I_{t-1}) = c\left(F\left(\Delta \ln p_{1,t} | I_{t-1}\right), F\left(\Delta \ln p_{2,t} | I_{t-1}\right); \theta_c\right)\right) f_1\left(\Delta \ln p_{1,t}; \theta_1 | I_{t-1}\right) f_2\left(\Delta \ln p_{2,t} \theta_2 | I_{t-1}\right). \tag{15}$$

where $c\left(F\left(\Delta \ln p_{1,t} | I_{t-1}\right)\right)$ is the copula function, θ is the vector containing all the parameters of the conditional model, θ_i is the vector of the univariate marginal i. As we want to estimate the parameters of the equation 15, we may write the conditional log likelihood function as follows:

$$l(\theta; \Delta \ln p_{1,t}, \Delta \ln p_{2,t}) = l_c\left(\theta_c; F\left(\Delta \ln p_{1,t} | I_{t-1}\right), F\left(\Delta \ln p_{2,t} | I_{t-1}\right)\right)) + l_1\left(\theta_1; \Delta \ln p_{1,t}\right) + l_2\left(\theta_2; \Delta \ln p_{2,t}\right). \tag{16}$$

Equation 16 helps to clarify our aim. Using the factorization above, it is possible to split the multivariate model in two univariate models and one "dependence model". Moreover, this suggests that we can make use of this factorization in the estimation process. Our complete model can be written as stated in equation 17:

$$\begin{array}{rcl} \Delta \ln p_{1,t} & = & \beta_0 + \beta_1 \epsilon_{t-i} + \sum_{i=1}^{p} \gamma \Delta p_{1,t-i} + \sum_{i=1}^{p} \lambda \Delta p_{2,t-i} + e_{1,t}, e_{1,t} \sim NID\ (0, \sigma_e^2) \\ \Delta \ln p_{2,t} & = & \beta_0 + \beta_1 \epsilon_{t-i} + \sum_{i=1}^{p} \gamma \Delta p_{1,t-i} + \sum_{i=1}^{p} \lambda \Delta p_{2,t-i} + e_{2,t}, e_{2,t} \sim NID\ (0, \sigma_e^2) \end{array} \tag{17}$$

where the bivariate joint distribution of $e_{1,t}$ and $e_{2,t}$ will be completed by the copula model and ϵ_{t-i} is the deviation of the long run relationship between $\ln p_{1,t}$ and $\ln p_{2,t}$ at time $t-1$.

We had evidence that some VECM coefficients of model 17 vary over time, which may be a consequence of the LNG growth use overt the natural gas prices short run relationship. To deal with this feature we decided to modify our model to accommodate this result. The solution was to use a Time Varying Parameters Error Correction Model (TVP-ECM) which is a combination of the Kalman Filter Approach (Harvey, 1989) and the VECM stated above. This model was first proposed by Hall (1993). Ramajo (2001) and Li, Wong, Song and Witt (2006) presented more recent applications of this model. With non-fixed coefficients this model is able to capture the long run relationship between the variables and allows a flexible way to deal with possible non stability of short run adjustments. The measurement equation is stated as follows:

$$\begin{array}{rcl} \Delta \ln p_{1,t} & = & \beta_{1,0,t} + \beta_{1,1,t} \epsilon_{t-i} + \sum_{j=1}^{p} \gamma_{1,j,t} \Delta p_{1,t-j} + \sum_{j=1}^{q} \lambda_{1,j,t} \Delta p_{2,t-j} + e_{1,t}, e_{1,t} \sim NID\ (0, \sigma_e^2) \\ \Delta \ln p_{2,t} & = & \beta_{2,0,t} + \beta_{2,1,t} \epsilon_{t-i} + \sum_{j=1}^{p} \gamma_{2,j,t} \Delta p_{1,t-j} + \sum_{j=1}^{q} \lambda_{2,j,t} \Delta p_{2,t-j} + e_{2,t}, e_{2,t} \sim NID\ (0, \sigma_e^2) \end{array} \tag{18}$$

where the bivariate joint distribution of $e_{1,t}$ and $e_{2,t}$ will be completed by the copula model and ϵ_{t-i} is the deviation of the long run relationship between $\ln p_{1,t}$ and $\ln p_{2,t}$ at time $t-1$, $\beta_{i,j,t}$, $i = 1, 2$, $j = 0, 1$, $\gamma_{i,j,t}$, $i = 1, 2$, $j = 1, ..., p$, $t = 1, ..., n$, $\lambda_{i,j,t}$, $i = 1, 2$, $j = 1, ..., q$, $t = 1, \ldots, n$. To complete the TVP-ECM model we need to specify the state equation, which is given below:

$$\begin{bmatrix} \beta_{i,t} \\ \gamma_{i,t} \\ \lambda_{i,t} \end{bmatrix} = \begin{bmatrix} \beta_{i,t-1} \\ \gamma_{i,t-1} \\ \lambda_{i,t-1} \end{bmatrix} + [\varepsilon_{i,t-1}] \tag{19}$$

where $\beta_{i,t}$, $i = 1, 2$ is a vector containing $\beta_{i,j,t}$, $j = 0, 1$, $\gamma_{i,t}$, is a vector containing $\gamma_{i,j,t}$, $j = 1, ..., p$, $\lambda_{i,t}$, is a vector containing $\lambda_{i,j,t}$, $j = 1, ..., q$ and $\varepsilon_{i,t-1}$ is the vector of error terms $(2 + p + q \times 1)$, which we assume to be $N(0, \Sigma_\varepsilon)$, Σ_ε diagonal.

Given the complexity of the proposed model, we decide to implement a three step estimation procedure. In the first step we estimate and test the long run relationship using equation 20:

$$\ln p_{1,t} = \alpha_0 + \alpha_1 \ln p_{2,t} + \epsilon_t, \epsilon_t \sim \text{ i.i.d. } D(0, \sigma_\epsilon^2). \tag{20}$$

Using the estimated residuals of equation 20, we apply Phillips and Ouliaris (1990) to test cointegration. If cointegration is confirmed, we replace the error terms in equation 17 or 18 to estimate the VECM equations.

Next, we used the residuals of the VECM or TVP-VECM model to estimate the Copula Model. In this step it is necessary to transform the original residuals into bivariate observations in the $(0, 1)$ interval. This may be done by using a model for the residual or not using a model. In this paper we decide to use the empirical distribution function to obtain the "unifomized" observations. This procedure of estimation, known as semi-parametric, has the important advantage of eliminating possible complex and sometimes unreliable assumptions in the marginal

distributions.

In the context we are using the copula approach, it is important to quote Patton et al. (2006) and Patton (2006). In these papers, the authors show that the Sklars' theorem is still valid with conditional marginal distribution functions, not only with general distribution functions. So if X and Y are both continous random variables the copula is unique, and is the joint distribution conditional on W, of the random variables u and v which are defined as $u = F_x(x|W)$ and $v = F_y(y|W)$.

If W has a dominant property, in a manner defined by Patton et al. (2006) - some examples of dominant properties in component processes are a trend, a strong seasonal component, a strong business cycle component or distinct breaks in conditional mean - then W does have an impact in the joint density. Also other variable without dominant properties still can be included in the conditioning set. One relevant information in this case is that tests for the existence or not of a particular dominant property will exist in some cases, such as for first-order stochastic dominance, but others will need to be developed.

5 Estimation

5.1 Data

We used logged monthly natural gas prices of the main trading points in United States, United Kingdom and Belgium, Henry Hub, NBP and Zeebrugge, respectively. The data is available at Bloomberg. For Japan we use the weighted average of monthly LNG selling prices from the main suppliers of the country (Australia, Indonesia, Malaysia, Qatar, Abu Dhabi, Brunei, Oman and United States), which is also available at Bloomberg.

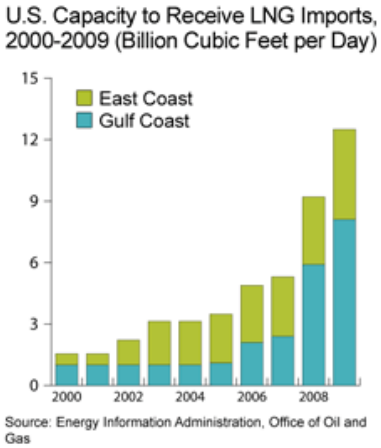
The period under consideration is from April 2001 to February 2009, totalizing 95 observations. We choose to focus on this data interval in our initial hypothesis that the LNG growth was the key in the observed path of the natural gas prices worldwide. We observe the growth trend in the LNG market after 2000.[3] One factor contributing to the world growth in the LNG trade is the declining cost structure of all phases of the supply chain, which has allowed the cost at which LNG becomes economically viable to fall within the year range in 2001 of natural gas prices. Another reason is that LNG helps diversify supply base and increase reliability. We have many examples in the recent period of natural gas supply challenges around the world, as such:

- Jan 2006 - Russian Gazprom cutting off pipeline natural gas supplies to Ukraine
- Jan 2008 - Turkmenistan cut gas exports to Iran resulting in Iran cutting exports to Turkey. Subsequently, Gazprom increased natural gas exports to Turkey.
- Jan 2009 - A dispute with Ukraine led Russia to curtail gas exports for 3 weeks.

The figure 1 is an example of the increasing importance of LNG, showing the American evolution in the LNG imports capacity.

[3] According to the American Energy Information Administration, natural gas reserves that would be extremely expensive to transport through pipelines to potential markets are commonly referred to as "stranded reserves." Stranded reserves are expected to be a major source of natural gas for world LNG trade. It has been estimated that stranded reserves make up about 50 percent of the natural gas reserves held by the top 10 producers countries in 2001.

Figure 1



Source - EIA, USA, 2009.

Figure 2 shows the graph of the four monthly series we use in our empirical exercise. One can observe that all of them present a co-movement that increase until the Sub-Prime Crisis. After November 2008, these series continue to move together, but in a decreasing trend. Now, we are going to examine whether this behavior is or is not a consequence of some integration between the regional markets.

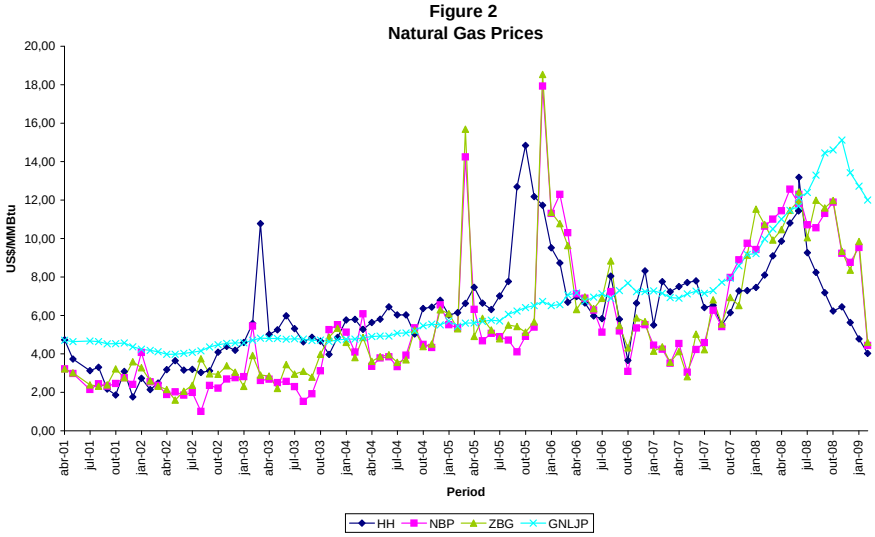


Table 1 presents the descriptive statistics of the four natural gas price series. As one can see, NBP has the lowest mean and LNGJP has the largest mean. The largest value reached by a series was US$ 18.53 per MMBtu, which was reached by Zeebrugge.

Table 1 - Descriptive Stats				
	HH	NBP	LNGJP	ZBG
Mean	6.238792	5.604731	6.690526	5.730849
Median	6.026800	4.675329	5.690000	4.787310
Maximum	14.84230	17.92724	15.12000	18.53347
Minimum	1.760900	1.007813	3.980000	1.594868
Std. Dev.	2.574337	3.455316	2.767300	3.362999
Skewness	0.862907	1.132787	1.467827	1.338481
Kurtosis	4.045268	3.730036	4.295450	4.523493
Jarque-Bera	16.11444	22.42705	40.75599	37.55333
Probability	0.000317	0.000013	0.000000	0.000000
Sum.	592.6852	532.4495	635.6000	544.4307
Sum Sqr. Dev	622.9577	1122.285	719.8471	1063.118

5.2 Step-by-Step of the Model Estimation

We initially ran unit root tests to verify the stationarity of each series. We used the Dickey and Fuller (1979) test and found non-sationarity in all series of this work. The results are shown in the next section.

After verifying stationarity we test for a cointegration relation. There are many procedures to test cointegration between variables: Johansen (1988), Stock and Watson (1988), Engle and Granger (1987) and Phillips & Ouliaris (1990). We decided to use a residual based test, specifically the Phillips and Ouliaris (1990) test, which consists of running an ordinary least squares involving pair of prices to obtain the cointegration vector and the residuals. The null hypothesis is that there is no cointegration. The chosen test has a superior power performance in large samples and slower rates of divergence under cointegration than others tests (Phillips & Ouliaris, 1990).

But cointegration only documents a long run relationship between the variables. Once we find cointegration, it is necessary to search for a better specification with an Error Correction Model (ECM) in order to account for the long and the short run relationships between the variables. We estimate a VECM for each pair of prices. As not all the pairs presented significant VECM, we then test for the presence of structural break in each of them. When there is some indication of structural break, a Time Varying Parameter Error Correction Model (TVP-ECM) is indicated. We used the CUSUM test to account for structural breaks and only the pair NBP-HH showed some sign of it. Consequently, we ran a TVP-ECM for this pair of prices.

Finally, the VECM's and the TVP-ECM estimations showed that these were not sufficient models to explain all the short run relationships between the variables. However, the Phillips and Ouliaris test showed that in the long run the variables cointegrate in pairs. Therefore, we decided to apply the Copula Analysis for each pair of prices in attempt to understand how this dependence works in the short run. Although the estimated Copula Functions explain how the joint movements of each pair of prices occur in the short run, more investigative work is still necessary to understand the instruments that are making these joint movements possible.

6 Results

Initially we apply the Augmented Dickey-Fuller test to verify series stationarity, which demonstrate that all four natural gas prices are non-stationary at the 5% significance level. Table 2 shows the unit root test for the log of price series.

Table 2 - Unit Root Tests*

Variables	Components	τ-Statistic
LHH	Intercept and Trend	-2.2585
LNBP	Intercept and Trend	-3.365
LZBG	Intercept and Trend	-3.1801
LGNLJP	Intercept and Trend	-2.2824

* H0: Series have a unit root at 5% of significance.

5% Critical Value: -3.45

Although the ADF test stated the non-stationarity of the series, a linear relation between them could be stationary, indicating that there exists a cointegration relationship. Therefore, they have a common behavior in the long run. In our research, the presence of cointegration shows that natural gas prices are functioning together, which will be a proxy to validate the Law of One Price.

Next, we test for cointegration between all combinations of natural gas prices[4] (Henry Hub, NBP, Zeebrugge and "LNGJP") using the Phillipis & Ouliaris (1990) test. Tests including more than two variables are found inconclusive whether there is cointegration or not. It is then not possible to evaluate the Law of One Price in a global manner.[5]

When making pair analysis, we find statistical evidence of cointegration between the logs of Zeebrugge and NBP, NBP and Henry Hub and Zeebrugge and Henry Hub, meaning that a long run relationship among them exists. The LNGJP does not cointegrate with any of the other series. Main results are shown in Table 3.

Table 3 - Phillips and Ouliaris Test

	Test Statistics
LZBG - LNBP	97.7079 ***
LNBP - LHH	62.1115 **
LZBG - LHH	65.2486 ***

**5% significance (48.84)

***1% significance (65.17)

Figure 3 shows the graph of each pair of prices where we find cointegration. It clearly shows that the pair NBP-Zeebrugge has a strong relationship. The other two pairs also have common behaviour, but in a weak way.

[4] We applied the lag lenght criteria in the VAR estimation preceding the cointegration test. The Schwarz Information Criteria indicated one lag for the three pairs of prices analysed.

[5] We intend to test the constrain $\beta = (1\ -1)$ in the subspace cointegration.

Figure 3 - Pairs of Log Gas Prices

NBP - ZBG HH - NBP HH - ZBG

In Table 4, we report the three cointegrating equations, all of them statistically significant. These results show that the long run relationship is much stronger between the natural gas markets in the United Kingdom and Continental Europe. Normalizing the variation in the Belgium market price to 1%, the price in the United Kingdom varies 0.75%. When analyzing the European markets vis-a-visa the long run relation in the American market is not very strong. The Henry Hub varies less than 0,40% while the European prices varies 1%.

Table 4 - Cointegrating Equations

Variables	Normalized Coefficients	(standard errors)
LZBG	1.000	
C	0.314	(0.051)
LNBP	0.745	(0.048)
LNBP	1.000	
C	0.270	(0.165)
LHH	0.383	(0.119)
LZBG	1.000	
C	0.505	(0.147)
LHH	0.294	(0.106)

After verifying the Cointegration relation between the series, we now test the existence of an Error Correction Model (ECM) for each pair of prices. First, we worked with the traditional ECM from Engle and Granger (1987), which considers fixed parameters. In Tables 5, 6 and 7 we report the results of the ECM Estimation for Zeebrugge-NBP, NBP-Henry Hub and Zeebrugge-Henry Hub respectively. In each column the dependent variable is the first number that appears in the header. We run the ECM in both directions, attempting to identify which market has influence on the other.

Table 5 - ECM Estimation for LZBG and LNBP[1]		
	LZBG - LNBP	LNBP- LZBG
C	0.009 (0.029)	0.007(0.033)
Cointegration Residual	-0.222 (0.212)	0.532(0.231)**
LZBG (-1)	-0.340 (0.174)*	-0.186(0.191)
LNBP (-1)	-0.051(0.149)	-0.180(0.163)

[1]Standard Errors between brackets.

***1% ,**5% and *10% of significance.

According to the results in Table 5, one can see that the VECM is not valid for the pair Zeebrugge-NBP, as the coefficients estimates are not significant. In the equation where the log of Zeebrugge price is the dependent variable only the auto-regressive coefficient is significant. And, in the other direction, when NBP price is the dependent variable, only the long run component (cointegration residual) is significant.

Table 6 - ECM Estimation for LNBP and LHH[1]		
	LNBP - LHH	LHH- LNBP
C	-0.008 (0.1348)	0.246 (0.095)**
Cointegration Residual	-0.225 (0.077)***	0.049 (0.054)
LNBP (-1)	-0.229 (0.104)**	0.030 (0.073)
LHH (-1)	0.007 (0.075)	-0.140 (0.053)***

[1]Standard Errors between brackets.

***1%, **5% and *10% significance.

Table 7 - ECM Estimation for LZBG and LHH[1]		
	LZBG - LHH	LHH- LZBG
C	0.006 (0.119)	0.232 (0.095)**
Cointegration Residual	-0.237 (0.076)***	0.055 (0.060)
LZBG (-1)	-0.318 (0.101)***	-0.133 (0.052)
LHH (-1)	0.002 (0.067)	0.069 (0.080)**

[1]Standard Errors between brackets.

***1%, **5% and *10% significance.

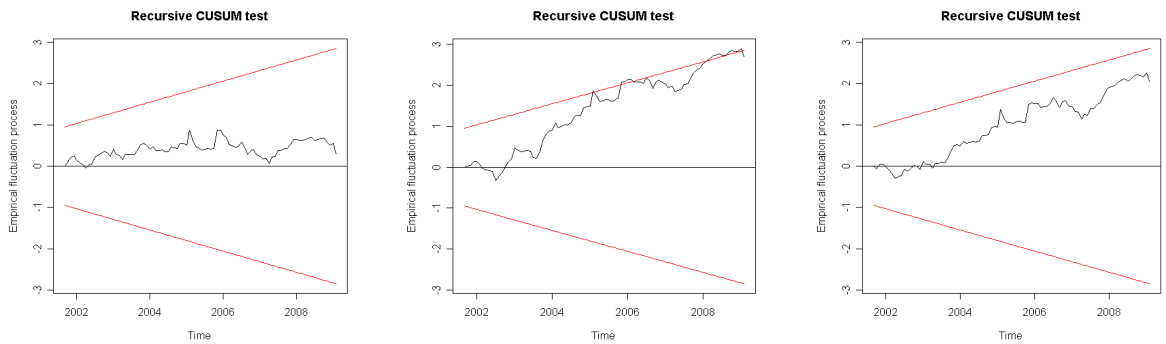
Tables 6 and 7 show that the VECM is valid when we analyze the American market against the European markets. When working with NBP or Zeebrugge data and using the European market as the dependent variable, the long run component parameter is significant and the auto-regressive parameter is also significant and explains the short run adjustments. On the other hand, when the American market is the dependent variable, only the constant and the auto-regressive coefficient are significants. These results suggest that, to some extent, the American market is the market that has influence on the others.

However, the VECM results show that it is not enough to account for all the dependences between the series in the short run, as the coefficients of the explanatory variable related to the external market are not significant. Therefore, we decided to run a Structural Break Test to try to identify if dependency was observed for any pair

of prices. When there is some suspicion of structural break, a Time Varying Parameter Technique is suggested to provide a better way of modeling the Error Correction Model.

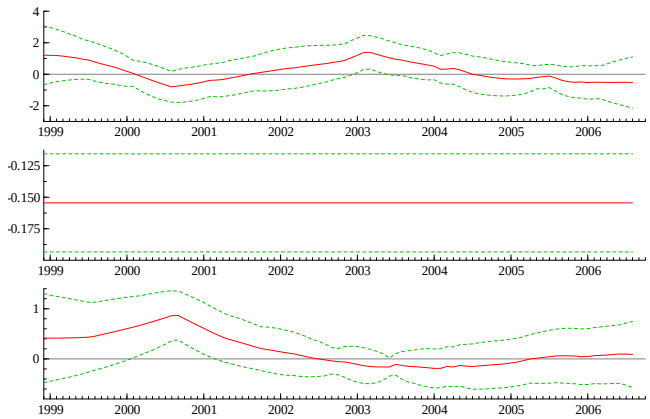
Figure 4 - Structural Break Test - CUSUM

ZBG - NBP NBP - HH ZBG - HH



The CUSUM test plots a pair of lines that are the 5 percent critical lines. Movements outside the critical lines is suggestive of parameter instability. The cumulative sum is generally within the 5% significance lines. However, as one can see in figure 4 in 2005, 2006 and 2008 ,we have some evidence of instability and so, a structural break for the pair NBP-HH. For this pair we decided to run a TVP-ECM. The results are shown in Figure 5. The first plot of this figure is the time-varying coefficients for the long run adjustment component of the Error Correction Model. The second plot gives the dynamics of the autoregressive parameters and the last plot presents the explanatory variable parameters. One can see that the estimated coefficients for the long run adjustment and the autoregressive components are not significant once the confidence interval contains the zero. For the explanatory variable, the estimated coefficients are significant only during the year 2000.

Figure 5 - Time Varying Parameters - ECM (NBP-HH)



Since the VECM's and the TVP-ECM are not appropriate techniques to model the short run relationship between the variables, we decide to estimate Copula Functions for each pair of prices in attempt to figure out how the short run dependence works. Tables 8, 9 and 10 show the results for the Copula Estimation. The best fitting estimation is given by a combination of the log likelihood and the "Goodness of Fit" (GOF) statistic.

Table 8-CopulaAnalysis ZBG-NBP				Table 9-CopulaAnalysis NBP-HH				Table 10-CopulaAnalysis ZBG-HH			
Copula	Param.	LogLik.	GOF	Copula	Param.	LogLik	GOF	Copula	Param.	LogLik.	GOF
Normal	0.765	38.170	0.024	Normal	0.288	3.403	0.527	Normal	0.172	1.163	0.615
t1	0.738	52.686	0.060	t1	0.178	-5.649	0.102	t1	0.135	-16.247	0.215
t2	0.812	54.615	0.522	t2	0.257	3.538	0.553	t2	0.165	-2.729	0.487
t3	0.830	53.837	0.654	t3	0.288	4.781	0.796	t3	0.175	-0.219	0.643
t4	0.836	52.862	0.682	t4	0.301	5.003	0.864	t4	0.179	0.584	0.653
t5	0.838	51.947	0.656	t5	0.308	4.996	0.858	t5	0.180	0.918	0.696
t6	0.839	51.126	0.681	t6	0.312	4.927	0.868	t6	0.181	1.079	0.688
t7	0.837	50.395	0.661	t7	0.313	4.843	0.887	t7	0.181	1.165	0.685
t8	0.836	49.743	0.640	t8	0.314	4.759	0.882	t8	0.181	1.213	0.673
t9	0.835	49.159	0.612	t9	0.314	4.679	0.853	t9	0.181	1.241	0.697
Gumbel	2.552	48.671	0.743	Gumbel	1.224	3.304	0.373	Gumbel	1.107	0.996	0.373
Clayton	1.938	33.997	0.000	Clayton	0.442	4.218	0.311	Clayton	0.232	1.225	0.379
Frank	8.106	43.399	0.353	Frank	1.932	4.104	0.692	Frank	1.058	1.341	0.699

As one can see in Table 8 that is shown above, the pair Zeebrugge-NBP the Copula Function that best explains the behaviour of these prices in the short run is the $t - Student$ Copula with 2 degrees of freedom. This means that the prices in these markets move together, mainly in extreme periods. As it was exposed in previous sections, in a $t - Student$ Copula the lower dependence at the extreme distributions support increases with the degree of freedom.

Another important result related to the pair Zeebrugge-NBP is the fact that we reject the $Normal$ Copula. As we have mentioned in Section 4, the $Normal$ Copula has the characteristic of no dependence at the extremes of the bivariate distribution ($\lambda_L = \lambda_U = 0$). The $t - Student$ Copula is more realistic once the natural gas prices in these markets move together and are stronger during extreme periods.

Table 9 shows that the results for the pair NBP-Henry Hub and the $t - Student$ Copula with 4 degrees of freedom achieved the best fit, which confirms the fact that prices in these markets are more related at extreme occasions. As we explained in Section 2, NBP and Henry Hub are huge natural gas spot markets and strongly represents the european and the american markets, respectively.

Finally, Table 10 presents the results for the pair Zeebrugge-Henry Hub. The Copula that best describes the dependence of these series is the $Frank$ Copula. As we have seen in Section 4, the $Frank$ Copula (and also the $Normal$ Copula), has no dependence at the extremes of the bivariate distribution ($\lambda_L^F = \lambda_U^F = 0$). This result is very intuitive once the Henry Hub and the Zeebrugge markets are very distant from each other and the Zeebrugge market does not have the magnitude observed in the NBP market.

7 Conclusion

The natural gas market has been suffering many changes all over the world during the last decades and these transformations have caught the attention of some literates on the subject in an attempt to explain a possible convergence between the main regional natural gas markets (the North American, European and Asian/Pacific markets). The main studies on this matter use the Cointegration Technique and the Kalman Filter Approach. In this article we use Error Correction Model (VECM), Time Varying Parameters Error Correction Model (TVP-ECM) and Copula Analysis to examine if a short run dynamic between these regions exists and to analize the "dependence" between these markets, if there may be one.

Cointegration tests including more than two variables were not conclusive, which makes it not possible to evaluate a global integration of the markets. This probably happenned because the LNG market, which is the instrument that provides the missing link to the regions, is still very incipient.

We then analyze convergence among pairs of prices. We use logged monthly natural gas prices for Henry Hub in the United States, NBP in the United Kingdom, and Zeebrugge in Belgium. For the Japanese market we use an average of the main LNG selling prices. All data goes from April 2001 to February 2009. These tests show that the Japanese market does not integrate with any other, probably because the Japanese market is still too much indexed to oil prices through long term contracts, whereas in the United States and the United Kingdom, Henry Hub and NBP both represent spot markets respectively. Also in Continental Europe one can already find contracts indexing natural gas prices to the spot market in UK. When continuing the cointegration tests, the pairs Henry Hub-NBP, NBP-Zeebrugge and HH-Zeebrugge presented a long run relationship.

We run the VECM for each pair of prices to try to identify a short run dependence between the prices. For the pairs NBP-Henry Hub and Zeebrugge-Henry Hub, this model indicate a possible influence of the American market in the European markets. However, the results are not enough to account for all the short run dependencies. This model is not significant at all for the pair NBP-Zebbrugge, which is a sign that these markets move together, without relevant time delays; that is, they seem to move simultaneously.

Facing these results, we decided to test for structural breaks and only the pair NBP-Henry Hub presented some trace of it. Therefore we ran a TVP-ECM for this pair of prices. Nevertheless, the smoothed states estimates obtained were not significant.

In order to understand the short run relationship between the natural gas prices, we applied the Copula Approach. For the pairs Zeebrugge-NBP and NBP-Henry Hub we found that the short run relation could be represented by a $t - Student$ Function, indicating that these markets move strongly together during extreme periods. On the other hand, for the pair Zeebrugge-Henry Hub the copula obtained was the $Frank$ Copula, which has the characteristic of no dependence at the extremes of the bivariate distribution.

To improve our results, it would be interesting to implement some additional research, for example:

1. Working with daily frequency data. In this case, when estimating the TVP-ECM it will be necessary to model the error of the measurement equation with a GARCH component, in order to incorporate the higher volatility coming from the new frequency in the specification.

2. Incorporating a proxy for transport costs among the regions in the state equations of the TVP-ECM.

Nonetheless, the application of VECM, TVP-ECM and Copula Technique is a valid exercise, since there are no articles on the topic of natural gas market integration using these methodologies thus far and it will certainly help for a better comprehension of the behavior of the natural gas prices among the international market. Considering

the important role of the natural gas in the global energy scenario, the results we have found herein are an important tool to the private and public sectors planning and to forecast the global energy market equilibrium.

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CHAPTER 3

LNG Market Growth Worldwide and its Consequence to the Brazilian Energy System

PART 2

LNG Terminals and the Value of Switching in the Brazilian Electric Energy Market*

Abstract

In this paper, we search to calculate the operational flexibility value to the national electric system bring by the three PETROBRAS' thermo power plants in the Northeast, which use liquified natural gas (LNG). To illustrate our point, we run a Real Options exercise, in which we compare the marginal operational costs including these thermo power plants in the system with the marginal operational costs without them. To simplify our case study, we use the hypothesis that the PETROBRAS' thermo power plants will only use the LNG as a fuel and not the Bolivian gas pipeline. The simplification is reasonable, since the Northeast subsystem is not linked to the Brasil-Bolivian gas pipeline. As a first result, our exercise using the Real Options technique shows that the LNG can have an important role in the Northeast subsystem and in the Brazilian system as a whole, especially when the reservoirs are in a low level or, in other words, when the marginal operational costs of the hydro power plants are high.

*Paper co-authored by Marcela Ferreira (Petrobras and EPGE/FGV) and professor Edson Gonçalves (Accenture and EPGE/FGV).

1 Introduction

This paper presents a valuation study of operational flexibility brought by the regasification terminals of liquefied natural gas (LNG) to the Brazilian power system. We applied the Real Options approach, a method based on the options valuation, but also very used in analyzing real projects and investments.

Our illustrative empirical exercise will be to estimate this flexibility for the Brazilian Northeast Subsystem. This region was chosen because of the simplicity of no alternative way to the gas supply, as the Northeast is not linked in the Brazil-Bolivia pipeline.

Therefore, we calculate the flexibility option value given by the Northeast thermo power plants, which entered the system after the installation of the regas terminal in Pecém, Ceará. With this value we were able to find out which level of marginal cost in that subsystem determines when is better to turn on the thermo power plants that use natural gas from the regas terminal. That is, we could calculate the minimum operational cost or water cost between immediate and future costs on the Northeast Subsystem.

Firstly, we applied the mean reverting model to the Henry-Hub (HH) series, which will give the thermo power plants operating costs, since HH is a proxy of the LNG price in the Atlantic Basin. We also modeled the water series with the conventional mean reverting model, as done in similar works that use this series in a stochastic approach. After the parameters estimation of these processes, we simulated them using the Monte Carlo approach. In the future, we will use these costs in the integrated Brazilian dispatch system program, to compare when it is profitable to turn on the thermo power plants using the LNG or when is better to use the water from the reservoirs to attend the Northeast subsystem demand.

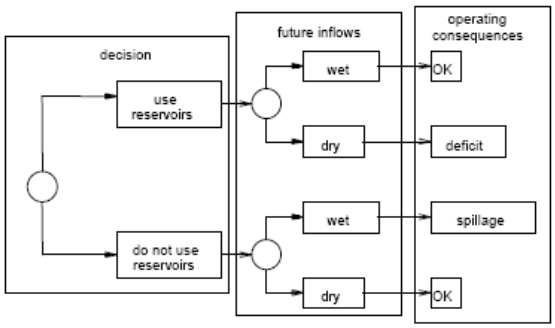
In the next section we give some insights about how the Brazilian power system works and explain the Brazilian entrance in the LNG market. Section 3 presents a literature review. In Section 4 we present the model. Finally, Section 5 shows the results and Section 6 our conclusions.

2 The Brazilian Power System

The Brazilian Power System is hydro-based. Thermo power generation is just a little proportion of the total installed capacity (around 23%, ANEEL 2009). According to Pereira et al (1998), hydro power plants have the advantage of using a "free" energy stored in their reservoirs to meet demand, thus avoiding fuel expenses in thermal units. However, the availability of this hydro energy is limited by reservoir storage capacities. This characteristic introduces a relationship between the operative decision in a given stage and the future consequences of this decision. Then, different from the thermal systems, hydro systems operation is coupled in time, which means that a today's

decision affects future operational costs, as described in Figure 1.

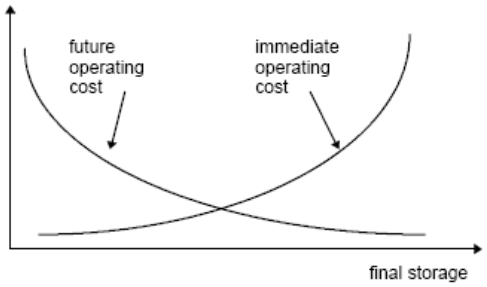
Figure 1 - Decision Tree in Hydrothermal System



Source: Barroso et al. (2003)

The trade-off between immediate and future operational cost in a hydro-based system is showed in Figure 2. The immediate cost function - ICF - is related to thermal generation costs at stage t. As the final storage increases, less water is available for energy production at that stage, then, more thermal generation is needed and costs increase immediately.

Figure 2 - Immediate and Future Costs versus Final Storage

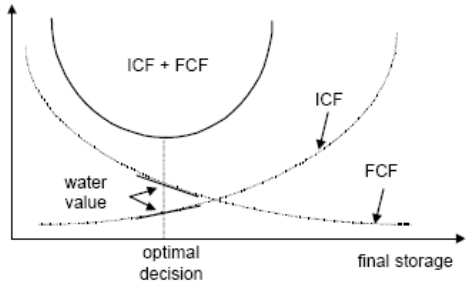


Source:Barroso et al. (2003)

On the other hand, the future cost function - FCF - is associated with the expected thermal generation expenses from stage $t+1$ to the end of the planning period. We see that the FCF decreases with final storage, as more water becomes available for future use.

According to the authors, the optimal use of stored water corresponds to the point that minimizes the sum of immediate and future costs. As shown in Figure 3, this is also where the derivatives of ICF and FCF with respect to storage become equal. These derivatives are known as water values.

Figure 3 - Immediate cost function and future cost function



Source- Barroso et al. (2003)

In Brazil, the National System Operator (ONS) is the institution responsible for the coordination and operation of the power system. It uses a software denominated NEWAVE to solve a stochastic dynamic programming model, that gives the Marginal Operational Cost (CMO) and the water value. Based on the hydrological conditions, the demand for electric power, the fuel prices, the deficit cost, the entry of new projects into operation and the availability of equipment used for generation and transmission, this model set the prices, achieving an optimal result regarding the period being studied, defining both the hydro and thermal power generation for each submarket. As a result of this process, the Marginal Operational Costs (CMOs) are obtained for the period at stake, for each load level and for each submarket.

According to the Brazilian Electric Power Commercialization Chamber (CCEE), in the first instance, the maximum utilization of hydro power available in each period is the most economical premise, since it minimizes fuel costs. However, this premise results in greater risks of having future deficits. The greatest supply reliability is obtained by keeping the level of the reservoirs as full as possible, which means by using more thermal generation and, therefore, by increasing operational costs.

In the Brazilian dispatch system, a system highly dependent on hydrological conditions, it is important to ONS to be able to value all the flexibilities that the system has, to operate and to attend the demand, respecting the premises of cost optimization and risk minimization.

Until know, the flexibility in thermo plants using natural gas was not so relevant, since the only way to have natural gas was by the Brazil-Bolivia pipeline, with "take or pay" contracts. Nowadays, with the introduction of the LNG regas terminals to supply thermo power plants, the ONS has a new option to consider when calculating the marginal cost of the whole system.

2.1 Mechanisms of the Electricity Price Determination

The Brazilian dispatch system minimizes the sum of future and immediate costs, subject to the reservoirs levels, the demand level and the generation plants capacities and the solution of this system establishes the spot price.

In other words, the instrument that determines the spot price of electricity in Brazil, also called Settlement Price for the Differences (translation for Preço de Liquidação das Diferenças - PLD), is result of the optimization of mathematical models based on current storage and future water inflow, i.e., the price is set by an assumption of energy supply as a function of rainfall. Actually, according to Moreira et al (2003), the spot price in Brazil is

an optimality condition of these models. It is equal to the operational costs of the marginal utility at the optimal point. This price reflects the short-term condition of shortage.

These mathematical models purpose to find an optimal equilibrium solution between the current benefit obtained from the use of the water and the future benefit resulting from its storage, measured in terms of the savings from the use of fuels at thermal plants.

The following table summarizes the process used to compute the price of electric power at Chamber of Electrical Energy Commercialization (CCEE), together with the appropriate legislation.

Table 1 - History of PLD Process

Period	Characteristics
September 2000 to May 2001	Monthly "Ex-ante" price per submarket per load level.Computed using the Newave Model (ANEEL's Resolution no. 334/2000) and Official SRG/ANEEL Letter 96/2000
June 2001	Monthly "Ex-ante" price per submarket per load level.Computed using the Newave/Newdesp Model for the North and South submarket which were not included in the rationing. (ANEEL Resolution 202/2001, GCE 12/2001) and Official ANEEL Letter 116/2002.As regards the Northeast and Southeast/Midwest submarkets (under rationing) the deficit cost of R$684.00 per MWh was adopted (GCE Resolution 12/2001).
July 2001 to January 2002	Weekly "Ex-ante" price per submarket.Set pursuant the procedures set forth by GCE (GCE Resolutions nos. 12/2001, 49/2001, 54/2001, 77/2001, 92/2001, 102/2002 and 109/2002).
February to April, 2002	Weekly "Ex-ante" price per submarket.Computed using the Newave/Newdesp Models with weekly revisions (GCE Resolutions 109/02 and ANEEL Resolution 70/2002)
From May 2002 on	Weekly "Ex-ante" price per submarket.Computed using the Newave/Decomp Models (ANEEL Resolutions nos. 42/2002, 228/2002, 395/2002, 433/2002, 794/2002, 27/2003, 29/2003, 377/2003, 680/2003, 682/2003, 686/2003, ANEEL's Homologated Resolutions nos. 002/2004 and 286/2004, ANEEL Official Letters nos. 401/2003, 402/2003, 873/2003, 850/2004 and 01/2005, CNPE Resolution 10/2003, Decree 5177/2004)

Source - CCEE

The PLD is an amount computed on a weekly basis for each load level predicated on the Marginal Operational Cost, which in turn is limited by a maximum and minimum price in effect for each determination period and for each submarket. The calculation of the price is predicated on the "ex-ante" dispatch, that is, it is determined based on envisaged information existing prior to the actual operation of the system, taking into account the declared availability amounts regarding both the generation and the consumption envisaged for each submarket. The complete process for the calculation of the spot price (PLD) consists in the use of the computational models NEWAVE and DECOMP, the result whereof is the Marginal Operational Cost for each submarket, computed respectively on a monthly and on a weekly basis.

Nevertheless, the consensus in Brazil nowadays is that would be better to move to a pricing mechanism that, beyond the supply, also takes into account the demand.

Several market models for the design of liberalized power markets have been used and implemented in many countries throughout the world. Basically one could distinguish two market mechanisms:

- bilateral contracts
- power pools

In the first case, sellers and buyers freely enter into bilateral contracts for power supply with the basic idea to establish a free energy market. Sellers will normally be generators and buyers will be distribution companies and

eligible consumers. In this case, the lack of a system operator can lead to serious imbalances, so this market was never put into practice in Brazil.

The pool model, for its turn, has the main objective to minimize the system cost operation, hence the need to centralize the system operations. In this model, generators and sellers, according to their individual strategies, make their offers and bids. And the system operator sets the market price. Given the physical characteristics of the sector, operations coordinated by a central operator - called in the literature of the system operator - ensure the system reliability.

In the pool market, the market clearing price is the marginal cost of the marginal unit in the absence of transmission constraints. In economics terms, the market clearing price is the point of intersection of supply and demand curves. In the presence of transmission constraints, the cost of producing energy differs and thus prices vary by location.

This is known as locational marginal pricing (LMP) or nodal pricing and is used in some deregulated markets, most notably in the PJM Interconnection, New York, and New England markets in the USA and in New Zealand.

According to Kennedy (2002), these two differing models (pools and bilateral contracts) would be equivalent in a world without transaction costs. The author states the following:

> "In a world with transaction costs, the contracting model may result in a sub-optimal outcome. In other words, price and quantity that do not re.ect real-time demand and supply. In a pool, prices and quantities should reflect actual demand and supply, more so depending on how far ahead of real time trading occurs. Though prices in a pool may be more volatile than in a contracts market, there are hedging instruments available (for example contracts for differences). In terms of institutional capacity, a simple contracts market is more straightforward and less expensive to set up than a power pool."

The advantage of pool mechanisms is that they give more optimal outcomes. The disadvantage of pool mechanisms is that higher costs would be necessary to set up such a pool. This disadvantage should not be over-estimated as the bilateral contracts mechanism would also require some form of central balancing mechanism. Also the frequently stated theoretical disadvantage of the pool mechanism, higher price volatility, is of limited relevance, as financial instruments can be used for hedging.

At the same time it has become apparent that both models (pools and bilateral contracts) might not be so different. A pool could have bilateral contracts alongside the pool and in a bilateral contracts mechanism a voluntary power exchange could be considered. To better illustrate the difference between both models one can distinguish between market models with central dispatch of generating units and mechanisms with self-dispatch of generating units. Normally, central dispatch of all generating units is related to mandatory pools. Self-dispatch means that generators decide on the dispatch of their own generating units and this regime applies to bilateral contracts models.

The characteristic of central dispatch can offer important advantages:

1. It allows for more integrated treatment of generation and transmission plant. This means that transmission constraints can be managed more efficiently.

2. The principle of central scheduling and dispatch normally builds on current practices for systems that are in the process of implementing liberalized market models.

3. Central dispatch allows for the application of nodal pricing. Nodal pricing can only be applied if all relevant information for both generation and transmission are known at a central level. Examples of the application of nodal pricing can be found in the US, Singapore Chile and Argentina.

In Brazil, electricity demand and supply is coordinated through a “Pool”(Ambiente de Contratação Regulado, ACR). Demand is estimated by the distribution companies, which have to contract 100 per cent of their projected

electricity demand over the following 3 to 5 years. These projections are submitted to an institution (Empresa de Planejamento Energético, EPE), which is responsible for estimating the required expansion in supply capacity to be sold to the distribution companies through the pool. The price at which electricity is traded through the pool is an average of all long-term contracted prices and is the same for all distribution companies and each distribution company have different portfolios of contracts. To optimize the pool functioning, self-dealing (i.e., the purchase of electricity by distributors from their own subsidiaries) is not possible. Therefore, vertically-integrated companies need to be unbundled. The Brazilian pool differs from those in other countries (the former UK electricity pool, the Scandinavian Nordpool) because the former is based on long-term contracts, whereas in the latter case it focuses on very short-term contracts.

In parallel to the "regulated" long-term pool contracts, the Brazilian system has a "free" market where generators and consumers deal the extra power demand that were not previously predicted.

2.2 LNG in Brazil

Before the recent installations of LNG regas terminals in Brazil, the natural gas market was provided by national production and, mainly, by imports from Bolivia. These imports, as already said, do not allow a flexible way to contract natural gas, since it is based on "take or pay" contracts. This lack of flexibility and the consequent small reliability in the integrated power system were the great motives to the installation of LNG regas terminals in Brazil.

The first regas terminal in Brazil was installed in Pecém (CE) in 2008 and established the national entrance in the LNG international market. Since then, a new natural gas supply source is available to the Brazilian power system, increasing energy reliability. In 2009 another regas terminal was installed in Rio de Janeiro to supply the Southeast region.

The main reason to install regas terminals in Brazil was the increasing in the volatility of seasonal power demand, due to the climate variations during the last decades. With this flexible natural gas supply source, the thermo power plants can be turned on more frequently during dry periods (between May and November, when the rain occurrence is smaller) and so, more water will be available in the reservoirs for future hydro generation.

The regas capacity in the Pecém terminal is of 7 million cubic meters per day and represents half of the natural gas demand driven to thermo power plants in Brazil. It also represents an additional supply of 11% in the current national natural gas supply, which is 60 million cubic meters per day (July, 2008). The gas processed in this regas terminal will be firstly used in the generation of three thermo power plants: Termoceará (CE), Termofortaleza (CE) and Jesus Soares Pereira (RN).

The optimization of the strategy to buy LNG in the international market is a difficult task that PETROBRAS will have in the LNG terminals context. The company will need to administrate the risk of assign many contracts with different deliver dates, to avoid the surcharges in the loads in case of the ONS ask for the thermo power plants operation.[1]

[1] For its relevance to the Brazilian energy scenario, it is important to note that Petrobras also need to consider relevant aspects of strategic behaviour in its decisions. It is not expected that the company take the position that a private company could be at every time, because the private companies are profit guided in their decisions.

Table 2 - LNG Import Terminals

Facility	Nominal Capacity (mmtpa)	Nominal Capacity (mmcfd)	Owner	Status	Startup
Pecem	2.01	255	Petrobras	Operational	2009
Baia de Guanabara	4.11	521	Petrobras	Operational	2009

Source: Wood Mackenzie

About the current domestic pipeline scenario in Brazil, there are four gas transmission grids, all of which are operated by Transpetro – a subsidiary of state-controlled PETROBRAS. The largest of these four grids carries associated gas production from Campos Bay to the major metropolitan areas of Rio de Janeiro, Sao Paulo and surrounding states. Another transmission grid moves gas from the Campos Bay fields to industrial customers and cities in the state of Espirito Santo. The remaining transmission systems are along the northeast coast – one from Pecem in the Ceara state to Pilar in Alagoas, and the other between Aracaju in Sergipe and Itabuna in Bahia state. These serve customers in the cities of Fortaleza, Recife and Salvador – and surrounding states. The two southern grids are connected to each other, and the two northeast grids are also connected to each other.

Brazil has begun to import LNG recently, so it is difficult to know the LNG pricing structure that will be the mandatory. Given its position as a southern hemisphere importer, they are expected to import the majority of LNG during the period when LNG demand is traditional low i.e. the northern hemisphere summer. This therefore puts them in a position whereby they can negotiate for spot/short-term volumes when prices are likely to be lower. Much of the competition for LNG supplies at this time of the year comes from the US so prices may include some sort of indexation to the Henry Hub (to reflect LNG players' ability to sell into the US market).

The table below gives an indicator of gas prices in Brazil at different oil prices. Given that there has been a limited correlation between oil price and the Brazilian gas price in the past, the analysis below uses the European market as a proxy to give an indication of how the gas price in Brazil will vary with oil price, as it becomes increasingly linked to the supply and demand dynamic of the wider global gas market.

Table 3 - Gas Price Estimates

Oil Price – Brent ($/bbl)	20	30	40	50	60	70	80	90	100
DES LNG Price ($/mmbtu)*	3,10	4,20	5,30	6,40	7,50	8,60	9,70	10,80	11,90
Regasification Cost ($/mmbtu)*	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
Regasified Price ($/mmbtu)*	3,45	4,55	5,65	6,75	7,85	8,95	10,05	11,15	12,25
Transportation Cost to Market ($/mmbtu)*	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07
Market Wholesale Gas Price ($/mmbtu)*	3,52	4,62	5,72	6,82	7,92	9,02	10,12	11,22	12,32

3 Literature Review

3.1 The Real Options Approach

The Real Options approach is a tool for analysis of real opportunities and investments based on the derivatives traditional valuation. According to Copeland and Antikarov (2001), a real option is the right, but not the obligation, to take an action (as such deferring, expanding, contracting or abandoning) at a predetermined cost called the exercise price, for a predetermined period of time (the life of the option). Considering managerial flexibility, real options is a concept distinguished from net present value, or discounted cash flows, which deals only with expected cash flows, discounted at a constant rate, since risk is assumed to be unchanging during the project duration.

Real options are classified primarily by the type of flexibility that they offer. Based in Trigeorgis (2002), we can show some examples, as such:

1. deferral option - is an American option found in many projects. Suppose the firm has a one-year license granting it the exclusive right to defer undertaking the project for a year (e.g., to construct a new plant of the same kind being considered). This option will give the value of the investment opportunity provided by the license.

2. option to expand - Once a project is undertaken, management may have the flexibility to alter it in various ways at a different times during its life. The option to expand is an excellent example of the strategic dimension of a project. Management may find it desirable, for example, to make additional follow-on investment if it turns out that its product is more enthusiastically received in the market than originally expected.

3. option to contract - Analogous to the option to expand a project is the option to contract the scale of a project's operation by forgoing planned future expenditures if the product in not as well received in the market as initially expected. The option to contract can thus be seen as a put option on the part of the project that can be contracted, with an exercise price equal to the part of planned expenditures that can be canceled.

4. switching option - This option allows for managerial decisions to switch, possibly at specified switching costs, among alternative "modes" of operation (e.g., projects, machines, fuel, technologies) at multiple decision points or in each period.

5. option to abandon - In addition to temporally not operating in a given year or terminating a project in its current use earlier than originally expected in order to either switch to its future best alternative use or sell its assets on the second-hand market, management may find it justifiable to abandon a project during construction to save any subsequent investment costs

According to Marreco et al (2007), when applying the Real Options approach, the first step is to identify the existing options in the project. The second step is to choose the appropriate evaluation method. There are three ways in valuing an option:

1. Partial Differential Equations resolutions;

2. Simulations;

3. Dynamic Programming.

It is a well known fact that, in many cases, we do not have a close form solution to differential equations. Marreco et al (2007) quote a particular case when the differential equations can have a solution, using the Black & Scholes formula. However, this is not always useful and sometimes it is necessary to use numerical methods, when we will find a solution through successive iterations.

The most famous simulations method is the Simulations of Monte Carlo (SMC). The SMC encompasses many real applications, including complicated decision rules and complex relations between the option value and the based asset value. In this method, the variables are changed to create thousands of evolution possibilities to characterize the based asset path from the present date until the option expiration.

The SMC is a method more and more used in the derivatives applications, including in the real options approach. The Monte Carlo method solves the problem through a direct simulation of the physical process, in a way that is

not necessary to write the real option differential equation. It is an extremely flexible tool, able to encompass many specific details from real life problems, including many constraints, complex payoffs and many uncertainty sources. Dias (2005) describes the method as an antidote for the "Curse of Dimensionality" problem. He also says that the method helps the modeling, allowing the solution of more complex real problems.

Finally, the dynamic programming could be illustrated by the binomial model[2], proposed by Cox, Ross e Rubinstein (1979). This method uses a diagram in which are represented all the possible values in each time period of the option's life. The binomial option pricing model is widely used as it is able to handle a variety of conditions for which other models cannot be readily applied. It also requires relatively simple math and can be easily implemented in software or even in a spreadsheet environment.

3.2 Thermo power Flexibility Analysis

According to Nascimento (2009), the operational flexibility is the most analyzed and precificated option in the thermo power context. This evaluation considers profitable to continue thermo plant operation if the electricity spot price is above the variable cost. Nonetheless, when the variable cost achieves an upper level, the flexibility turns it possible to reduce the generation in that plant or even stop operation to avoid losses.

In spite of this operational flexibility be the most highlighted one, in the present paper we will focus in an additional format for this flexibility: the switch-input option. As the denomination states, in this option, in each period, the agent choose the smallest operational cost that is possible when the plant can switch an input, as such the fuel. The idea is that the flexibility in the input choice creates value to the real asset.

According to Trigeorgis (1996), if there is no substitution cost between the inputs, the value of the flexible project can be seen as the value of the project without flexibility plus the sum of the option values of the choices in future periods. The following equation presents this argument:

$$V_{option} = PV_{flexible} - PV_{rigid}, \tag{1}$$

in which V_{option} can be seen as the flexibility premium and PV means project value.

Kulatilaka (1993.1) presents a general model of flexibility using Real Option technique to capture the strategic impact of flexible projects. As we already know, discounted cash flows (DCF) analysis ignores highly volatile environments and flexible technologies.

In Kulatilaka (1993.2) the author applies his general model to the case of an industrial steam boiler that can switch between using residual fuel oil and natural gas. In this exercise neither discount rates nor expected cash flows can be taken as strictly exogenous. Comparing the flexible fuel boiler with boilers that can be fired with natural gas only or residual fuel only, the flexible ones, despite the additional investment ($\triangle I$) necessary, creates a valuable asymmetry: higher oil price volatility increases average net cash flow as "benefits accrue when oil prices fall, but losses are limited by the price of gas" (in each period, the flexible boiler cash flow is higher by the amount $max(P_{oil} - P_{gas}, 0)$, which is formally identical to the pay-off of a call option). Furthermore, the investor still has the option to switch back to oil in the future in the event of a price reversal of sufficient magnitude (which is analogous to a put option on the oil price).

First of all, Kulatilaka presented a risk-neutral formulation, where: There are m modes of operation: $m = 1, \ldots, M$; the switching cost from mode j to mode $k = cjk$; $cmm = 0$ and $Income\ Flow = \pi(P_t, m, t)$.

The switching cost make a forward-looking analysis necessary as, in his application, the probability distribution of future oil to gas price ratios affects the current choice of technologies.

[2] The binomial pricing model uses a "discrete-time framework" to trace the evolution of the option's key underlying variable via a binomial lattice (tree), for a given number of time steps between valuation date and option expiration.

Future net profit flows assuming that "the firm always chooses the current mode to maximize the present value of current plus discounted expected future profits net of switching costs", the Bellman Equation, is given by:

$$F(P_t, m, t) = \max_t \{\Pi(P_t, l, t) - c_{ml} + \rho E_t[F(P_{t+1}, l, t+1)]\}, \tag{2}$$

where $l, m = 1, ..., M; t = 0, ..., T$ and $\rho = e^{r\Delta t}$, in which r is the risk-free interest rate.

The uncertainty faced by the firm is concentrated on the value of the state variable, which is exogenous and stochastic, following a process like:

$$\frac{\triangle P_t}{P_t} = \mu(P_t, t)\triangle t + \sigma(P_t, t)\triangle Z_t \tag{3}$$

In order to account for risk-averse investors in this framework, Kulatilaka used certainty equivalent drift rates on the cash flows, which are simply the actual drift minus the risk premium that would emerge in market equilibrium on an asset with the same risk features as the stochastic variable (Cox, Ingersoll and Ross, 1985).

When evaluating the cost saving of a dual-fuel boiler over the two single-fuel boilers (oil and gas), Kulatilaka found that the value of flexibility exceeds the incremental investment cost of purchasing a dual fuel boiler. However, this result makes a linkage between the markets and therefore may reduce the volatility of relative price changes, potentially reducing the future value of flexibility (Caballero, 1991).

Another article that makes flexibility analysis is Moreira et al (2004) where the authors studied the competitiveness of thermo power generation in Brazil, where hydro power supplies most of the country's demand at a very low price most of the time, but, on the other hand, the system is very vulnerable to seasonal water affluence variations. They used a stylized system, with one hydro and one thermo power plant, without transmission constraints/losses and applied the Bellman recursive method to solve the stochastic model. However, Markovian dynamics imply that the system expansion is predefined, that is,

> "investors do not react to the price evolution over time and the system is expanded according to a predefined plan, whatever the energy price is. (...) To have a more realistic model for long-term expansion planning, the authors considered the uncertainties in the power demand forecast and in natural gas price, besides the uncertainty in water affluence, as the load and gas price are correlated to the macro-economical variables gross national product growth and world economic growth."

They achieved some interesting conclusions:

- The regulation policy should not be based only on the energy deficit cost if it expect to attract investments in power generation;
- The power traded in the spot market is highly vulnerable to the system unbalance degree;
- Flexible systems optimizes the operation of thermo power plants and does not increase the critical price;
- Long term forward contracts may be used as hedge to revenue uncertainty;
- Thermo power expansion are economical if hydropower investment cost is 3 times the amount of the thermo power investment cost;

- Thermo power plants may be not competitive because of their operational inflexibility that increases the operational cost up to 70%.

A more recent analysis on flexibility valuation is the paper of Marreco and Carpio (2006) where the authors also studied the operational flexibility in the Brazilian Power System. As already mentioned here, the Brazilian Power System is highly dependent in hydrological conditions, which makes necessary the existence of thermo power plants to supply part of the energy during dry periods, then, avoiding deficit costs in the future.

However, dispatch revenues are not sufficient to turn these thermo power plants economically feasible. Therefore, the authors used Real Options Theory to create a methodology to compute the fair value of a financial subsidy to be paid to thermal generators for their availability to the system. Their approach was based on the one adopted by Kulatilaka (1998) and Trigeorgis (1999). The operational flexibility was represented by two modes of power generation: thermo power plants (mode A) and hydropower plants (mode B). "For each node in $t = T$ they calculated the value of this flexibility option and then discounted it by the riskless rate according to the neutral risk probabilities that were calculated by the binomial method". As a numerical example, they "ran the model for the Southeast subsystem and found a flexibility value of $US\$\ 4.52$ billion that represents $US\$\ 497/MW$ per year, value that represents only 0.05% of total investment in a natural gas thermo power plant. This means that a 100MW thermo power plant should receive $US\$\ 49,700$ for each year of its economic lifetime.

4 Model

The mean-reversion process has been considered the natural choice for commodities pricing. According to Laughton & Jacoby (1995), basic microeconomics theory tells that, in the long run, the price of a commodity ought to be tied to its long-run marginal production cost or, in case of a cartelized commodity like oil, the long-run profit-maximizing price sought by cartel managers. It means that, although the oil prices have sensible short-term oscillations, it tends to revert back to a "normal" long-term equilibrium level. Other important mean-reverting evidence comes from the futures market, as pointed out by Baker et al (1998).

Mean-reversion model was first described by Vasicek (1977) for the interest rate dynamics, but was subsequently adapted in other fields including energy markets. According to Skorodumov (2008), the most common models that consider mean reversion in the Geometric Brownian Motion (GBM) mainframe are the models which consider mean reversion to the long term mean and mean reversion to the long term price logarithm. While second model seems less natural, it has some modeling advantage. Schwartz (1997) used the following equation to represent the one-factor model of a mean reverting commodity price S_t:

$$dS_t = \alpha S_t(\mu - \ln S_t)d_t + \sigma S_t dZ_t \tag{4}$$

In this model, we have the spot price mean-reverting to the long term level:

$$E[St] = e^{\mu - \sigma^2/2\alpha} \tag{5}$$

The speed of this reversion is given by the mean-reversion rate α, which is taken to be strictly positive. So if the spot price is above the long term level, then the drift of the spot price will be negative and the price will tend to reverts toward its long-term level. In the same way, if the spot price is below the long-term level then the drift will be positive and the price will tend to move back towards $E[S_t]$.

A key property of a mean-reverting process is the half-life $t_{1/2} = \ln(2)/\alpha$. This is the time that takes for the price to revert half way to its long term level from its current level.

Concerning the estimation, the spot price can be estimated in a simple and robust way via linear regression. Applying the Ito's Lemma for $X_t = ln(S_t)$, the equation 4 can be written as:

$$dX_t = \alpha(\mu^* - X_t)d_t + \sigma dZ_t \tag{6}$$

where $\mu^* = \mu - \frac{\sigma^2}{2\alpha}$.[3]The equation can be discretized as:

$$\Delta X_t = \beta_0 + \beta_1 X_{t-1} + \sigma\varepsilon_t, \varepsilon_t \tilde{} \ N(0,1) \tag{7}$$

where $\beta_0 = \alpha\mu^*\Delta t$ and $\beta_1 = -\alpha\Delta t$.The interpretation is that observations of the spot price through time can be considered as observations of the linear relationship between ΔX_t and X_t in the presence of noise $\sigma\varepsilon_t$.

The equation for ΔXt is an arithmetic Ornstein-Uhlenbeck process and it is the continuous time analogous of the first-order autoregressive process, AR(1), in discrete time. According to Skorodumov (2008), the classical steps in testing the mean reversion in a series of prices ΔX_t is to test whether in the equation 7 the β_1 coefficient is significantly different from 1.

