MACROECONOMIC EFFECTS OF SHOCKS IN THE ELECTRICITY MARKET: A NARRATIVE APPROACH

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ABSTRACT

This work estimates the effects of electricity market shocks on economic activity, using structural autoregressive vectors (SVAR) identified through narrative information around key historical events for the Brazilian electricity sector. This economy went through a major exogenous energy supply crisis in 2001 and a tariff shock in 2013, resulting from a new law. The results show that economic activity responds negatively to both generation and tariff shocks, with an increase in inflation, public debt, and interest rates at the initial moment. Unlike the tariff shock, which has a greater contractionary effect on the economy, in the generation shock, economic activity recovers faster given the new cycle of rains and the use of other sources of generation. These results are maintained in the robustness analysis that uses other variables to measure economic activity and different data frequencies.

Keywords: Electricity market. Structural shocks. Narrative sign restrictions.

JEL classification: Q43, C32, O13.

RESUMO

Este trabalho estima os efeitos de choques no mercado de eletricidade sobre a atividade econômica, usando vetores autorregressivos estruturais (SVAR) identificados por meio de informações narrativas em torno de eventos históricos importantes para o setor elétrico brasileiro. Essa economia passou por uma grande crise exógena de oferta de energia em 2001 e um choque tarifário em 2013, decorrente de uma nova lei. Os resultados mostram que a atividade econômica responde negativamente tanto a choques de geração quanto tarifário, com aumento da inflação, da dívida pública e das taxas de juros no momento inicial. Ao contrário do choque tarifário, que tem um efeito contracionista maior sobre a economia, no choque de geração a atividade econômica se recupera mais rapidamente dado o novo ciclo de chuvas e a utilização de outras fontes de geração. Esses resultados são mantidos na análise de robustez que utiliza outras variáveis para medir a atividade econômica e diferentes frequências de dados.

Palavras-chave: Mercado de eletricidade. Choques estruturais. Restrições de sinais narrativas.

Classificação JEL: Q43, C32, O13.

Área 7 – Infra-estrutura, transporte, energia, mobilidade e comunicação.

1 INTRODUCTION

Shocks to the supply or price of energy affect households and firms in different ways. Energy is an important factor for moving people and goods, in heating/cooling environments, enabling the use of utensils, machines, and equipment, whether in a home or a factory. These may be some of the reasons that help explain why the demand for this good is inelastic (Killian, 2009). Csereklyei, Rubio-Varas, and Stern (2016) highlight a set of stylized facts about energy and economic activity. First, as income increases, per capita energy consumption increases, but energy intensity decreases. Thus, developing countries tend to have a higher energy intensity. Second, there is a convergence of energy intensity and the energy/capital ratio over time between countries. