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Article

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A GARCH Model to Understand the Volatility of the Electricity Spot Price in Brazil

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ABSTRACT

Electricity is sensitive to extreme price events and spot price volatility is an inherent characteristic of competitive electricity markets. The purpose of this article it to model the realized volatility of electricity spot price in Brazil. The Brazilian electricity industry presents unique characteristics and because of this price varies a lot in a short period. So, we developed a GARCH model using 862 weekly observations to understand the realized volatility in the four different market. We conclude that the spot price in Brazil presents high volatility that presents risk to agents. This high volatility is associated with institutional factors and the increase in the share of renewable energy in the electricity mix.

Keywords: Volatility, GARCH Model, Spot Price, Brazilian Electricity Market
JEL Classifications: C32, Q40, Q41

1. INTRODUCTION

Market oriented reforms had significant consequences for the electricity industry worldwide. Among these consequences are the impacts on the industry structure, on new forms of investment, and on transactions in the industry. In this sense, after deregulation in the industry, spot markets were created to meet some important goals: increase flexibility of transactions, allow adjustments between the contracted power and the energy generated, and to be a reference to long-term contracts. Namely, a spot market is an important adjustment mechanism between demand and supply (Newbery, 1995).

Electricity is much more vulnerable to extreme price events than other commodities because of its non-storability, high transmission costs, high demand price inelasticity, and more recently, due to the increase of the share of renewable energy in the electricity mix (Newbery et al., 2018). Therefore, price volatility is an inherent characteristic of competitive electricity markets. Electricity spot price volatility analysis has been reported in the literature for most competitive electricity markets around the world (Bhattacharya et al., 2007). Electricity spot price volatility refers to unpredictable fluctuations of the price observed over time. Given the uncertainty associated with electricity prices, and such a wide variety of options, the applications of volatility analysis to competitive electricity markets are undoubtedly useful for market agents (Shahidehpour et al., 2002).

In Brazil, electricity has been traded in competitive wholesale markets for over two decades, following the beginning of electricity sector deregulation in the 1990s. The spot market in the country actually is a market for differences, as explained in Hunt and Shuttleworth (1996). Spot price is determined by the system operator on a weekly basis. As hydropower plants are responsible for 65% of the electricity produced, the spot price is given by the value related to the point which minimizes both the immediate and future costs of the system operation. The marginal costs of the system depend on the level of water available in reservoirs.

The purpose of this article is to model the realized volatility of the electricity spot price in Brazil. The main motivation for this research was the mere observation of price variations in a short period. For example, in June 2019, the price rose 3 times in a period of 2 weeks. Therefore, understanding price volatility is crucial for market players and policy makers.

2. BACKGROUND

Sadorsky (2012) points out that modelling and forecasting volatility lies at the heart of modern finance, because good estimates of correlation and volatility are needed for derivative pricing, portfolio optimization, risk management, and hedging. According to Bello et al. (2017), electricity prices are more volatile than other goods affected by extreme values. Electricity prices vary according to the demand, weather patterns, regulation patterns, market power, and other reasons. Price fluctuations are a specific feature inherent to liberalized electricity markets. The stochastic properties of volatility in spot electricity prices present substantial modelling challenges. There are a variety of research papers which deal with price volatility in electricity markets that can be found in the literature.

Angelus (2001) and Mount (2001) consider that forecasting electricity prices is a difficult task due to factors such as the uncertainty about demand and supply, climate change, and the non-storability of electricity. In Alvarado and Rajaraman (2000), the periodic part of the price variations for an unknown market is separated out using a frequency-domain method, and volatility of the remaining part is analyzed. Dahlgren et al. (2001) used a value at risk methodology to study the volatility of prices in the Californian market. Li and Flynn (2004) analyzed price volatility of fourteen markets worldwide, with widely varying price volatility behaviors being observed across different markets.

Worthington et al. (2005) developed a multivariate GARCH model to understand the interrelationship among prices and price volatilities in the five Australian electricity markets. Volatility features of the Nord Pool day-ahead electricity market was studied in Simonsen (2005) for a 12-year period up until the year 2004, and the research concludes that electricity shows a higher level of price volatility when compared to other financial markets. Tashpulatov (2013) estimated the volatility of prices in England and Wales and found that the introduction of price-cap regulation did achieve the goal of lowering the price level, albeit at the cost of higher price volatility.

Karakatsani and Bunn (2010) developed and applied three complementary modelling approaches using GARCH, in order to uncover fundamental and behavioral price volatility drivers over time, and across intra-day trading periods. They found that GARCH effects diminish when each of the sources of volatility are accounted for. There are therefore several studies using a univariate GARCH approach to estimate volatility in electricity and energy markets, as in Zareipour et al. (2007), Hadsell et al. (2004), Higgs (2009), Chan and Gray (2006), Girish (2016), and Qu et al. (2018). However, no significant GARCH study modelling the volatility of Brazil's electricity market has been published. In sum, volatility of electricity spot prices depends on the characteristics of each market. Additionally, electricity supply is inelastic at high output levels. Every region's generation capacity is composed of a unique mix of technologies, which differ by marginal cost and by their ability to quickly change the level of output.

3. THE BRAZILIAN ELECTRICITY SPOT MARKET

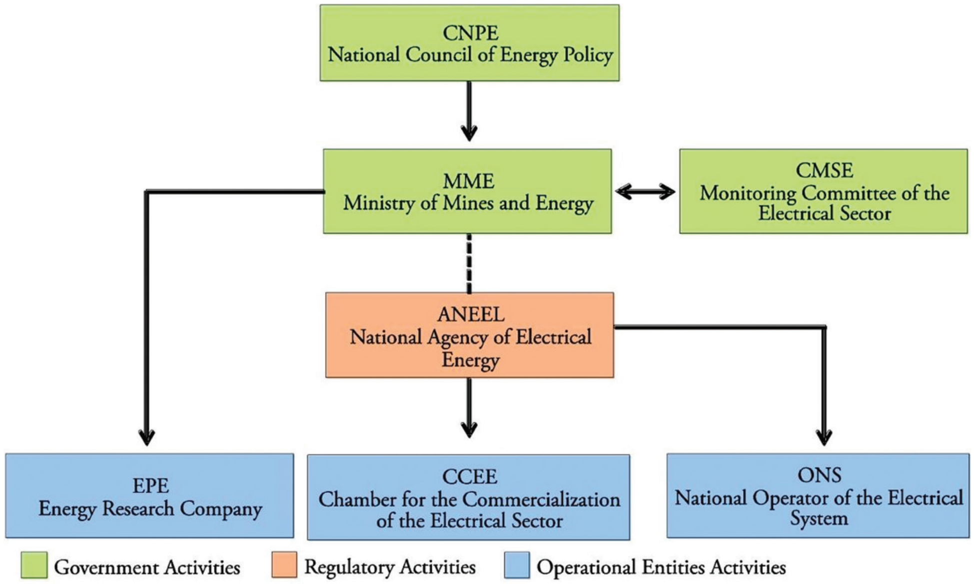
The Brazilian electricity sector is a large-scale hydro-thermal system characterized by the presence of large reservoirs, high capital intensity, and large interconnections. The main institutional feature of the Brazilian electricity sector is the predominance of hierarchy as a governance structure. Until the 1990's in Brazil, Eletrobras, the state owned holding, was at the top of the hierarchy. Eletrobras controlled nearly 90% of supply and was responsible for planning and operating the whole system. This governance structure was created in the 1950's, based on state monopoly. The governance structure became more relevant in the 1970's, when efficiency gains from the interconnection of the system and economic growth resulted in a virtuous cycle, with decreasing short and long-term marginal costs. The increase in demand was linked to the increase in supply.

The Brazilian electricity sector has faced two important institutional reforms in previous decades. In 1996, the Brazilian electricity industry (BEI) was restructured for the 1st time, with the main purpose being to introduce competition and enhance investments in the industry. Nearly 80% of the distribution companies and 20% of the generation companies were privatized. Some companies remained state-owned, and two (CEMIG and COPEL) were not unbundled. The 2001 supply crisis made clear that both private and public investments in electricity had decreased. After 2003, the government designed a new model for the Brazilian Electricity Industry that strengthened the role of the state in the industry.

Although these reforms tried to introduce competition in generation, it is possible to say that the BEI is far from being a competitive market. As Araujo (2001) states, in a hydroelectric system like in Brazil, coordination is far more important than competition. The most important feature of the short-term Brazilian market is the existence of two market operators, with different functions. On one hand, the physical system operator—the National System Operator (ONS)—is responsible for the coordination and control of the installation operations for the generation and transmission of electric energy in the national interconnected system, under the supervision and regulation of the National Electric Energy Agency (ANEEL). On the other hand, the Electric Energy Trading Chamber (CCEE) is responsible for energy purchase and sale transactions. Figure 1 shows the BPS institutional agents. It is important to notice the significance of the government in the planning of the industry, which also includes the methodology used to determine prices.

Regarding the commercialization of electricity, two distinct markets were created for the negotiation of energy trade contracts: the Regulated Contracting Environment (ACR), in which the agents of generation and distribution of energy participate; and the Free Contracting Environment (ACL), in which generators,

Figure 1: Brazilian electricity industry institutional agents



Source: (MME, 2013)

electricity dealers, importers, and free consumers of energy participate (CCEE, 2019). The institutional model of the electricity sector provided a set of measures to be observed by the agents, such as the requirement to meet all demand by the distributors and free consumers; as well as permanent monitoring of the continuity and security of supply to detect conjunctural imbalances between supply and consumption (CCEE, 2019).

The Brazilian energy grid is diversified, with many sources of generation (hydraulic, biomass, wind, photovoltaic, amongst others), with smaller projects alongside larger ones, distribution across the various geographic regions of the country (Vahl et al., 2013), and increased private sector participation (Rego and Parente, 2013). However, hydropower is responsible for approximately 65% of electricity produced, which has an impact on price.

The commercialization of electricity occurs in two different markets: the ACR, subject to the rules established by the regulatory agency and government directives; and the ACL, which allows generators and traders to freely commercialize energy (Rendeiro et al., 2011).

The Brazilian electricity sector exhibits unique characteristics. Approximately 65% of the electricity is generated by hydroelectric plants, almost 15% comes from wind farms, and nearly all generation, transmission, and distribution systems are nationally interconnected. Unlike other countries, in Brazil there is no electricity market *per se*. The short-term electricity price in Brazil is known as the settlement difference difference price (PLD) and it reflects the difference between what was contracted and what was really consumed. This concept is well described in Ferreira et al. (2015).

The PLD reflects, for instance, the opportunity costs for short-term electricity:

i. For the generator, who can sell non-contracted electricity.
ii. For consumers, who can buy or sell the differences between what was contracted and what was effectively consumed.

The PLD is not determined by demand and supply, but by a computational program that takes into account the availability of water for immediate use and for future use. Balanced operation of the system involves a compromise between depleting (using water) and not depleting (using thermal plants) the reservoirs. The decision variable is the volume of water stored at the end of the operational period (Ferreira et al., 2015). This decision is associated with the immediate cost function (ICF) and the future cost function (FCF); in this case, the cost to use or to store water in reservoirs.

In the case of the Brazilian electricity sector, the spot price of electricity is a function of the characteristics of the industry, i.e., the availability of water in reservoirs and the precipitation level, the marginal costs of thermal plants, and transmission constraints. In most systems, the hydroelectric energy prices tend to be somewhat volatile in the short term and more volatile in the medium term. This is because in the short term, there is a transfer of electricity from low-load to high-load periods by modulating the supply and reducing price volatility. While in the medium term, the price of energy is more volatile because the hydraulic systems were designed to ensure the supply of electricity in adverse hydrological conditions.

The Brazilian electricity sector is divided into four subsystems: Southeast/Midwest, South, North, and Northeast, which represent the geographic regions of the country. The system operator defines, according to stochastic programming, the price for each subsystem on a weekly basis.

The electricity contracts are registered at CCEE, which measures the amounts actually produced or consumed by each agent. The differences established are settled in the short-term market, or spot market, at the PLD (CCEE, 2019). The PLD is determined on a weekly basis for each load level, with a cap and a minimum price, and is used to value the energy that was not contracted by the agents of CCEE (surplus or difference) in the spot market (Araujo et al., 2008). The PLD reflects the marginal cost of new electricity in the system. In the rainy season, when supply and demand for electricity in the country are balanced, the price of electric power is lower, as is, consequently, the PLD. When the water reservoirs are low, there is a lack of energy, and the thermal plants are linked to a high marginal cost, pushing up the energy price and the PLD (Dalbem et al., 2014). The PLD, due to the way it is defined, does not give accurate economic signaling for the agents. Moreover, in situations of prolonged drought, the PLD tends to reach and park for many months at extreme values, clearly without adherence to the average cost of energy. This contributes to exacerbating financial risk in the commercialization of energy, bringing in return only very limited benefits in the form of signaling for the restriction of consumption by consumers.