The real simulation of this model is given by the following equation that uses an exact discretization that allows large Δt :

$$S_t = \exp\{\ln(S_{t-1})(\exp(-\alpha\Delta t))] + [(\mu - \sigma^2/2\alpha)))(1 - \exp(-\alpha\Delta t))] + [\sigma SQRT((1 - \exp(-2\alpha\Delta t)))\ N(0,1)]\} \tag{8}$$

Where SQRT(.) is the square root operator. The simulation is very simple, you get the sample paths of S_t by sampling the Normal distribution and using the equation above.

The expected value for S_t in the simulation is given by taking the expectations - including the convexity adjustment - in the above equation:

$$E[S_t] = \exp\{[\ln(S_{t-1})(\exp(-\alpha\Delta t))] + [(\mu - \sigma^2/2\alpha))(1 - \exp(-\alpha\Delta t)] + [(\sigma^2/4\alpha))(1 - \exp(-2\alpha\Delta t)] \tag{9}$$

For the risk-neutral simulation, we need to subtract from $\mu^* = \mu - \sigma^2/2\alpha$ the normalized risk-premium $(\gamma - r)/\alpha$, where γ is the risk-adjusted discount rate for the underlying asset X. Doing this, we have the risk-neutral equation:

$$S_t = \exp\{[\ln(S_{t-1})(\exp(-\alpha\Delta t))] + [(\mu - \sigma^2/2\alpha) - (((\gamma - r)/\alpha))(1 - \exp(-\alpha\Delta t))] + [\sigma(SQRT((1 - \exp(-2\alpha\Delta t))/(2\alpha)))\ \mathrm{N}(0,1)]\} \tag{10}$$

If we take the expectation of the above equation, we have the expected value of the future prices in the risk-neutral format, because the random term has zero mean, from the standard Normal distribution, and considering the convexity adjustment.

4.1 Real Options Exercise

[3]It means that the long-run equilibrium price (real process) depends on both the volatility and the reversion speed.

In this paper, our exercise will be a valuation study of operational flexibility in the national electric system after the regasification terminal installation in the Northeast subsystem. In other words, we will compare the marginal cost operations in the subsystem in the presence of the PETROBRAS thermo power plants that use the LNG with the marginal cost operations without those thermo power plants.

According to Marreco and Carpio (2005), thermo power plants represent operational flexibility for the national system operator provided they can be dispatched in dry periods to supply part of the load when reservoir waters are too low. And deficit costs can be avoided as a result. The authors also highlight the importance of the complementarity between thermo and hydro power in Brazil, once most hydro power plants are too far from consumers, increasing the necessity in transmission investments and costs. In that way, thermo power plants are a good alternative for regions with hard to access transmission, and where system constraints result in temporary blackouts. A good characteristic of these thermo plants is that they are building in shorter periods than hydro plants and have lower capital costs.

The estimation consists in model the Henry-Hub series and the water affluence series as mean-reverting brownian motion processes. With the parameters of these stochastic processes, we run the simulation of paths for both series. The traditional simulation method looks for produce many hypothetical situations, with software computer assistance, which use generators of aleatory variables to creation of scenarios, allowing the analysis of the various probability distributions from the possible values assumed by these variables.

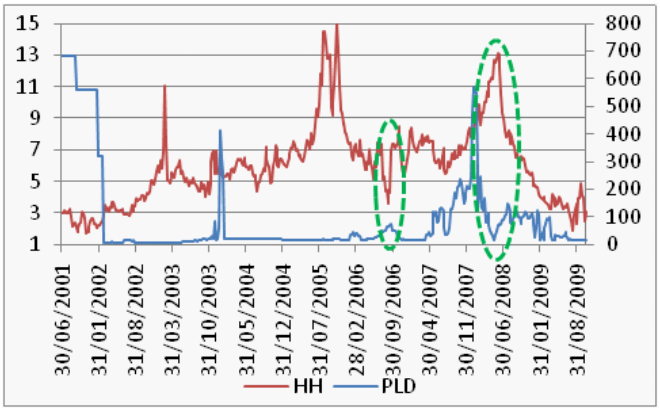
4.2 Stochastic Processes Estimation

The water affluence and the natural gas price are stochastic processes, whose parameters can be estimated based on historical data. The processes need to be uncorrelated and the random errors are presumed to have zero-mean Normal distributions.

However, it is common knowledge that the HH series and the spot price (known as PLD and result of the optimization of hydro power utilization) of the Brazilian electric energy system have a correlation, expected to be negative. This happens because of the seasonality in the natural gas market and the rain period in Brazil. Actually, the high natural gas demand period in the North coincides with the rain period in Brazil.

We estimate the correlation between the HH and the PLD and we found -0.2929. The result indicates the necessity to work with the seasonality characteristic observed in these series.

Figure 4 - Correlation Between HH and the Spot Prices (PLD)

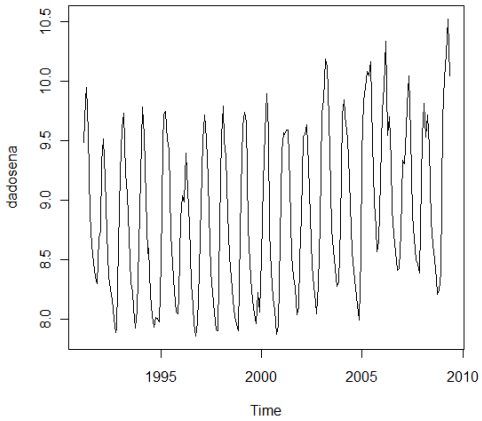


Source - Bloomberg and CEEE.

To the water affluence, we will use a long-term historical data series, collected since 1930. According to Moreira et al (2004), the water affluence in the main Brazilian hydrological basins is suitably modeled by a stationary periodic autoregressive process. Removing the periodic or seasonal component, the remaining process AR(1) can be also modeled as a mean reverting process.

In our specific case, we need to model only the Northeast hydrological basin. This original data series is plot in figure 5.

Figure 5 - Water Affluence - Northeast Subsystem



Applying the decomposition of additive time series in the water influence, we have the seasonal and the trend components separately, as seen in figure 6.

Figure 6 - Water Affluence Series Decomposition - Northeast Subsystem

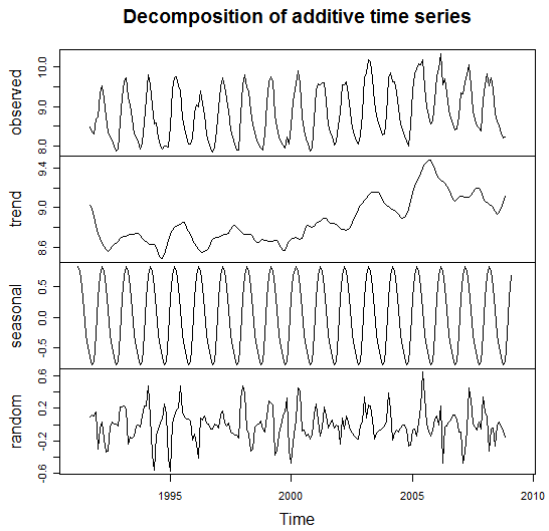


Figure 7 shows the water affluence series without the seasonal component. We test the hypothesis of mean reversion in the water affluence series.

Figure 7 - Water Affluence - Northeast Subsystem - Without the Seasonal Component

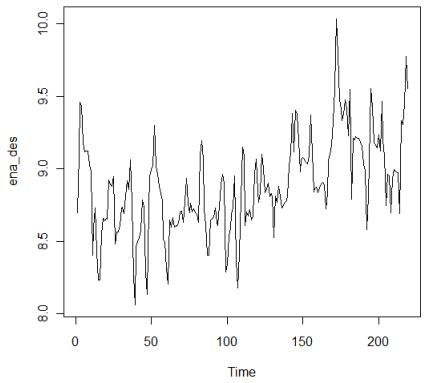


Table 4 shows the result of the Phillips-Perron test in the AR(1) equation of the water affluence series, which test the mean reverting hypothesis. As one can see, with the coefficient of the water affluence lag between 0 and 1, we cannot reject the mean reverting hypothesis.

Table 4

Phillips-Perron Unit Root Test in the Water Affluence Series

	Coefficient	T-stats	P value
Intercept	1.8103***	4.982	1.27e-06
Water_{t-1}	0.7966***	19.505	2e-16

Signif. codes: 0'***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

As showed before in the present chapter, in spite of the main LNG markets (United States, Continental Europe and England) are staying more and more connected, we still don't have a global price to the LNG. Nonetheless, it is a common practice in the Energy Economics literature the use of the Henry-Hub (HH) series as a proxy to the LNG price. The HH is a pricing point for natural gas futures contracts traded on the New York Mercantile Exchange (NYMEX). In our specific case, the monthly HH series is also a reasonable choice to model the LNG for many reasons:

(i) We will calculate the value of switch-fuel in the Northeast subsystem. With the geographic position of the Brazilian Northeast, HH is the main proxy for the LNG in the Atlantic basin.

(ii) Because of the possibility of natural gas storage in the American market, the HH attenuate volatility, becoming a better trend to the natural gas price.

(iii) Agents decisions in the HH market are done in a monthly basis.

Then we will use the HH series, from 1991.2 to 2009.10, plus an average estimated shipping cost to the main LNG producers to Brazil (Wood Mackenzie, 2010), as shown in table 5.

Table 5 - LNG Cost Stack Estimates

Units: *US$/mmBtu*

	WM Estimated FOB Cost	WM Estimated Shipping Cost	WM Estimated Regas Charge	Total Cost @ Border Point
NLNG Expansion	0.44	0.58	0.50	1.52
NLNG Plus	0.56	0.58	0.50	1.64
Atlantic LNG 1	1.05	0.40	0.50	1.95
Qatargas-2	-	1.53	0.50	2.03
RL 3	-	1.53	0.50	2.03
Qatargas-4	0.10	1.53	0.50	2.13
Algeria LNG	1.00	0.68	0.50	2.18
NLNG 6	1.23	0.58	0.50	2.31
Atlantic LNG 4	1.69	0.40	0.50	2.59
EG LNG	1.71	0.60	0.50	2.81
ELNG 2	1.83	0.91	0.50	3.24
ELNG 1	1.98	0.91	0.50	3.39
Damietta	2.01	0.93	0.50	3.44
Angola LNG	3.52	0.63	0.50	4.65
Yemen LNG	2.87	1.34	0.50	4.71
Peru LNG	3.39	1.16	0.50	5.05
Snohvit	5.95	0.95	0.50	7.40

Source: Wood Mackenzie

Figure 8 shows the HH series with all components. In figure 9, we apply the filter to get the series without the seasonal component.

Figure 8 - Henry-Hub

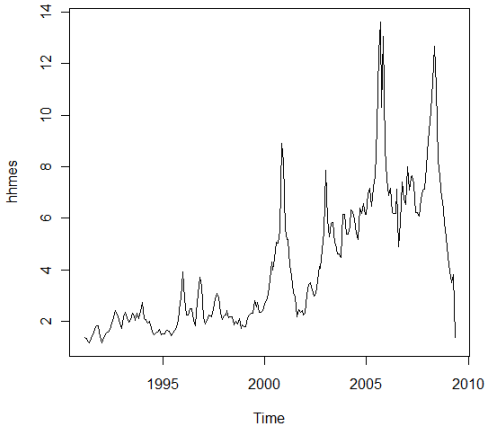


Figure 9 - Henry-Hub Series Decomposition

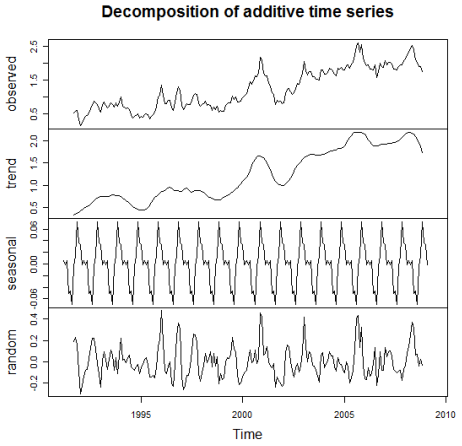
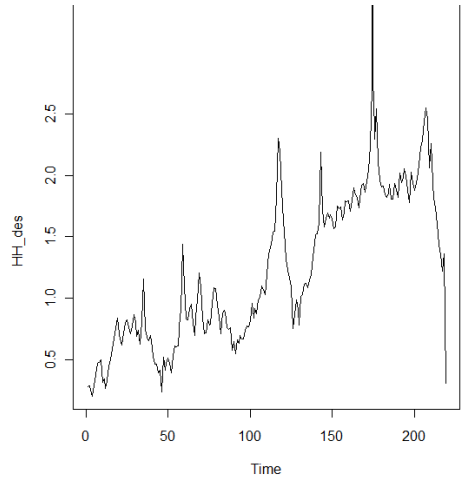


Figure 10 presents the HH series without the seasonal component.

Figure 10 - Henry-Hub - Without the Seasonal Component



We test the mean reverting hypothesis in the HH series from figure 10. Applying the Phillips Perron test we also can not reject the mean reverting hypothesis in the water affluence series from the Northeast basin.

Table 6			
Phillips-Perron Unit Root Test in the HH Series			
	Coefficient	T-stats	P value
Intercept	0.045	1.822	0.0699
HH_{t-1}	0.963***	52.706	2e-16
Signif. codes: 0'***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '			

With the AR(1) coefficients from both series we can estimate the mean reverting parameters for both series, which include the long run mean, the velocity of the adjustment and the volatility of each process.

Table 7		
Parameters Estimation		
	Water Affluence (in log)	HH (in log)
β_0	8.8926	1.22210
β_1	0.2043	0.00345
σ	0.21997	0.16738

5 Results

In this section we will report the results of the simulations of Monte Carlo (SMC) of the Henry Hub price adjusted by the shipping cost (our proxy of LNG price) and the simulations of the water affluence.[4] [5]Both will give us the costs of the fuels among which the PETROBRAS (and, in a general point of view, the Brazilian electricity system) has the flexibility to choose to operate the thermo plants in discussion.

Figures 11 and 12 show the average value of 10,000 simulations of the stochastic process by SMC for the HH price and for the water affluence in the Northeast basin.

Figure 11 - Simulated Average Log (HH) Price and

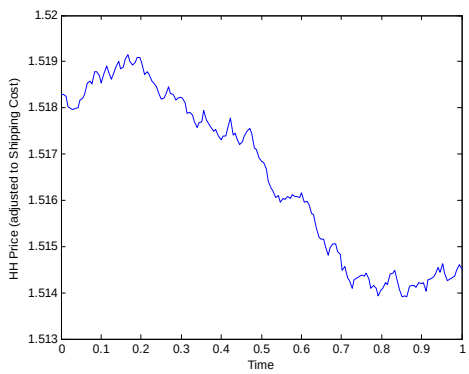
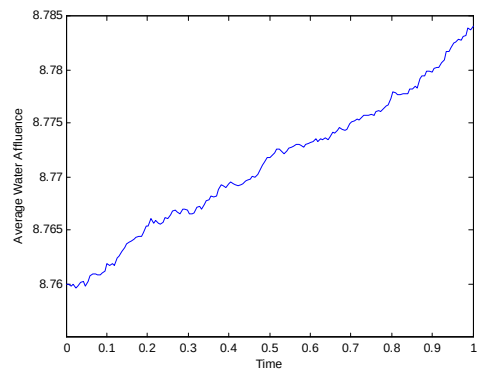
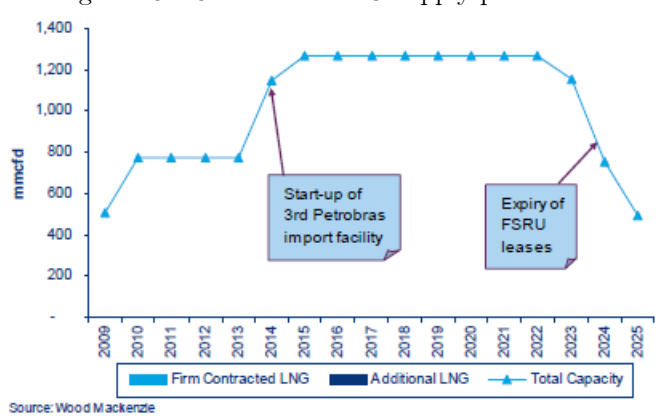


Figure 12 - Simulated Average Log(Water) - Northeast



The figure 13 shows the start-up of the third PETROBRAS import facility of LNG, in middle of 2014. Then, we will use this time length to calculate the real option, because the third import facility could be an opportunity to evaluate the LNG use in the Brazilian electric system.

Figure 13 - Contracted LNG supply position in Brazil



[4]The following numeric exercise is just an example of the value that the thermo power plants using LNG can aggregate to the system. The example using real data is in the scope of the study and will be the continuity of this paper, when we have access to the NEWAVE and DECOMP programs.

[5]The SMC were executed in the Matlab software, using a code conceded by professor Fernando Aiube (Petrobras and Puc-Rio), whom we would like to thank. The Real Options calculations, in turn, were done in VBA (Visual Basic for Applications). The functions used in this part of our exercise are listed in the Appendix B.

The risk-free interest rate used in the exercise (r) should be a real interest rate with a similar maturity of the real options exercise time horizon. In this case, will be used an interest rate for 5 years (until 2015): Brazilian treasury bills indexed to the inflation (IPCA index), called NTN-B[6]. As a reference, we use the real interest rate from the market quotation of the NTN-B with expiration date in 05/15/2015. In 10/12/2010, this annual real interest rate was 5.9199 %.

However, we have monthly variation in our data. So it is necessary to use the interest rate after the conversion: $(1 + 0.059199)^{\frac{1}{12}}$. It results in a real interest rate of 0.48% per month.

We use the simulated HH price series as a proxy to the operational cost of the thermo power plants. So, consider Ci = LNG operational cost (approximately the Henry Hub price adjusted by the shipping cost) and Cj = Hydropower plants operational cost in the Northeast subsystem. As we do not have, at the present moment, this real operational cost of the hydro power plants without the thermo power plants of Termoceará (CE), Termofortaleza (CE) and Jesus Soares Pereira (RN), we will simulate the real options exercise with some extreme possible operational costs (from US$/MWh 3 to US$/MWh 18, based on historical CMOs to the Northeast subsystem)[7].

The decision rule for the exercise is[8]:

A) If Power supply > Power Demand $\Longleftrightarrow$ option is the use of the thermo power plants or only the hydro power plants $\Longleftrightarrow$ $Cash\ Flow = min(Ci, Cj)$

Ci = LNG operational cost (Henry Hub adjusted by the shipping cost)

Cj = Hydropower plants operational cost in the Northeast subsystem

B) If Power supply < Power Demand $\Longleftrightarrow$ option is use the thermo power plants or incur in the deficit cost $\Longleftrightarrow$ $Cash\ Flow = min(Ci; Deficit\ Cost)$

Ci = LNG operational cost (Henry Hub adjusted by the shipping cost)

Deficit Cost = Established by a technical note from the Energy Ministry (MME) and EPE. The last edition is from 2009 and is listed in table 8.

Table 8 - Deficit Cost

Load Reduction	Deficit Cost (US$/MWh)
0% < LR < = 5%	617.81
5% < LR <= 10%	1332.80
10% < LR <=20%	2785.14
LR > 20%	3164.99

Source - MME and EPE. Exchange Rate in Nov,12,2010.

We use a Northeast power supply fixed in time, the average of the mean reverting process simulated for the water affluence, showed in figure 12. For the Northeast power demand until 2015, we had simulated a random walk

[6] The source of this data is the ANDIMA website, at www.andima.com.br.

[7] The calibration of models is a common practice in the Real Options literature. For example, when we are analyzing an option that is not traded on the market or that has little liquidity. In our case, we did not use the real operational cost of the hydro power plants, because we didn't have access to the NEWAVE and DECOMP programs until the time of this thesis defense.

[8] In our case, we can add that the described decision rule is a choice of a risk-neutral firm, as in Dixit & Pyndick (1994). The authors show many papers that associate this category of decision rule with risk-neutral agents.

process with drift, as done in Moreira et al. (2004).

The real option exercise has the following equation:

$$V_{option} = PV_{flexible} - PV_{rigid},$$

in which the present value of the option with no flexibility is given by:

$$PV_{rigid} = \sum_{t=1}^{62} \frac{[Cj]_t}{(1+r)^t}$$

and the present value of the option with flexibility is:

$$PV_{flexible} = \sum_{t=1}^{62} \frac{E[min(Ci, Cj)]_t}{(1+r)^t}, if\ supply > demand \text{ or}$$

$$PV_{flexible} = \sum_{t=1}^{62} \frac{E[min(Ci; Deficit\ Cost)]_t}{(1+r)^t}, if\ supply < demand$$

The proportion of the simulated points in which it is better to choose "B" in the decision rule is very restricted. Then, we do not observe a significative difference in the exercise between the application of the different deficit cost levels. The results of the exercise are valid to deficit cost in the range of US$/MWh 617.81 to US$/MWh 3164.99.

Operational Cost of Hydro Power Plants	Option Value (in US$)
US$/MWh 3	-10.06
US$/MWh 6	5.25
US$/MWh 9	88.17
US$/MWh 12	235.97
US$/MWh 15	396.20
US$/MWh 18	556.42

The exercise illustrates how the use of the LNG can be a topic of utmost importance to the Northeast subsystem and to the Brazilian system as a whole, especially when the reservoirs are in a low level or, in other words, when the marginal operational costs of the hydro power plants are high.

From the US$/MWh 6 operational cost level on up, it is profitable to have a system using the PETROBRAS thermo power plants operating with the LNG. The value added to the system is very sensitive to this operational cost increase, which is a sign of the already exposed trade-off between immediate and future operational cost in a hydro-based system.

6 Conclusions

The Brazilian dispatch system is highly dependent on hydrological conditions. In this scenario, it is an important task to the Brazilian energy sector institutions to be able to value all the flexibilities that the system has to operate and to attend the demand, respecting the premises of cost optimization and risk minimization.

Until know, the flexibility in thermo plants using natural gas was not so relevant, since the only way to have natural gas was by the Brazil-Bolivia pipeline, with "take or pay" contracts. Nowadays, with the introduction of the LNG regas terminals to supply thermo power plants, the ONS has a new option to consider when calculating the marginal cost of the whole system.

This paper is a first attempt to identify the importance of the LNG use in the Brazilian electric energy system. We had applied the Simulations of Monte Carlo in stochastic processes and the Real Options technique to analyze the possible value added by the use of the LNG in the thermo power plants Termoceará (CE), Termofortaleza (CE) and Jesus Soares Pereira (RN). We also tried to understand the pricing mechanism adopted in the Brazilian electric sector and its consequences to the system operation.

The next step in this study will be to use the real costs in the integrated Brazilian dispatch system program (NEWAVE) to compare when it is profitable to turn on the thermo power plants using the LNG or when it is better to use the water from the reservoirs to attend the Northeast subsystem demand.

7 Appendix A

Following Skorodumov (2008), in this appendix, we present the connection between the one-factor model and the Ornstein-Uhlenbeck stochastic processes. Suppose that the commodity price follows the mean-reverting process:

$$dS_t = \alpha S_t(\mu - \ln S_t)d_t + \sigma S_t dZ_t$$

where α is the speed of mean reversion and μ the long run mean level. Applying the Ito's Lemma for $X_t = lnS_t$, we have,

$$d(\ln S_t) = \frac{dS_t}{S_t} - \frac{(dS_t)^2}{2S_t^2}$$

Using that $dS_t^2 = \sigma^2 S_t^2 dt$, the equation can be written as:

$$dX_t = \alpha(\mu^* - X_t)d_t + \sigma dZ_t$$

with $\mu^* = \mu - \frac{\sigma^2}{2\alpha}$. The above expression is the arithmetic Ornstein-Uhlenbeck. In order to find its long term mean, we will apply the following Ito's substitution $f(X_t, t) = X_t e^{\alpha t}$ to the antecedent equation. The result is:

$$d(X_t e^{\alpha t}) = \alpha\mu^* e^{\alpha t} dt + e^{\alpha t}\sigma dZ_t$$

which, fot its turn, has the following solution:

$$X_t = X_0 e^{-\alpha t} + \mu^*(1 - e^{-\alpha t})$$

The long run mean can be obtained from this last equation when we apply $lim_{t\to\infty} E[Xt] = \mu^*$. Thus, the long run mean of S_t is $E[S_t] = e^{\mu - \frac{\sigma^2}{2\alpha}}$.

8 Appendix B

In this appendix, we present the functions used in the VBA to simulate the Real Options exercise. They are the Cholesky and BoxMuller functions. The fist function was used to take account the correlation between HH price, the water affluence and the electricity demand. The second function is an algorithm to generate random numbers.

1) *Function cholesky (sigma As Object)*

```
Dim n As Integer
Dim k As Integer
Dim i As Integer
Dim j As Integer
Dim x As Double
Dim a() As Double
Dim M() As Double
n = sigma.Columns.Count
ReDim a(1 To n, 1 To n)
ReDim M(1 To n, 1 To n)
For i = 1 To n
 For j = 1 To n
 a(i, j) = sigma.Cells(i, j).Value
 M(i, j) = 0
 Next j
Next i
For i = 1 To n
 For j = i To n
 x = a(i, j)
 For k = 1 To (i - 1)
 x = x - M(i, k) * M(j, k)
 Next k
 If j = i Then
 M(i, i) = Sqr(x)
 Else
 M(j, i) = x / M(i, i)
 End If
 Next j
Next i
cholesky = M
End Function
```

2) *Function BoxMuller()*

```
Randomize
Do
 x = 2 * Rnd() - 1
 y = 2 * Rnd() - 1
 dist = x * x + y * y
Loop Until dist < 1
```

```
BoxMuller = x * Sqr(-2 * Log(dist) / dist)
End Function
```

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CHAPTER 4

Brazilian Road Concessions: An Analysis of the Main Obstacles to a Successful Case

Abstract

This article attempts to understand the current Brazilian Road Concession process. First we discuss historical aspects of Brazilian roads and theoretical aspects of concessions, with special attention to the regulatory components that a government needs to consider when planning a framework for road concession programs. Then we detail the Brazilian experience in road concessions, reviewing both stages of the federal road concession program and one example of a state level program: São Paulo state's approcah. We also analize the new concession format that coexists with the former road concession program (called in Brazil, Public-Private Partnership - PPP). Finally we evaluate the Brazilian experience with road concessions, showing the main obstacles to be overcome in the Brazilian road sector. Our study concludes that the competitive bidding process applied nowadays to road concessions in Brazil cannot be used together with the clause of Financial-Economic Equilibrium that rules road concessions. For reasons broadly discussed, a good regulatory alternative to the Brazilian case would be the use of a different auction model: the Present-Value of Revenue (PVR) auction.

1 Introduction

Brazil has a road network of 1.6 million kilometers, of which 12% are paved (2004, DNIT). Until 1940, Brazil had a very rudimentary road infrastructure, which according to Carvalho et al. (2003) was characterized by a lack of technology and pavement. The Jopert Law of 1945 introduced a new model of road infrastructure provision. This new regulation reestructured the National Department of Roads (DNER), created in 1937, and established a fund called National Road Fund (*Fundo Rodoviário Nacional* - FRN), with resources from fuel taxes, to finance road infrastructure works. The FRN transfers became the main source of funds for Brazilian states and cities to construct and maintain roads and was very important for the improvement in the pavement in the 1960s and 1970s. Federal data[1] indicate that Brazil had (including Federal, State and Municipal roads) 1,200 km of paved roads in 1954, increasing to 50,590 km in 1970. In 1990, this total was 148,121 km and is around 217,800 km in 2010. The following Table presents the improvement in the Brazilian Federal roads specifically.

Table 1 - Evolution of Brazilian Paved Roads (km) - Federal Network

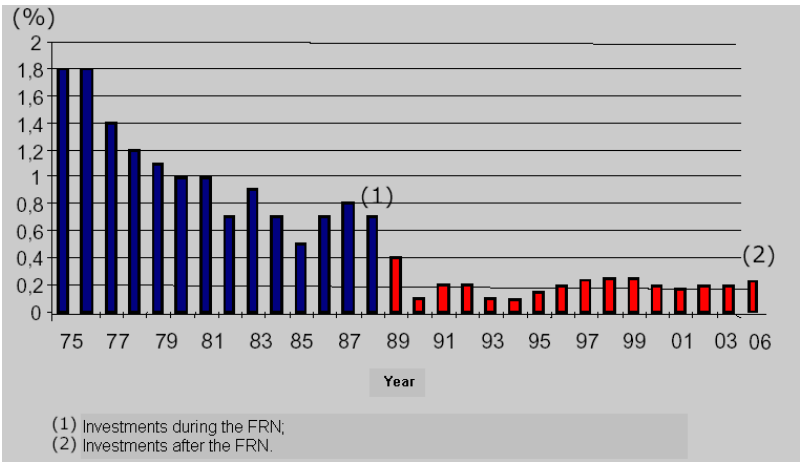
Year	Paved	Unpaved
1930	59	na
1937	81	na
1939	207	na
1959	7,457	22,373
1960	8,675	23,727
1970	24,146	27,394
1980	47,487	38,604
1990	50,372	13,460
1995	51,370	14,046
2000	56,097	14,522
2005	58,166	14,651
2010	61,967	13,759

Sources: PNV and Andreazza (1974)

After the Oil Crisis, of the 1970s, Brazil's severe fiscal restrictions caused a depletion of funds in the FRN, which was closed by the new Constitution in 1988. Thereafter, the investments in transportation did not have a direct line item in the Federal budget. Consequentially, investment in the sector diminished (see Figure 1) resulting in the deterioration of Brazilian roads.

[1] In http://www.estradas.com.br

Figure 1 - Brazilian Investments in Transportation as a Percentage of GDP



Source - *Associação Brasileira de Concessionárias de Rodovias*,ABCR (Presentation of the President, May 2007).

Karam (2005) reported that a recent attempt to capture resources for the sector by the implementation of CIDE (*Contribuição de Intervenção no Domínio Econômico*), a tax on imports, exports and comercialization of oil and its derivatives and on ethanol. The government planned to give support to the sector funding. Nonetheless, the amount obtained was not enough to serve all the investment needs of the Brazilian road sector.

Carvalho et al. (2003) claimed that the then current state of Brazilian roads still reflected the afore mentioned condition. They presented research results from the 2002 study of the National Confederation of Transport (*Confederação Nacional dos Transportes* - CNT), which evaluated the condition of 45,294 kilometers of paved roads, at the federal and state level. This research concluded that almost two thirds of the evaluated roads had deficiencies in pavement quality, signage, or engineering, and according to Karam (2005), this road condition generates externalities: international organizations associate an estimated 2% loss in GDP for Latin American countries due to the condition of this roads.

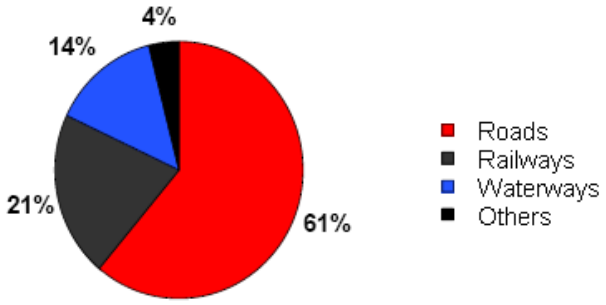
In this paper we study the current process of Brazilian road concessions. The Brazilian use of public-private partneships, as pointed by Ribeito et al. (2001), can be highlighted among developing countries, due to its dimension and the different approaches used to the different challenges faced (federal and states concessions independently designed, faced different problems and provided different results). In this way, In Section 2, we consider historical aspects of Brazilian roads. In Section 3, we enumerate theoretical topics in concessions, with special attention to the regulatory aspects that a government needs to consider in designing road concession programs. In section 4 we detail the Brazilian experience in road concessions, both the federal road concession program stages and also examined one example of a state level program (the São Paulo's state). We also explain new concession format that coexists with the road concession program (called in Brazil Public Private Partnership - PPP). In Section 5, we undertake a theoretical analysis of the Brazilian experience with road concession, identifying the main obstacles to be overcome in the Brazilian road sector. Section 6 concludes our article.

2 The Role of Roads in Brazil

The Brazilian government has a history of prioritizing roads over railways and waterways. An example of this fact was Juscelino Kubitschek (President from 1956-1960), who conceived and built Brasilia and offered many incentives for road construction. Kubitscheck was responsible for the instalation of the big car makers in Brazil - Volkswagen, Ford and GM came to Brazil during his government - and one of the points used to attract them was government support for road construction.

From January 1995 through September 2001, the Brazilian federal government invested US$ 6.41B in transports[2]- an amount that accounted for 28% of the total investments for that period[3]. No other sector had a budget of this magnitude - in this period, Defense had 17%, Health 15% and Education 9%. The Ministry of Transportation is one of the most sought after by the political parties which support the government.

Figure 2 - Brazilian Freight Transportation Network



Source - *Agência Nacional dos Transportes Terrestres* - ANTT (2006)

As shown in Figure 2, more than 60% of freight transport occurs by roads, making Brazil a "Road Country" (Duarte, 2007). However the considerable lack of investment in Brazil's road network results in its having the lowest density of most comparable countries, including its comparison in BRIC - Russia, India and China - as seen in Table 2.

According to ABDIB (*Associação Brasileira de Infraestrutura*), the Brazilian Association for Infrastructure, Brazil is one of the 20 economies of the world, and, in this group, has the lowest proportion of paved roads, 12%. In this regard, Brazil lose in comparison of his three competitors from BRIC countries: Russia, with 85% of roads with pavement, India, with 47% and China, with 87%.

[2] Transports here means national accounts investments in roads, waterways, railways and airports.
[3] source: "The FHC Goverment, A Balance"; several authors

Table 2 - International Comparison of Roads

Countries	Extension of Road Network (km)	Density (km/1000km^2)
USA	194,731	21.3
Russia	87,157	5.1
China	65,650	7.0
Canada	64,994	7.0
India	63,518	21.4
Germany	45,514	130.3
Australia	41,588	5.5
France	32,682	59.9
Brazil	**28,556**	**3.4**
Japan	23,168	61.8
South Africa	22,298	18.3
England	16,893	69.9

Source - ABCR

3 Road Concessions and its Regulation

A concession is a contract between the public power and a private legal company, the concessionaire, in which the public entity authorizes the private party to provide a good or a service. This contract is ruled by restrictive clauses, which, for example, indicate the period that the concessionaire will be responsible for the service, set quality parameters for this service and determine penalties in case of non-performance by the firm. Finally, it is worth noting that the goods are public property and are returned to government after the concession period.

A recent development that already is in common practice in developed and developing countries is the increasing participation of the private sector in the funding of infrastructure projects, due to the resources bottlenecks arising from increased social demands. The more accepted way of increased private sector participation is with the use of concession contracts. One of the advantages of the concessions, according to Kerf et al (1998), is the possibility of a competition for the field in a situation where the company providing the service has significant market power. We can argue that a strong rationale for the concessions is to regulate natural monopolies.

From the point of view of a private company, a concession is valid only if it generates an adequate rate of return over the capital. This is possible if the concessionaire has a revenue source, which can be a direct payment by the conceiving power , a toll tax or a combination of both mechanisms. However, it is important to recognize that the presence of a toll is not necessarily the sign of concession. Some Brazilian states have roads that are totally maintained by government tolls, as is the case of some roads in the states of São Paulo, Paraná and Rio Grande do Sul administrated by their *Departamentos de Estradas e Rodagens* - DERs (State Department of Roads).

In this context, there are two questions that arise especially for developing countries: Why the government chooses to grant a road concession and why charge a toll? Inspired in Hart (2002), Engel, Fischer & Galetovic (2009) and Grout (1997), Carvalho et al. (2003) list possible responses for both questions. According to Carvalho et al (2003), the authors say that good reasons to grant a concession are:

- Private administration of the road: The transfer of control from public to private administration may bring significative gains. The public sector may take care of other roads or other important public services like

education and health. Another gain occurs when private sector has costs advantages over the public sector in this kind of business.

- Inclusion of additional services: The concession can be followed by a bundle of services that previously was not available, as such medical assistance, environmental programs and road-side assistance.
- Capital attraction: Possibly the main reason when a country chooses to implement a concession. It was the case for Argentina, Chile, Colombia, Mexico, Malasian, Thailand and Indonesia.

About the reasons to charge the toll, they say:

- It is a way to recover the operation and maintenance costs of the roads: Most of time, the revenue from the concessionaire is generated by the toll charge.
- It is necessary to improve the efficient use of the roads: Many trips and freight transportation that would have occurred when a road is open would not happen with the presence of a toll.
- The distribution of the transport tends to be more efficient with the toll. For example, a load transported for long distances and with a smaller aggregate value per ton should be transported by train or water, while a load with a bigger aggregate value transported for short distances should be shipped on trucks.
- Finally, the authors assert that it is fair that only those who use the service pay fot it. It might be considered unfair that taxes from a person who does not own a car be used for road construction or maintenance. Toll is a way to reduce this kind of cross subsidy.

The concession cost consists of direct costs and capital costs. The latter is a composite of the return for the investor plus the risk premium. The concession risk, on the other hand, is a composite of factors beyond the control of the conceding power (risk of traffic fluctuation, country risk) and control factors (well designed contracts, commitment with a stable regulatory framework).

There are three standard ways to model the bid for a road concession: with the highest concession fee as the bid; without a fee but with the smaller toll as the bid; and, a third way that enhances the two parameters of bid in a same auction.

In the first case, the company that offers the highest amount to the government wins and, in this auction design, the government chooses the toll. This kind of system was implemented mainly by countries in Latin America in the 90s, to improve the public accounts. The second method, largely applied in developed countries as such the United States and some European countries that do not need generate revenue, the winner is the firm that accepts the smallest toll per vehicle, without any offer to the government. In the last case, also used in the United States, the company with the best combination of a concession fee offer and a toll offer wins.

When there is a concession fee, the value that the winner will outlay, most of time, is incorporated into the toll bid. For this reason, the tolls tend to be larger. Nevertheless, there are a bundle of other components impacting the toll, such as the project level difficulty and the necessary changes - improvement on the roads - to be implemented by the concessionaire.

Engel, Fischer & Galetovic (2009) summarize reasons for a government to use concession instruments:

(i) The concessions are more efficient, because the same firm is responsible for construction and maintenance of a project. Another assumption raising efficiency in concessions is that private firms are more efficient than public ones.

(ii) Compared to the traditional public provision, concessions have distributional advantages because those who benefit from a project pay for it and also it is easier to charge tolls closer to the marginal costs in this context. Another consideration is that goverments retain resources to spend on other urgent matters.

(iii) Concessions can filter 'white elephants'. A competitive auction screens projects that are not profitable without government subsidies.

In spite of these advantages, the concessions experience in Latin America may be seen as disappointing. Engel, Fischer & Galetovic (2003), found evidence that Latin American countries saved less than expected as a consequence of two characteristics of these projects. The first feature of these countries' experiences in concessions was that governments re-negotiated contracts; secondly, they gave generous guarantees to the firms. The authors concluded that renegotiations benefit firms with political connections, rather than the most efficient ones and, with big guarantees, bad projects are not filtered, which defeated the purpose of concession.

Engel, Fischer & Galetovic (2003) determined that the described scenario in Latin America's concessions was the result of two designs flaws: weak regulation and poor risk allocation. The authors comment that concessions must be better regulated, for example, having deadlines and quality of construction in the building phase and tolls, maintenance and quality of service regulation in the operation phase. It also should have fair solutions to contractual oversights. On the other hand, the fixed-term contracts of many concessions is the reason for the poor risk allocation. As a solution, the authors suggest flexible term contracts, introducing a model know as "Present-Value-of-Revenue" (PVR) auction, which we will explain in the last section of the present paper.

3.1 Regulatory Regimes in Road Concessions

According to Littlechild (2002), both types of policies – competitive bidding and utility regulation – have been adopted, over the last two decades, as part of the shift in funding from the public sector to the private sector all around the world.

For the road sector, governments increasingly have been using the competitive bidding or "competition for the field" process to grant roads to the private sector in a regime called toll rate regulation. According to Dhall (2007) it is a good option: When competition is infeasible, as in a natural monopoly, the best option available is to allocate the sole right to supply a specified market, i.e, a concession, through a competitive process. This is the case of road concessions and is why competitive bidding, or a Demsetz auction, is widely adopted in the sector.[4]

However, the choice for competitive bidding is not exempt from problems. Dhall (2007) emphasizes that the possibility of renegotiation is inherent in many concession contracts assigned by competitive bidding, given the long period of concession and the uncertainties involved regarding demand growth, price and related variables. The renegotiation also could be opportunistic. The author says that competition law enforcement (enforcing regulation regarding competition) is the best way to avoid collusion. Littlechild (2002) quotes Peacock and Rowley (1972), saying that the authors questioned whether the production function was independent of the choice between competitive bidding and utility regulation:

[4] A Demsetz auction is a system which awards an exclusive contract to the agent bidding the lowest price. This is referred sometimes to "competition for the field." Actually, the idea of competition "for the field" goes back 150 years to a paper by Edwin Chadwick in 1859. It was popularized by Demsetz in the 1960s.