4. DATA, THE MODEL, AND RESULTS

The data used in this article is the weekly price for medium load of the four sub-systems data on wholesale electricity prices obtained from the Electric Energy Trading Chamber's website (www.ccee.org.br). The time period covered is from January 1, 2003, to September 21, 2019, totalizing 886 observations. Prices before 2003 were disturbed by the 2001-2002 supply crisis, so they were not used in this research.

4.1. The GARCH Model

A GARCH model is a useful generalization of the ARCH model developed by Engle (1982), and was first introduced by Bollerslev (1986). This model is also a weighted average of past squared residuals, but it has declining weights that never go completely to zero. It gives parsimonious models that are easy to estimate, and even in its simplest form, has proven surprisingly successful in predicting conditional variances. It describes volatility clustering and excess kurtosis (although not entirely). The most widely used GARCH model asserts that the best predictor of variance in the next period is a weighted average of the long-term average variance, the variance predicted for this period, and the new information in this period that is captured by the most recent squared residual. Such an updating rule is a simple description of adaptive or learning behavior and can be thought of as Bayesian updating (Engle, 2001).

The basic principle of GARCH is that great changes are followed by great uncertainties, and small changes are followed by small uncertainties. In the standard GARCH model, a series of returns is usually represented by a constant average C plus Gaussian innovation, as described in Bollerslev (1986).

As the literature suggests, the benchmark model for capturing this principle is a simple first order autoregressive model (AR (1)), as in Cuaresma et al. (2004). AR (1) process is given by:

$$p_t = \alpha + \beta p_{t-1} + \eta_t \quad (1)$$

Linear ARMA models have an assumption of constant variance and covariance functions, or homoskedasticity. In the case of electricity prices, autoregressive conditional homoskedasticity (ARCH) models, given by Engle (1982), usually yield better results, as the literature suggests. However, as electricity spot prices are usually volatile, the generalized autoregressive conditional homoskedasticity (GARCH) model fits better because it models the time-varying volatility process (Engle, 2001).

The standard GARCH (1.1) model is represented by:

$$y_t = \mu + \varepsilon_t \qquad \varepsilon_t \sim N\left(0, \sigma_t^2\right),$$

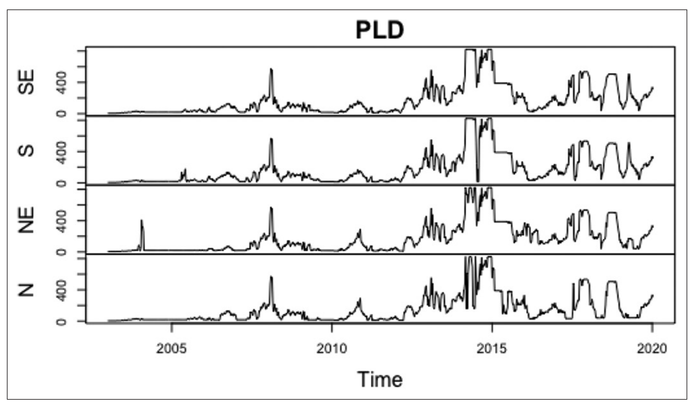
$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2$$

Where, ε_0 and σ_0^2 are constant. The conditional variance is a deterministic function of the model parameters and past data. Figure 2 presents the data from January 2003 up until September 2019, for the four subsystems.

Most volatility analysis studies consider the logarithmic return over arithmetic return (Jorion, 2001; Christoffersen, 2003), hence, logarithmic return is also used in the present work. The log return for each subsystem was calculated and shown in Figure 3, where it can be asserted that the series are non-stationary, and serially uncorrelated.

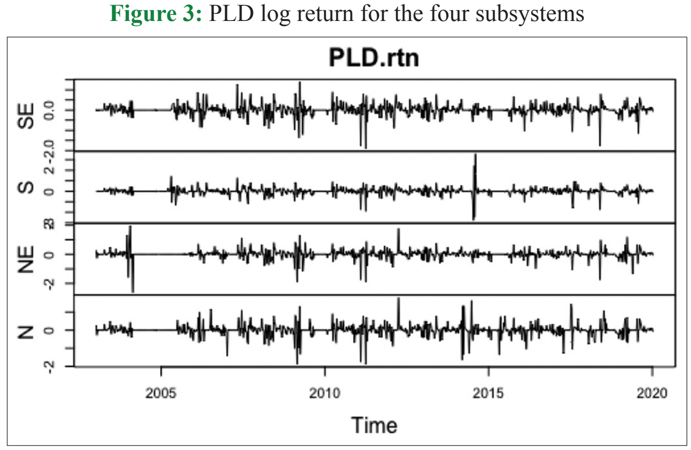
The conditional mean equation is estimated using the autocorrelation function (ACF), which helped to identify and specify AR and MA

Figure 2: PLD of the four subsystems in Brazil, from 01/2003 until 09/2019 – (R$)



Source: data from www.ccee.org.br

Figure 3: PLD log return for the four subsystems



Source: Data from www.ccee.org.br

terms for capturing and representing the spot price dynamics. The first difference was rendered for all four subsystems in Brazil, as shown in Figure 4.