On the other hand, we have "competition in the field," that is the case when two or more agents win a contract to provide the good or service competitively.

"Regulation was likely to involve greater X-inefficiency, and less innovative competition. However, the bidding solution had problems associated with lack of parity at contract renewal and with ensuring that contractual commitments were in fact honoured."

In the same way, Williamson (1976) and Goldberg (1976) also expressed concerns about competitive bidding. They argued that such an approach would have other problems of its own, for example in terms of exposure to risk and the costs of contracting to deal with uncertainty and changing circumstances, the same argument that Dhall (2007) advances.

Turning to traditional utility regulation, Littlechild (2002) says that in the 1960s, there was active discussion about the inadequacies of US public utility regulation. There were concerns that it was ineffective or had undesirable side effects. In this context, according to Jamison & Berg (2008), what we see now is a recent movement away from cost-based regulation to price-based regulation, generally involving some form of price caps, often with profit-sharing between stockholders and customers. The United Kingdom was the pionner in the introduction of price caps (Beesley and Littlechild, 1989; Weyman-Jones, 1990).

The authors say that the purpose of these regulatory policy changes has been to avoid the inefficiencies linked to cost of service and regulation (Braeutigam and Panzar, 1989): The Averche-Johnson effect (over capitalization which leads to production and allocative inefficiencies); cross-subsidization (entering competitive markets and recovering costs from core customers); excessive or inadequate service quality; and, employee or managerial slack. The magnitude of these inefficiencies is an empirical question, but studies of the impacts of competitive pressures and 'incentive' regulation suggest that the inefficiencies associated with traditional regulation were significant. Nonetheless, it is hard to distinguish between the competition effect and the regulation effect, since reductions in entry barriers and incentive regulation often occur at the same time. Jamison & Berg (2008) conclude, then, that perhaps competitive pressures should be given more credit for the productivity advances and new service introductions arising in recent years.

With the increasing replacement of rate-of-return regulation by incentive regulation in the regulatory systems, it is interesting to highlight, the article by Sappington (1994), which identified in his survey ten guidelines for designing incentive regulation plans: (i) use incentive regulation to better employ the firm's superior information; (ii) prioritise regulatory goals and design incentive regulation to achieve stated goals; (iii) link the firm's compensation to sensitive measures of its unobserved activities; (iv) avoid basing the firm's compensation on performance measures with excessive variability; (v) limit the firm's financial responsibility for factors beyond its control; (vi) adopt broad-based performance measures where possible, unless their variability is excessive; (vii) choose exogenous performance benchmarks; (viii) allow the firm to choose among regulatory options, while recognizing the interdependencies among the regulatory options that are offered to the firm; (ix) promise only what can be delivered and deliver whatever is promised; and, (x) plan for the rare, unforeseen event, but minimise after-the-fact adjustments to the announced regulatory policy.

Sappington (1994) points out that:

" ... the design of sound, effective regulation in particular settings will require careful attention to the idiosyncratic features of the environment. The best incentive regulation plan in any given setting will vary according to regulatory goals, institutional and technological factors, the nature of the information asymmetry between regulation and firm, and the commitment abilities of the regulator."

Berg (2003) summarizes two main types of traditional regulation:

- Cost-of-service regulation (including return on rate base regulation) provides an opportunity to cover costs. It also provides companies with an incentive to over/under invest in plant, inflate costs, and cross-subsidise. Reg-

ulators generally try to remedy these perverse incentives through regulatory lag, sliding scales, and efficiency audits/reviews.

- Price cap regulation provides companies with incentives to cut costs. It also dampens the effects of cost information asymmetries between companies and regulators. Service quality and infrastructure development may suffer. However, incentives to over-invest in capital and to cross-subsidize are less than with cost-of-service regulation.

Armstrong (2008) concludes that the choice between these two formats of regulation will depend mainly on the relative importance of the two forms of investment. This means that in situations where the main objective is to induce the regulated firm to employ its existing infrastructure in a more efficient way, a price cap regime may be better. On the other hand, in contexts where there is a history of severe under-investment in key infrastructure, a guaranteed rate of return on investments may be a better choice.

However, price cap regulation also has a negative implication. According to Alexander & Irwin (1996), many studies comparing the betas[5] of British firms subject to price cap regulation with those of U.S. firms subject to rate-of-return regulation found that the U.S. firms have lower betas, as expected. Empirical work for the World Bank from Oxford Economic Research Associates seems to confirm these conclusions.[6] As a consequence of the differences in betas, firms subject to price cap regulation have to pay an extra percentage for their capital. The author concludes that this characteristic of price cap regulation is not necessarily a good strategy, but is important that regulators take account of the effect of regulation on the cost the regulated firm has to pay investors for capital.

Estache (2000) discusses price and quality regulation aspects that characterize the sector of transport infrastructure and also performance indicators that the sector's regulators should be able to rely on to improve the results of their work. In the chapter about toll road regulation, the author says that a contract for a road concession must specify the regulatory approach and enforcement mechanism. If using rate of return regulation, the agreement should specify the basis for the regulation, the maximum rate of return allowed, and the calculations required to monitor the concession performance. If using toll rate regulation, the agreement should specify the maximum toll by vehicle type, the index used to adjust toll rates, and the time period for toll rate adjustments. Some degree of creativity is allowed here. According to Estache (2000), Peru, for example, adjusts the standard formula to include a premium for improvements in safety over the targets specified in the contract. The contract also should include the specific procedure for calculating and revising the toll schedule.

Using a simple model of commuter railways where congestion exists, Kidokoro (1997) says that price cap regulation causes congestion compared to rate-of-return regulation, showing the following results:

- price cap regulation in which the cap is made contingent on congestion, can correct the congestion without distorting cost-reducing efforts;
- price cap regulation in which the cap depends on investment in transportation capacity, can also correct the congestion but distorts cost-reducing efforts.

Related to the topic of regulatory regimes, a "Financial Equilibrium" clause is included in many road concession contracts and legislation. According to Guasch (2004), this clause appears in the contracts (sometimes explicitly

[5] According to Alexander (1996), the risk that affects a firm's capital cost can be measured by a statistic called the firm's beta. Betas are used by investors worldwide and are an important factor in their decisionmaking. A firm's beta measures the extent to which the firm's returns vary relative to those of a diversified portfolio of equity holdings.

[6] The results show that price cap regulation is associated with higher betas than rate-of-return regulation in Canada, Japan, and Sweden, as well as in the United Kingdom and the United States. Rate-of-return regulation is associated with betas ranging from as little as 0.2 in the U.S. gas industry to 0.62 in Japanese telecommunications, while price cap regulation is associated with betas ranging from 0.5 in Swedish telecommunications to 0.87 in British telecommunications.

and sometimes implicitly) and in principle, is a valid pillar of any concession contract because private investors should be allowed to have a fair rate of return on their investments. We may assume that it will be available more frequently in concessions with rate of return regulation. The author also says that this clause ought to be subject to many obligations, as such cost-efficient operation and when it does not happen, it becomes a feature making concessions more prone to renegotiation. Engel, Fischer & Galetovic (2009) add that *ex ante* financial equilibrium should follow from a prudent bid and not from *ex post* renegotiation justified by the fact that costs became higher than expected.

Guasch (2004) gives a simplified representation of this financial equilibrium clause with the following equation:

$$R = PQ - OC - T - D = rK_i, \tag{1}$$

where R is profits, P is tariffs, Q is quantity or output, OC is operation and maintenance costs, T is taxes, D is depreciation, r is the opportunity cost of the capital, and K_i is the invested capital. If we have a transfer fee as award criteria, it appears under K_i. On the other hand, if we have the lowest tariff, it appears under P. The author comments that an appropriate bid always has an analysis that balances this equation. In the case of a strategic bidding with opportunistic behaviour, as such a very agressive bidding, in the case that the left side of the equation (profits) is less than the right side (returns on capital), that is:

$$R = PQ - OC - T - D < rK_i. \tag{2}$$

In this case, the bidding (choice of transfer fee or tariff to support the equation) does not provide the firm with financial equilibrium. One firm may have this behavior looking for winning the concession, with the expectation of a latter renegotiation, claiming that the equation does not balance and that a higher tariff or a lower fee is necessary to assure the financial equilibrium for the concession. The incompleteness of the contracts allows this low-balling effect to happen in road concessions.

4 Brazilian Road Concessions

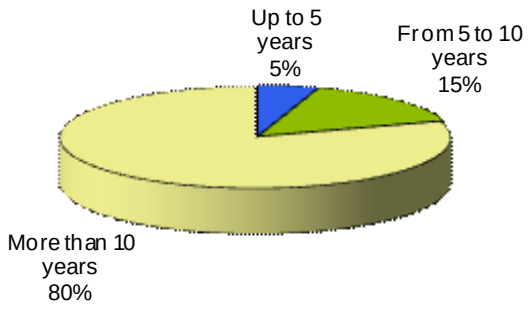
4.1 The Brazilian Road Concessions Program (RCP) - General

As already mentioned, Brazilian roads conditions were bad in the 90s, with very low level of investments, as shown in Figure 1, almost an unsustainable situation[7]. Figure 3, shows that, during the 90s, paved roads were not object of much funding by the Federal Government. Conditions remained deteriorated due to lack of investment.

A common problem in developing countries at that time was the lack of money to invest in infrastructure due to an increase in social services demands. This scarcity of economic resources added to the Brazilian dependency on roads led the government to introduce a concession program based upon partnerships between the public and private sectors. According to Ribeiro et al (2001), among, the several types of operation and management contracts of private participation in infrastructure, concession is characterized by temporary transfering recuperation and maintenance services in exchange for exploitation rights such as payment of toll.

[7] According to the IPEA (Economics Research Institute), poorly maintained roads may cause inefficiencies: Increase of up to 38% in the vehicle conservation cost ; up to 58% in the fuel consumption; up to 100% in the travel time; and up to 50% in the accidents.

Figure 3 - Age of Pavement in Brazilian Roads (last repair) - Federal Network (2003)



Source - SGP/DNIT

According to Ribeiro et al. (2001), in the middle of the 90s, a technical group was formed to identify and select the Brazilian roads in terms of economic return and attractiveness to the private sector. They analyzed 52,000 Km and selected approximately 15,000 Km to include in the Brazilian concession program. After the selection, the group concluded that the primary goal was to repair the existing network and then construct new roads. Therefore, the group adapted the traditional BOT (Built-Operate-Transfer) system to a ROD (Recuperate, Operate and Devolution) model, as pointed by Almeida, 1994.

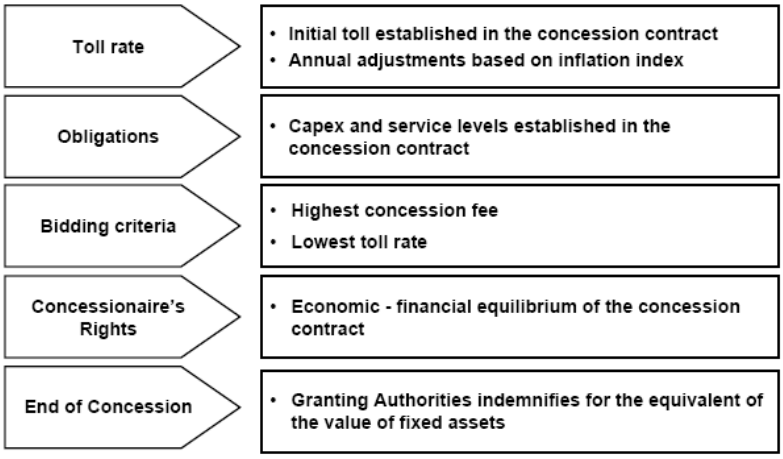
The Brazilian road concession regulatory framework is formed by the Federal Concession Law (Decret 8987/95) and the Federal Bidding Law (Decret 8.666/93) and for several State concession laws. The regulatory institution is the ANTT (Brazilian Transportation National Agency), created in 2001 with the mission of regulating and administrating concession contracts for roads and railways.

Before the auction, the government prepares viability studies, with considerations for the service level to be offered, the investments needs, traffic evolution in the roads, and the number and location of toll houses. Figure 4 shows the main characteristics of the Brazilian road concession model. The initial toll (choosed by bid or by the government) is established in the contract and annual adjustments are made based on the inflation index. Concessionaire obligations, such as the capital expenditure and service level also are established in the concession contract.

On the other hand, the concessionaire has the right to maintenance of the economic-financial equilibrium of the concession[8], which has been interpretated by the regulators as the maintenance of a pre-determined internal rate of return. The government reassumes the control of the road after a pre-defined period and fixed-terms and conditions.

[8] The contractual clause of economic-financial equilibrium is better explained in the Renegotiations section of this paper.

Figure 4 - Brazilian Road Concession Features



Source - International Conference on Meeting India's Infrastructure Needs with PPP.

In this context, the Brazilian road concession (including Federal and State concessions) has a magnitude of 13993 km from a total of 60469 paved roads. The Federal program specifically has 11218 km and 2775 km are the responsibility of the States. Table 4 shows the current roads conceded in Brazil, at the Federal and State levels. The two most important road concession programs in Brazil are the Federal and the São Paulo State program.

A study conducted by the Confederation National of Transportation - CNT in 2006 classified the Brazilian highways that have been concessioned with the following status: excellent and good with 79.7% and regular, bad and very bad with 20.2%; the same study also classified general roads (not only conceded ones), and the results were: 25% excellent and good and 75% regular, bad and very bad.[9]

[9] As a matter of comparison, before the concessions, a study conducted by the Confederation National of Transportation - CNT in 2001 classified the Brazilian highways as follows : 2.9% Very Good condition; 28.4% Good condition; 66.3% are deficient; 2.2% Bad; 0.3% Very Bad.

Table 3 - Conceded Roads in Brazil

States	# Conceded Roads
Federal Government	13
São Paulo	13
Rio Grande do sul	7
Paraná	6
Rio de Janeiro	3
Bahia	1
Espírito Santo	1
Minas Gerais	1
More 6 Roads were conceded in 2009:	
São Paulo	5
Federal Government	1

Source - ABCR

In the next three sub-sections we discuss the two stages of the Brazilian Federal road concessions program and the São Paulo program. In a last sub-section, we present renegotiation cases that reveal fragilities of the Brazilian road concessions program design.

4.2 Brazilian RCP - First Stage

The first stage of Brazilian road concession auctions occurred in 1995. In these auctions, 5 road segments were conceded (see Table 4). For each segment, the winner was the company that offered the smallest toll fee.

The main facts worth highlighting in the first stage road concession are the following:

- At the time of the first stage, the Brazilian regulatory framework for road concessions was very recent as were all the privatization processes in Brazil. This scenario was costly in terms of the existing regulatory risk;
- The economic situation also was a negative component in the risk calculated by the competitors, increasing the level of the toll required by the concessionaires;
- An interesting practive employed was the use of cross-subsidies; cases in which the operating profits of a toll road with high volumes of traffic are used to cover losses incurred on links with low volumes of traffic (or not tolled) in the network. This is particularly used in some states, such as Rio Grande do Sul and Paraná. Subsidies also are employed in toll roads individually, such as the Nova Dutra, in which the long distance traffic pays the toll, while in some areas the local drivers can enter and leave without being charged.

Table 4 - Brazilian Road Concession Program - First Stage

Roads	Concessionaire	Extension	Total Investments (US$) mil *
BR-116/RJ/SP	Nova Dutra	402.0 km	854.88
BR-101/RJ	Ponte	13.2 km	114.36
BR-040/MG/RJ	Concer	179.9 km	426.15
BR-116/RJ	CRT	142.5 km	916.92
BR-290/RS	Concepa	121.0 km	14.36
TOTAL		858.6 km	2,326

* June 15,2009 quote R$/US$ = 1.95 ; Current values from 2003, atualized by IGP-DI

Source: Brazilian National Road Transportation Agency (ANTT) and ABCR

A study from IPEA, the Brazilian Institute of Applied Economics Research, pointed that the toll fee charged in the roads from the first stage of the road concessions program increased 45% above the consumer inflation index (IPC-FGV) on the average, between 1995 and 2006. Soares & Neto (2006) say that the toll increased because the contract focused more on cost questions than on revenue questions. The researchers' perception is that the contractual rule of maintenance of the economic-financial equilibrium is benefiting the concessionaire.[10] The economic-financial equilibrium is defined in a road concession contract by the discounted cash flow that allows the concessionaire to have the unleveraged internal rate of return[11] guaranteed when the contract is assigned and is seen as the fundamental principle of the concession's legal regime.

They complement the argument:

> "The economic-financial equilibrium concept, which generates a wide discussion in the private sector, has been studied and operationalized. On the other hand, there was the necessity of a fair treatment of the consumer class, because the appropriate toll level does not have the right attention, even was studied or operationalized."

The authors say that the main problem with the economic-financial equilibrium clause in Brasil is that the regulator doesn't have control over concessionaire's financial data and this can permit the increase in the toll for the maintenance of this equilibrium. However, the findings of persistent actual earnings in the toll tariffs over time make the toll increase questionable. As was explained, the economic-financial equilibrium clause guarantees the initial rate-of-return to the concessionaire. As a consequence, the initial rate-of-return becomes the lowest return that the company will have. With this in mind, the authors say that we can expect that companies seek an increase in the rate-of-return through an increase in the actual tariff.

In addition, the authors note that government guarantees were gradually extended to cover exogenous adverse economic factors, as such an unexpected increase in input prices or other prices that unbalance the economic-financial equlibrium.

[10] The Law guarantees to concessionaires protection against risk of abuse of public power. This is the clause of economic-financial equilibrium maintenance of the concession. If this equilibrium is breached, concessionaires have the right to request a solicitation to rebuild it by toll revision. The public risks can be classified, according to Oliveira (2001), like economic, exogenous force, fortuitous ("Act of God"), financial caused by interest variations or by exchange rate variations. These are exogenous risks that make the execution of the concession costly to the contracted firm. There are two endogenous risks attributed to conceding power: the political and the regulatory.

[11] The second stage of Federal concession contracts established an internal rate of return of 8.95% to the concessionaires. In the first stage, this rate reached 24%.

In line with the argument of the IPEA study, that the regulator does not have control over the maximum internal rate of return, because the economic-financial equilibrium clause is used most of the times for the concessionaires benefit, the World Bank has developed an study (Verón & Cellier, 2010) in which the rate of return of Nova Dutra concession is simulated with two scenarios: one with low productivity gains and the other with high productivity gains.

Table 5 - Simulation of financial returns on Nova Dutra concession

	Contractual initial regulation parameters (real terms)	Base simulation with low productivity gains		Simulation with high productivity gains
		real terms	nominal terms	real terms
IRR on capital	17.58%	16.3%	27.0%	80%
IRR on equity	24% (estimated)	18.7%	29.5%	120%

Source: ANTT and World Bank calculations

According to Verón & Cellier (2010), the first simulation of the rate of return of the Nova Dutra concession was established in nominal terms taking into account: (i) observed and currently forecasted traffic revenues (traffic growth was slower than estimated - 3.45 percent p.a. instead of 5.8 percent- resulting in 2007 in a 15 percent shortage); (ii) a 1 percent yearly productivity gain on investments and operational costs, (iii) observed financing costs (with the strong hypothesis that the current debt structure of the sponsor (CCR) reflects the one of the concession), (iv) observed factor and inflation evolutions. The result shows that reductions in traffic were reasonably compensated by gains in financing costs as effective returns on capital would appear around 16.3 percent.

The second simulation has the unitary costs compatible with the ones observed for the second stage of the Brazilian road concessions program. The World Bank concluded that it would imply a much higher rate of return on capital. The second simulation was realized testing a 30 percent reduction in base unit costs compounded with a 3 percent annual productivity gain.

With these exercises, the World Bank has acknowledge of the sucess of the first stage of the Federal road concessions program, because it has created experience and relatively clear regulatory mechanisms and also because it has provided to the users good quality roads while the country underwent a prolonged and rigorous fiscal adjustment program. However, with the example of the Nova Dutra, it has been clear that the concessions design used in the road concessions program could allow that several large efficiency gains were not passed on to user prices, notably the decrease in the cost of capital and also probably large productivity gains in operations.

4.3 Brazilian RCP - Second Stage

The second stage of the Federal road concession program occurred in 2007 when 7 road sections were conceded (see table 6), totalizing 2600 km. The experience acquired in the first package of road concessions was applied successfully in the design of the second package. It included a better risk allocation, giving more responsibilities but also more latitude to the private operator. The regulation rules are now more focused on economic and quality aspects rather than on technical requirements as was the case for the first package.

At the time of these auctions, Brazil was in a completely different economic situation than it had been at the first stage of road concessions. The auction was in the São Paulo Stock Exchange (Bovespa), where many symbolic privatizations from the antecedent government of Fernando Henrique Cardoso were also done. In this auction, called

the Lulas Government's road concession, the state awarded the opportunity to the winners the right to exploit, for 25 years, tolls in some of the most important roads in Brazil, as such Régis Bittencourt, that connects São Paulo to another big city, Curitiba, in the South of the country. The winners, in turn, commit to invest US$ 9.75 billions in the maintenance, improvements and, in some cases, duplication of the segments.

Prior to 2007, the biggest action related to roads from Lula's government's, which took office in 2002, was the "Filler Operation' in 2005. The cost of this government program was US$ 210 millions: But of the 101 roads reconstructed, 48 presented deficiencies, according to the Union Accounting Court (TCU), a public audit agency.

Despite the previous experience in roads in Lula's government, the 2007 auction was seen as effective by many people. According to Paolino (2008), with a better defined regulatory framework, a smaller country-risk and a good supply of lines of credit, the government took advantage of the favorable conditions in 2007 and the second stage was evaluated as successfull. The bids were substantially below the maximum toll established in the auction requirements.

Table 6 - Brazilian Road Concession Program - Second Stage (Oct 9, 2007)

Roads	Concession	Extension	Total Investments (US$)*
BR-116/SP/PR	Autopista Régis Bittencourt	401.6 km	1.95 bi
BR-381/ MG/SP	Autopista Fernão Dias	562.1 km	1.74 bi
BR-116/376/101/PR/SC	Autopista Litoral Sul	382.3 km	1.59 bi
BR-101/RJ	Autopista Fluminense	320.1 km	1.18 bi
BR-153/SP	Transbrasiliana	321.6 km	0.77 bi
BR-116 /SC/RS	Autopista Planalto do Sul	412.7 km	0.97 bi
BR-393/MG/RJ	Rodovia do Aço	200.4 km	0.56 bi
TOTAL		2600.8 km	8.87 bi

* June 15, 2009 quote R$/US$ = 1.95

Source: Brazilian National Road Transportation Agency (ANTT)

The results obtained in the second stage of Brazilian road concessions, shown in Table 6, seem to confirm the private interest in the new contractual model, with the smallest toll bid as the auction winning criterion. The number of competitors in each auction increased in a significant way. A special characteristic of this second stage was the possibility of foreign competition and companies from Argentina, Spain, Portugal participated in the auctions, in addition to Brazilian companies. In Table 7, the winners' proposed tolls are from the data base July, 2007. These values were readjusted at the beginning of toll collection by the Consumer Price Index (IPCA-IBGE) and, after that, the values will be subject to annual readjustments.[12]

The auction attracted bids from 30 companies. However, the winner was the Spanish company OHL - Obrascón Huarte Lain. With concessions in Spain, Mexico, Chile, Argentina and also in Brazil (at the State level), the company won, without a consortium, five of the seven concessions segments offered and their bids were very modest compared to tolls charged for roads from the first stage of road concessions.[13]

[12]For each road, before the auction, the government prepared the PER (Road Exploitation Program). This document gives the number of toll houses in each road. This number varies for each road. For example, the Regis Bittencourt road concession which was awarded in the second stage, can have 6 toll collection houses on its 422 km, while Fernão Dias road concession can have 8 for its 1181km.

[13]It is important to note that, besides the overall economic conditions, the Selic rate (short-term interest rate), a relevant variable

Table 7 - Second Concessions Stage - Auction Results

Roads	Winner	Winning Bid[1](US$[2])	Discount[3]	Toll per 100 km[4](US$[2])	Competitors
BR-116	OHL Brasil S.A.	0.699	49.2%	1.04	13
BR-381	OHL Brasil S.A.	0.511	65.4%	0.72	15
BR-116/376/101	OHL Brasil S.A.	0.527	62.7%	0.68	17
BR-101	OHL Brasil S.A.	1.158	41.0%	1.80	8
BR-153	Consórcio BRVias	1.256	40.0%	1.56	10
BR-116	OHL Brasil S.A.	1.302	39.4%	1.58	10
BR-393	Consórcio Acciona	1.507	27.2%	2.26	3

[1] The winning bid was the minimum toll offer between competitors' bids per toll plaza defined in the edict.

[2]June 15, 2009 quote R$/US$ = 1.95

[3]Difference between the maximum toll established in the edict and the winning bid.

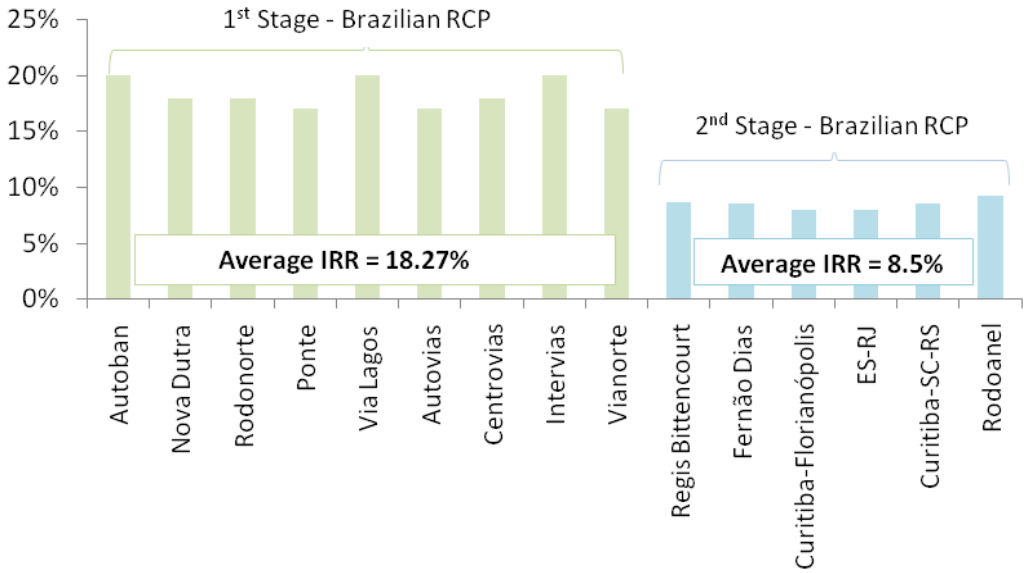
[4]Toll charged at each 100 km of road.

Source: Brazilian Ministry of Transportation (2008)

For the Fernão Dias road, OHL won its concession with the largest discount in the toll: 65% of the minimum toll indicated by the government. Because of this, OHL will charge $4.10 from the driver that crosses all 8 toll houses forecasted for the pathway of the road. Taking into account the distance, the toll will be 13% of the toll charged on the Bandeirantes road, known as the best road in Brazil, a benchmark road concessioned by the São Paulo's government in 1998. Comparing both concessions, some analysts say that the Lula's government concession focused on the cheapest toll and are skeptical about the quality that will be provided by OHL. The question is of whether the Fernão Dias Road have the level of quality to measure up its importance remains unanswered. In addition, the question of whether this new concessions model in Brazil will be sustainable in long-term also remains unanswered. We will need to wait a few more years to see the consequences of this arrangement in Brazilian road concessions.

to determine the concesisons internal rate of return, was around 20% in the first stage of the Federal program (in 1994) and dropped to 10% in the second stage (in 2007). This fact helps to explain the difference between the level of the bids in the tool phases of the Federal road concessions program.

Figure 5 - Federal Road Concessions Internal Rate of Return

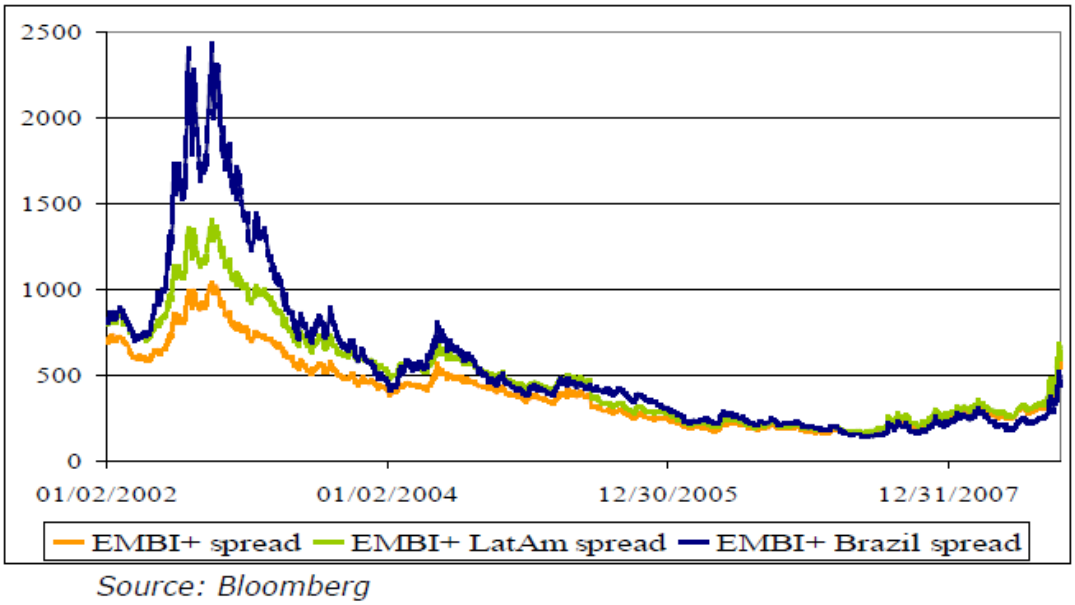


Source - Torres(2008)

Figure 5 shows the difference in the internal rate of return between both stages of the Federal Brazilian road concessions program. The second stage has an average internal rate of return less than half of the average observed in the first stage. It reflects many recent aspects, as such a smaller Brazilian country risk and a consolidation of the road sector regulation in Brazil. In Figure 6, one can see the declining trend in the country risk, one of the reasons for the lower bids in the second stage.

According to Véron & Cellier (2010), many factors might help to explain the results in the second stage, as such: ANTT traffic forecasts were pessimistically too low (surveys were carried out in 2004, 4 years before concession start, and at the end of a macroeconomic crisis); benchmark unitary construction prices were too high (discounts commonly observed at contract award were not reflected given the high frequency of contract additives); important liquidities in the international markets and especially in the Spanish concessionaires, as well as the decrease of country risk allowed a larger drop of the capital equity price than expected by ANTT.

Figure 6 - Country Risk (EMBI+) 1998 - 2008



in Verón & Cellier (2010)

The authors also points the possibility of a strategic move by the concessionaires, which might have had incentives to accept low returns and high risks. For example, the concessionaires that already have operations can optimize the long run use of productive factors, as first phase concessions are already halfway through their life-cycle. Also the international actors can consolidate implementation on the emerging Brazilian market.

4.4 Brazilian RCP - São Paulo's Concessions

After examining the two stages of Federal concessions, we will see the example of a State level program, the São Paulo's concessions program. The São Paulo road concession program was insititutionalized in 1998 and was part of the State Privatization Program (Programa Estadual de Desestatização), regulated by the Law number 9361, from 1996 and by the article 175 from Federal Constitution. Currently, the program is in its second stage.

The São Paulo's road network conceded in the first stage was divided in to 12 sections totalizing 3500 km, involving 168 counties and a population at about 20 million people (around 54% of the State population).

In this first stage, the winner was the company that offered the largest amount to the government. The auction design of these concessions was choosen mainly as a consequence of São Paulo's economic situation: The state had suffered a severe fiscal crisis in the 1990s and used privatization and concessions as a source of funds to mitigate the problem.

The second stage started at 2008 with the publication of the concession edicts of the west section of Mário Covas Rodoanel and more (phase 1) and from more five road sections (phase 2): Corridors D. Pedro I, Raposo Tavares, West Rondon, East Rondon and Ayrton Senna/Carvalho Pinto.

The winning selection criteria changed in the second stage. Following the trend given by the Federal Concession Program, the São Paulo government chose the smallest toll fee as the winning bid in the auctions for the second

stage of the state road concessions program. As results, we saw discounts from the price caps established in the edicts of up to 61%.

A difference between the Federal program and the São Paulo's program is the clause of economic-financial equilibrium. Both programs have this clause in their contracts, but the São Paulo clause does not permit a renegotiation of the toll. The variables that can be changed in São Paulo for the equilibrium be regained are the concession term, the amount of investment and the amount offered to the Government as winning criteria, as in the case of the first stage of the program. As we will see in the last section of this paper, the possibility of change in the toll level is a characteristic of the Federal program that may endanger the regulation of the Federal road concession.

4.5 Renegotiations

The Brazilian road concessions program is increasingly a target of discussion in the media and in specific studies of the transport sector. The main point in the discussions is the contract clause about the maintenance of economic-financial equilibrium that is a concessionaires' right.

The basic tenet of the economic-financial equation is that the concessionaire and the government will maintain a permanent equilibrium between the concessions' encumbrances and revenues.

In this context, the toll - main source of the concessionaires' revenue - will be the object of a periodic revision. Nevertheless, the toll can suffer a value change in exceptional situations, such as alterations in the government impositions of work in the roads, called the PER (Exploitation Road Program)[14] or unexpected changes in the level of revenue that concessionaires have with alternative sources, such as commercial buildings along the road or billboard advertisements.

This clause is not restrictive enough to avoid concessionaire bargaining. Actually, this clause leaves some margin of interpretation, which has allowed situations such as:

- The Brazilian Court of Audit (TCU) asked for a decrease in the level of the tolls from the roads conceded in the first stage of the Brazilian concession program. The institution says that, after the second stage results, with tolls at a much lower level, it is possible for the concessionaires managing the first conceded roads to continue to offer the service with smaller revenue. Now, the Brazilian Transport Regulatory Agency, ANTT, is studying how to do this. The concessionaries already are quoted in the media as accepting this kind of renegotiation if it would not endanger their financial equilibrium condition.

- The major concessionaire at the second stage auctions, OHL Brasil S.A.[15], already has started to consider realignment in the toll level of the roads it won in 2008. At the time of the auction, the company said that traffic intensification would compensate for the small tolls. With the world economic crisis and a possible change in the growth demand trend, they can use the clause of economic-financial equilibrium as a good argument to request a renegotiation.

Case 1 *Brazilian Tranports Regulatory Agency authorizes an increase in the toll of Rio-Teresópolis road concession*

[14] For example, the ANTT's Resolution Number 2.350, from Oct 31, 2007, approves the review and alterations in the PER and in the basic toll tariff for the BR-290/RS road, managed by Concepa company. Because of the alterations, the new basic toll was changed from US$ 0.93384 to US$ 0.93549.

[15] OHL Concesiones, the Spanish company, owns 7.9% of this Brazilian company.

Michelly Chaves Teixeira - Agencia Estado - Sep. 1, 2009.

SÃO PAULO - The ANTT authorized an increase in the tariff based on a review of the toll Rio/Teresópolis/Além Paraíba (BR-116/RJ) road, managed by CRT concessionaire. The toll will increase from the current $ 3.95 to $ 4.62, beggining September 2. The new amount corresponds to a tariff increase of 16.88%, determined by review and realignment over the basic toll tariff. According to ANTT, the change was authorized to guarantee the economic-financial equilibrium of the contract. The concessionaire closes the operation of a toll plaza located at Três Córregos, a city in Rio de Janeiro state, kilometer 71 of the road on September 2. The company will also postpone for two years the operation of a expected toll plaza in Sapucaia/RJ (km 14). During this period, only the main toll plaza in Imbariê/RJ (km 133,5) and the two auxiliar plazas located in Magé/RJ will be working.

Case 2 *The government strategic behavior*

World Bank - 2010

An example of strategic behavior of government was the unilateral decision to reduce tolls or not accept their programmed adjustments, with the objective of attracting public support during the election campaigns. This occurred in many states. In Paraná, only 50 days after the beginning to charge tolls, the government reduced tolls by 50%. Tolls have been readjusted in 2000 to compensate the loss occurred during this period. While the main problem has been solved, this fact underlines the problem of government incoherence between long-term engagements and short-term political interests.

About actual renegotiations, Schumaer (2003) classified the review that occurred in the Federal program between 1996 and 2002 in two types:

(i) Reviews done to reward anticipation or investments in new services not forecasted in the PER, but necessary for the improvement in safety and comfort for drivers or for the road neighbourhood.

(ii) Reviews that occurred between 1999 and 2000 were a function of political or tax changes. As such:

- In July 1999, the government canceled the realignment in tolls for the concessionaires as one of the agreements to stop the freight drivers strike;

- In August 1999, the Any Nature Services Tax (that was 5%) was removed from the tariff composition by a Brazilian Court of Audit determination.

4.6 Brazilian New Hybrid Road Concessions Model

A new model of concessions is gaining influence in the Brazilian transportation, coexisting with the concession program already detailed above. It is a model with greater government participation in the financing of the project, which will be implemented when the toll collection is insufficient to balance the private investment. Another possibility is to implement this model in projects where recuperation of total costs or a loss is expected.

Nationally, the regulation of this model started in 2004, with the Federal Law 11079/04. Preceding this law, States as such Minas Gerais and São Paulo already had enacted their own laws for the concession framework.

In Brazil, this new Public-Private Partnership model is a way to delegate public service to the private sector with a concession contract that can have one of two formats: sponsored or administrative.

The sponsored concession is one that enhances the toll collection, as is the case with the Concessions Law 8987/1995, with a pecuniary consideration from the public partner to the private one. On the other hand, in the administrative concession, the service is done directly or indirectly by the private sector. The government funds the whole service payment, a characteristic that make this concession only a rendering of services to public administration and, in this case, the contract may be ruled by Law 8666/1993.

Another feature of this new model is that it is applicable to public administration and all the entities controlled by the government. The service hiring necessarily requires an auction to assure the competition. Adittionally, as the Federal Concessions program detailed before, the new PPP Law doesn't forbid foreign firms from participating in the bidding process, but these firms may be discouraged by the subjectivity of criteria in the selection of the firms and also by the judicial insecurity that the next government will "understand" the contract awarded by the previous government and pay the amounts correctly to the private firm.

This new formulation of private participation started in Brazil long before the Federal Law 11079/04. During the Brazilian Empire, D. Pedro II formalized agreements with foreign companies for the construction of many railways throughout the country in 19th century. The reported law only established legal boundaries to these contracts between the government and private companies. As a result of this law, we have in Brazil projects such as road segments of BR-116 in Minas Gerais and Bahia states, the North-South Railway and the Road Arch in Rio de Janeiro.

The first Brazilian project in this new framework was line 4 in the São Paulo subway. The concession's contract indicated that the private partner would invest approximately US$ 370 million in the material provision and management of the subway operational system, while the government should have a disbursement of almost US$ 1billion on the construction of the railway and subway stations. After the service is available, the private partner has the right to receive the remuneration in two ways: (i) toll collection; (ii) pecuniary consideration pay by the state, according to the performance and the quality of the provided service.

Following, the Minas Gerais state and the Bahia state announced, respectively, the MG-050 Road project and a sewage project. The MG-050 road project, a sponsored concession, had forecast investments of US$ 330 million in a period of 25 years. For its turn, the sewage project, with investments totalizing US$ 133 million, is a administrative concession, with a fixed-term of 18 years, in which the State will remunerate, monthly, the private partner for the construction and operation of the sewer system.

There exist some deadlocks in the application of this new model at the Federal level in Brazil. An example of the problems with this new concession model is that, in the beginning of 2007, from the six ongoing projects with this framework, only two were not questioned in court. Most projects came to court questioning the use of the new concession model in the project. As said by Ariovaldo Pires, a lawyer from Albino Lawyers,

> "None of the judicial actions had questioned the PPP law, but the model chosen for concession or some detail of the law."

The author also quotes, for example, that in a PPP in the Minas Gerais state, the possibility of invert the qualification and opening bid phases was questioned in the Justice. Another aspect questioned in the Justice, in the São Paulo subway project, was if it was just a concession project and not a PPP project, because the government would not do any payment for the private company. The solution was create a payment from the government to the private company responsible for the subway construction.