The series of log returns for the four sub-markets is stationary, however, the autocorrelation functions suggest a non-significant serial correlation, with the exception of 1 lag. Thus, the log returns of the series of spot electricity prices are shown to be serially uncorrelated, however, dependent. Thus, for the four subsystems, volatility models were developed based on the weekly price log-returns. The models developed for all subsystems were GARCH (1.1) and generated the following equations, respectively:

- Southeast
  r_t=0.003+α_t, α=$\sigma_t\varepsilon_t$, ε~N (0,1)
  $$\sigma_t^2 = 0.01119 + 0.154\alpha_{t-1}^2 + 0.718\sigma_{t-1}^2$$
- South
  r_t=−0.003838+α_t α=$\sigma_t\varepsilon_t$, ε~N(0,1)
  $$\sigma_t^2 = 0.0299 + 0.418\alpha_{t-1}^2 + 0,3763\sigma_{t-1}^2$$
- Northeast
  r_t=0.00349+α_t α=$\sigma_t\varepsilon_t$ ε~N(0,1)
  $$\sigma_t^2 = 0.00775 + 0.17784\alpha_{t-1}^2 + 0.7685\sigma_{t-1}^2$$

Figure 4: Autocorrelation function of the four subsystems in Brazil

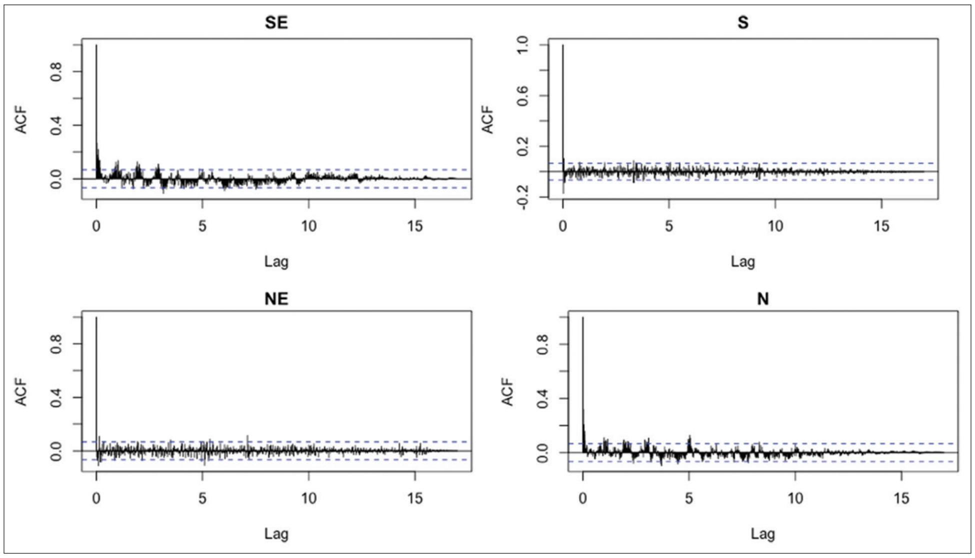
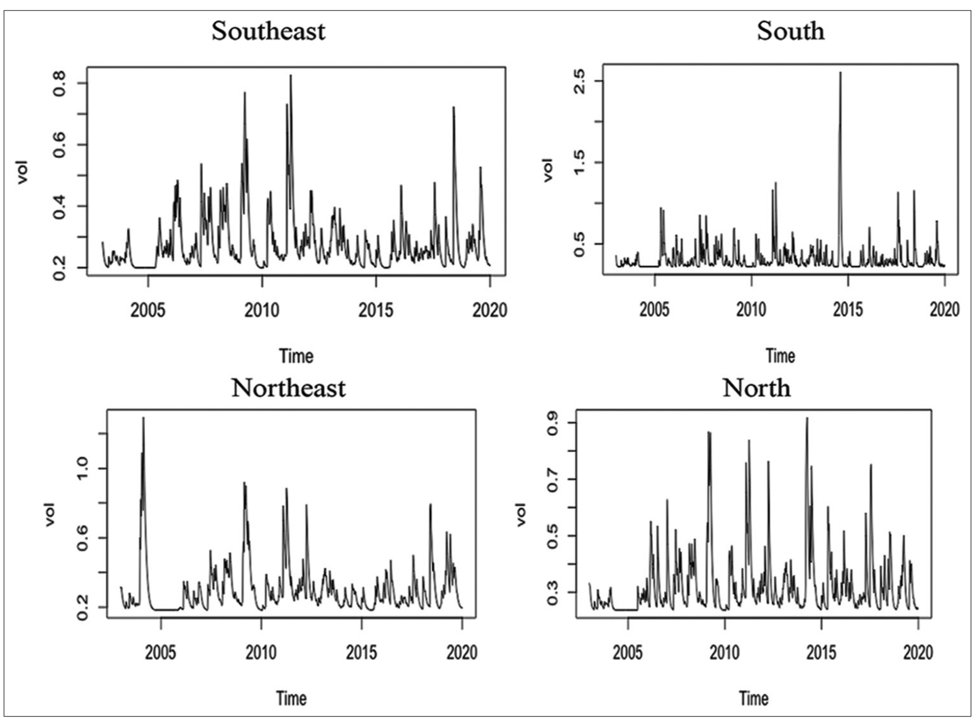


Figure 5: Realized volatility for the four subsystems in Brazil



- North
  $r_t=0.00536+\alpha_t$, $\alpha=\sigma_t\varepsilon_t$, $\varepsilon\sim N(0,1)$
  $$\sigma_t^2 = 0.0169 + 0.1610\alpha_{t-1}^2 + 0.6958\sigma_{t-1}^2$$

As all equations are statistically significant, it was possible to model realized volatility series for the four subsystems, as shown in Figure 5.

For the four markets, volatility was high in some periods and low in others, and it is possible to notice the presence of volatility clusters. As can be seen, for all the markets the PLD is very volatile, which represents high risk to players in the electricity industry.

The main cause of this volatility is related to the characteristics of the industry. Approximately, 65% of the energy generated in Brazil comes from hydro plants. In the past, before the reforms, hydro plants were responsible for 100% of the electricity produced in the country and large reservoirs were used to act as a hedge to guarantee the generation of electricity in dry periods. However, after the promulgation of the Federal Constitution was edited in 1988, and environmental concerns which prevented the construction of new reservoirs, it is not possible to build large reservoirs anymore. Nowadays, the backup is from thermal plants, especially oil and natural gas; but to determine the price, the system operator uses the same computational program as used when the system was a vertically integrated monopoly. In addition, since 2014, the share of intermittent sources in the electricity mix, especially wind, has increased. This has contributed to the high volatility in the spot price.

Spot prices are meant to give incentives. In the short run, spot prices give incentives to sellers and buyers. In the long run, spot prices give signals to investors. The increased participation of the run-of-river hydro plants will reduce the performance of the strategic reserve system and will require greater operational flexibility of existing reservoirs. This is in addition to requiring increased installed capacity of back-up plants, i.e., flexible thermal plants, especially during dry seasons.

5. CONCLUDING REMARKS

The purpose of this article was to model the realized volatility of the electricity spot price in Brazil. The PLD, corresponding to the spot price, has been very volatile, and by consequence, substantially unpredictable. These characteristics reduce the degree of certainty of the electricity sector's economic agents to considerably increase the economic and financial risks. To do so, a GARCH model was built with 862 observations. The model showed that the price is very volatile, and this represents a risk to agents as it is more difficult to forecast the electricity price.

The main cause of this volatility is related to the characteristics of the industry. Approximately 90% of the energy generated in Brazil comes from hydro plants. The price is calculated on an ex-ante weekly basis through dual stochastic dynamic programming models that analyze the current flow and the flow rates in the short, medium, and long terms. Thus, the spot price is the result of computer models, and by failing to take into account the demand side, the spot price is inadequate and gives inconsistent signal for future investments and providing long-term contracts. In relation to the volatility of the spot price, three factors were examined: a shortage of investment in the period after crisis, the end of the construction of new reservoirs. It was noted that these elements are interdependent, which implies that there is an increasingly explicit trend, which is that the PLD will become an even more volatile variable, contributing to instability in the Brazilian electricity market.

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