5 Economic Analysis of Brazilian Road Concessions Experience

As we have seen in this article, Brazilian road concessions have a combination of two regulatory regimes: competitive bidding and rate of return. The first one has a new format tested in the second stage of Federal Concessions. The auction of the second stage changed the pattern of the winners in the Brazilian road concessions and also, as we stated before, will need to be analysed in a few years to prove its sustainability.

The last one, the rate of return regime, on its turn, appears in Brazilian road regulatory context through the financial-economic equilibrium principle, which is in every road concession contract assigned at the Federal, State or Municipal level and allows renegotiations and even a lack of profitability control by the government.

Carvalho et al. (2000), have an outline of Brazilian road concession format. They say that the exploitation of a road segment in Brazil is executed by a public tender process and that this process is established by a competition announcement where the interested groups in the concession need to abide by three evaluation phases:

(i) Financial-Economic and Legal phase, when the competitor needs to prove its financial and economic capability through trial balance sheets and needs to have the minimum equity and liquidity index also as proof of their ability to honor commitments of their proposal to the concession. In the legal validation case, it is necessary to show negative certificates of tax. The competitors approved in this phase are able to advance to the next phase;

(ii) The second phase is about the technical and operational qualification of each competitor, which is evaluated through the strategic plan submitted by them. This plan should have at least the strategy to be adopted for the road administration in the concession term, highlighting the human resources, equipments, maintenance program, operational improvements, funds and way to capture of this amount.

(iii) In the last phase, proposals are analized and judged, according to criteria that vary depending on the state level that is promoting the concession.

After identification of the winner, following the final of the three phases above, the company is entitled to hold the concession and should constitute a new firm, with the exclusive activity to manage the road concession.

This competitive bidding part of the Brazilian road concessions regulation is an attempt to increase the competition in the sector and, as a consequence, generate smaller tolls to Brazilian consumers.

However, what comes next may conflit with the Demsetz auction: a traditional regulation, as such rate of return regulation, give by the economic-financial equilibrium clause. According to Soares & Neto (2006), many authors had analyzed conceptually the economic-financial equilibrium clause in Brazil. The general agreement is that the economic-financial equilibrium is represented by the equality of all the costs and revenues that will occur at each year of the concession contract execution, actualized for the n years of the concession. In this case, we see that authors define the economic-financial equilibrium through the Internal Rate of Return (IRR) concept, which indicates the concession ability to generate profitability. Thus, in the concession contracts, the IRR is the indicator of the evaluation of the economic-financial equilibrium of the contract:

$$\sum_{t=1}^{n} \frac{REC_{(t)} - EXP_{(t)}}{(1 + IRR)^t} = 0, \text{ in which,}$$

$REC_{(t)}$ = annual revenue considered as benefit of the private company, and
$EXP_{(t)}$ = annual expenses (investments and future costs) of the project.
These amounts are calculated with the following equations:

$$
\begin{aligned}
REC_{(t)} &= [Toll_{(t)} + Traffic_{initial}(1+r)^t]\ (1+i)^t \\
EXP_{(t)} &= [Inv_{initial} + \sum_{t=1}^{n} C_{fut(t)}\ (1+i)^t], \text{in which}
\end{aligned}
$$

$Toll_{(t)}$ =Toll offered by the winning company,

$Traffic_{initial}\ (1+r)^t$ = traffic volume in the year t estimated by the r rate,

$Inv_{initial}$ = Investment in the first year. (In the case of investments in many years, we need to multiply by $(1+i)\ t$).

$C_{fut(t)}$ = Future costs in the year t,

n = concession period (concurrent with the amortization period), and

t = analysis year.

Therefore, the IRR is defined, in the public tender process, when the winner introduces its initial toll. When they assign the contract, concessionaire and conceder agree that the initial toll is sufficient to generate the necessary revenues to the economic-financial equilibrium and to ensure the equilibrium IRR to the concessionaire. In this way, the imbalances that may occur with the time should be corrected by the maintenance of the initial IRR. Thus, the government is committed to attend the simple condition:

$$IRR_{(t)}effective\ \geq\ IRR_{(t)}initial\ (t=0),\ \text{in which}$$

$IRR_{(t)}effective$ = is the resulted IRR from the tariff review in year t, and

$IRR_{(t)}initial\ (t=0)$ = is the initial IRR that is implicit in the winning proposal of the concession auction.

Soares & Neto (2006) also comment that some authors are concerned about the maintenance of the economic-financial equilibrium, which depends on the government's ability to control concessionaire costs and revenues which is a very hard mission. The authors draw attention to the fact that, if there is no control by the government, concessionaires will tend to obtain excessive profits, and they point out that the government had the concern with maximal profitability in the competitive bidding process, since it choose a price cap for the toll bid, but there is the necessity to extend this concern in the subsequent concession phases, in the long term.

The government difficulty in tracking costs is due, in part, to the methodology used in the economic-financial equilibrium restablishment, that has the assumption that a sufficient revenue needs to be allowed, to cover efficient operational costs and to allow apropriate compensation to the invested capital. Soares & Neto (2006) conclude:

..."the conceding power has the arduous mission of verifying whether the investment was prudent and if the operational costs were efficient and adequate to be assigned to the consumers. This even presuppose checking concessions managerial decisions, to exclude the possibility of negative results were consequence of an equivocate choice or a poor quality administration."

Because of all these problems with the current miscellaneous in the regulatory regimes of Brazilian road concessions, some authors suggest a change in the Brazilian road concession format: the adoption of a flexible term for each concession, with this variable relevant to the concession auction.

Engel, Fischer & Galetovic (1997), in their seminal paper "Highway Franchising: Pitfalls and Opportunities", introduced the possibility of flexible term in a model called Present-Value-of-Revenue Auction. The authors describe an optimal public-private partnership (PPP) contract, highlighting the fact that the PPP advantages are further enhanced if the contract is implemented with a flexible term.

To reach these conclusions, the paper makes realistic assumptions: (i) The main source of uncertainty is demand uncertainty, which is assumed to be beyond the control of the concessionaire; (ii) Firms face limitations in diversifying across projects and consequentely charge a premium for the demand risk they bear; (iii) All firms have identical technologies; and (iv) The concession is assigned in a competitive auction.

In the scenario of user fees and high demand infrastructure projects, the authors recommend the use of the present-value-of-revenue (PVR) auction to assign PPP contracts.[16] The characteristics that make the PVR model advantageous for the Brazilian road concessions scenario are explained by the authors:

(i) A PVR contract reduces risk because when demand is lower than expected, the franchise period is lengthned. Conversely, when demand is higher, the period is shortened; If the project is profitable, then at sometime all necessary revenue will be collected. In this scenario, all the demand-side risk will be eliminated and the risk premium demanded by the firms will be reduced significantly. In one case study it is reduced by one third (Engel et al. (2001)).

(ii) PVR franchises should attract investors at lower rates than traditional Demsetz auctions with fixed terms. Annual revenues collected in both models are the same, however, in Demsetz franchise, the contract may default. On the other hand, in a PVR auction, the term is extended until the firm collects revenue equal to its bid.

(iii) PVR auctions also reduce the need for guarantees because the risk is much smaller.

(iv) PVR auctions reduce the possibility of opportunistic behavior. Contracts with fixed-terms can be renegotiated resulting in alterating the terms by increasing user tolls, or government transfers. The first option is impossible, because in the PVR approach, the term is variable. Increasing tolls is ineffective because it shortens the term without increasing the overall amount that the company will receive. Government transfers may occur, but they will be very difficult to explain to the public, once the company cannot argue that it will receive less revenue than it expected at the auction time.

(v) PVR concessions permit franchises to be adapted to changing circumstances and allow greater flexibility in setting user fees.

However, the authors comment that PVR auctions are only indicated in scenarios in which is possible to contract a measurable quality. It is an important assumption, since the PPP franchise holder has few incentives to increase demand for an infrastructure project, because it would shorten the contract term. Another important assumption in the use of the PVR approach is that major investments are not needed frequently. This characteristic makes roads a candidate for PVR contracts, while mobile service is not.

Based on Engel, Fischer & Galetovic, Pires & Giambiagi (2000) list many reasons why Brazil should consider the flexible-term auction for road concessions, such as:

(i) It will allow consumers to benefit from a reduction in the toll level before the end of the term predicted to the concession, in the case of the actual demand exceeds the estimates of the present value of revenues to the concessionaire estimated at the time of the concession;

(ii) It will reduce the company demand risk compared to the current model, because it can extend the maximum concession term, for example, from the current 20-25 years to 30 years;

(iii) It will reduce the probability of contract renegotiation, because the *ex ante* variables (which are known) are incorporated into the present value of revenues, while the *ex post* (unknown) are adjusted by the term. As a result, the risks of the 'winner's curse' and the transaction costs are reduced;

(iv) It will introduce more flexibility in addressing unexpecteded situations, through the possibility of adjusting concession terms, preventing renegotiations and all the problems that arise with them (discretionary action, capture,

[16] In this mechanism, the planner sets the discount rate and a user fee schedule, and firms bid the present value of the user fee revenue with which they need to do the work. The firm with the lowest bid win and the contract term lasts until the winning company has collected the user fee revenue that was requested.

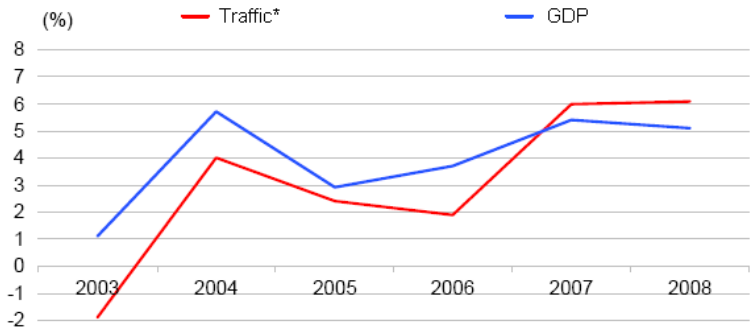
etc);

(v) It will reduce the regulatory costs, because, among other things, the regulator will not need to check actual costs of the concessionaire, which is the case in internal rate of return regulation. The regulatory costs would be concentrated in determining the vehicle flow to estimate the present value of the revenues. The flow would be verified with the instalation of adequate equipment, which would need periodical maintenance. Besides that, a inspection of service quality also would be necessary in this new model proposal.

Silva et al. (2004) conclude in their article that, by taking into account the potential variability in traffic, the option of a flexible term in Brazilian road concessions would reduce renegotiations and could be a better option for Brazil overall. As seen in Figure 7, this risk in traffic is relevant, since there is a strong correlation between the Brazilian gross domestic product and traffic volume. So, the uncertainty in toll collection, given the co-movement between the GDP and traffic in Brazil, is a negative component in the context of concessions with fixed-term contracts.

When public authorities fix the concession term and private concessionaires bid on the toll, public authorities usually do not take into account the specificity of each project for fixing the term. The concessionaire proposes tolls for recovering the full cost of investment during the fixed concession term. This practice leads to lower tolls on roads with a higher volume of traffic, thus creating congestion, while roads with less traffic will have higher tolls, preventing an increase in road users. Moreover, toll prices that are not proportional to the length of roads may be rejected socially.

Figure 7 - Brazilian Traffic and GDP Co-movement



* Traffic from the conceded roads (affiliate to ABCR)
Source: ABCR, IBGE and Fitch.

The Present-Value-of-Revenue Auction (PVR) model[17], the format that the authors above indicate to Brazilian road concession, was proposed first by Engel, Fisher and Galetovic (1997) and is already used in Chile. This model considers the present value of toll revenues, instead of bidding on tolls (or franchise lengths) as is the case for fixed-term franchises, as the bidding variable in the auction. The lowest bid wins and the franchise ends when that amount has been collected. The paper also shows that the welfare gains that can be attained by replacing fixed-term auctions with PVR auctions are relevant.

There are three main points that need to be highlighted in the Brazilian road concessions experience:

[17]Brazil currently does not use this type of auction.The most similar format in Brazil is the one applied in electricity transmission auctions in which the winning bid is the total lowest revenue necessary to construct and administ for 30 years the conceded transmission line. But, different from PVR auction, there is no flexibility in the terms of the contract.

(i) First, the economic-financial equilibrium clause should be eliminated or eliminated by some type of incentive regulation, such as benchamarking regulation.[18] According to Schumaer (2003), rate of return regulation does not provide incentives to cost constrain. The concessionaires that achieve a reduction in costs will not appropriate this efficiency, since the tariffs would be reduced to maintain the internal rate of return constant at the level initially agreed and restablished the economic-financial equilibrium. Another problem with this type of regulation is the huge amount of information that it demands, increasing the regulation cost. As a result of problems with monitoring, government cannot block renegotiations of road concessions tolls, which can be seen as a way to guarantee higher profitability to the concessionaires with a huge social cost to the country.

(ii) Second, the competitive bidding process is also in a 'tightrope' situation, because it was formulated with an intention to have real long term gains, as a result of the competition. Unfortunately, with the coexistence of an economic-financial equilibrium clause, companies approach concession auctions with the possibility of future renegotiations in mind and this can be a source of adverse selection in the Brazilian road concession experience.[19] The second stage of the Federal road concessions program, with a strict predilection for low tolls, only emphasized the potential for this kind of behaviour.

(iii) Third, as pointed out by other authors, a possible solution may be the substitution of the current model by the PRV model.

6 Conclusion

This paper examined Brazilian road concessions. As we saw, Brazil uses roads as its main transportation system: more than 60% of freight is transported on roads. With this circumstance in mind, we reviewed the road concession regulation literature, including three characteristics present in Brazilian concessions: tariff regulation by rate-of-return; concession through a competitive bidding process; and, concessions contracts ruled by an economic-financial equilibrium clause.

Brazil has road concessions at three governmental levels: Federal, State and Municipal. In the present paper, we reviewed the Federal program and the São Paulo State program. The Federal road concessions program is now on its second stage. The first stage was characterized by a relevant regulatory risk and the results were not favorable to consumers because of the high level of the toll bids. The second stage, had smaller toll bids, but only time will tell if the auction design and the concession contract (with large government guarantees through the economic-financial equilibrium clause) was the ideal way to select efficient firms.

Renegotiations are prevalent in the Brazilian road concessions experience and there is evidence that the economic-financial equilibrium clause in the contracts is the loophole by which they have been retained. Renegotiations weaken the potential gains of the competitive bidding process, rendering it less effective.

One possible solution for the road concession regulation in Brazil would be the adoption of a new auction design, proposed by Engel, Fischer & Galetovic (1997 and 2009). This model, the Present-Value-of-Revenue auction, with appropriate quality control by the regulator, would bring many positive aspects to Brazilian road concessions, allowing the potential expectation about concessions, at least in road sector, to become a reality.

[18] Benchmarking is the process of comparing the business processes and performance metrics including cost, cycle time, productivity, or quality to another that is widely considered to be an industry standard benchmark or best practice. Essentially, benchmarking provides a snapshot of the performance of a business and helps it understand where it is in relation to a particular standard.

[19] These companies can formulate a bid at a low and unrealistic level, only because of the possibility of renegotiation given by the economic-financial clause. If the government that is awarding the concession has a political motive, such as looking for votes in the next election, the process is in check and is not allocating efficiently. If this scenario becomes a reality, then the concessions sustainability in a long term does not exist.

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Concluding Remarks

The present thesis is a compendium of papers that seek to investigate relevant aspects of diverse infrastructure sectors in Brazil.

The main characteristic of this work is a microeconomic-based analysis concerned with mechanisms design topics, using econometric tools as an instrument to the comprehension of these relationships.

In the first chapter, our empirical exercises suggest that many factors affect, in the direction of economic intuition, the winning bid in transmission auctions. We estimated four reduced-based models and conclude that a better specification is to use the winning bid in level against the logarithm and a ratio of the bid with investments need. Finally, we model an economic experiment testing that an alternative design for the Brazilian transmission auctions, with neighboring lines auctioned simultaneously, would improve the rent extraction from the transmission companies.

The second chapter updates the modeling of the 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 misaligned with the current scenario. Our findings suggest that Brazilian residential consumers are more sensible to price and to income than the industrial ones. Also, it's important to note that the result of smaller short run elasticities (more inelastic) in the industrial sector compared to the long run may be a consequence of the huge increase in the self-production that occurred recently in the Brazilian industrial sector, because the companies that are still in the system probably have a smaller capability in switch the fuel or option to turn off the electricity. On the other hand, the result of smaller elasticities in the residential sector in the short run compared to long run may be a consequence of the substitution of old appliances for new energy efficient products. 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 then unity). The implications of our results - consequence of a better specification of electric energy with the TVP-ECM model - are important, because policy-makers should consider the possibility of varying responses of elasticities to its determinants. For example, income elasticities correctly estimated are essential to planning needs investments in power generation, while price elasticities are very important to regulation of electricity sector, where incentives are made within a tariff basis.

The first part of the third chapter is an analysis of the natural gas prices worldwide. In this paper, cointegration tests including more than two variables were not conclusive, which makes it not possible to evaluate a global integration of the markets. This probably happened because the LNG market, which is the instrument that provides the missing link to the regions, is still very incipient.

We then analyze convergence among pairs of prices. We use logged monthly natural gas prices for Henry Hub in the United States, NBP in the United Kingdom, and Zeebrugge in Belgium. For the Japanese market we use an average of the main LNG selling prices. All data goes from April 2001 to February 2009. These tests show that the Japanese market does not integrate with any other, probably

because the Japanese market is still too much indexed to oil prices through long term contracts, whereas in the United States and the United Kingdom, Henry Hub and NBP both represent spot markets respectively. Also in Continental Europe one can already find contracts indexing natural gas prices to the spot market in UK. When continuing the cointegration tests, the pairs Henry Hub-NBP, NBP-Zeebrugge and HH-Zeebrugge presented a long run relationship. We run the VECM for each pair of prices to try to identify short run dependence between the prices. For the pairs NBP-Henry Hub and Zeebrugge-Henry Hub, this model indicates a possible influence of the American market in the European markets. However, the results are not enough to account for all the short run dependencies. This model is not significant at all for the pair NBP-Zebbrugge, which is a sign that these markets move together, without relevant time delays; that is, they seem to move simultaneously.

Facing these results, we decided to test for structural breaks and only the pair NBP-Henry Hub presented some trace of it. Therefore we ran a TVP-ECM for this pair of prices. Nevertheless, the smoothed states estimates obtained were not significant. In order to understand the short run relationship between the natural gas prices, we applied the Copula Approach. For the pairs Zeebrugge-NBP and NBP-Henry Hub we found that the short run relation could be represented by a t-Student Function, indicating that these markets move strongly together during extreme periods. On the other hand, for the pair Zeebrugge-Henry Hub the copula obtained was the Frank Copula, which has the characteristic of no dependence at the extremes of the bivariate distribution.

The second part of the third chapter was a first attempt to identify the importance of the LNG use in the Brazilian electric system. We had applied the Simulations of Monte Carlo in stochastic processes and the Real Options technique to analyze the possible value added by the use of the LNG in the thermo power plants Termoceará (CE), Termofortaleza (CE) and Jesus Soares Pereira (RN). We also tried to understand the pricing mechanism adopted in the Brazilian electric sector and its consequences to the system operation.

The final chapter examined the Brazilian road concessions. We reviewed the road concession regulation literature, including three characteristics present in Brazilian concessions: tariff regulation by rate-of-return; concession through a competitive bidding process; and, concessions contracts ruled by an economic-financial equilibrium clause.

Brazil has road concessions at three governmental levels: Federal, State and Municipal. In the present paper, we reviewed the Federal program and the São Paulo State program. The Federal road concessions program is now on its second stage. The first stage was characterized by a relevant regulatory risk and the results were not favorable to consumers because of the high level of the toll bids. The second stage, had smaller toll bids, but only time will tell if the auction design and the concession contract (with large government guarantees through the economic-financial equilibrium clause) was the ideal way to select efficient firms.

Renegotiations are prevalent in the Brazilian road concessions experience and there is evidence that the economic-financial equilibrium clause in the contracts is the loophole by which they have been retained. Renegotiations weaken the potential gains of the competitive bidding process, rendering it less effective.

One possible solution for the road concession regulation in Brazil would be the adoption of a new auction design, proposed by Engel, Fischer & Galetovic (1997 and 2009). This model, the Present-Value-of-Revenue auction, with appropriate quality control by the regulator, would bring many positive aspects to Brazilian road concessions, allowing the potential expectation about concessions, at least in road sector, to become a reality.

In this thesis, we have widely presented studies and analysis in the infrastructure topic. In a general point of view, the present work contributes to policymakers and economists to the achievement of the infrastructure development objective and to the consequent Brazilian sustainable growth that it may cause.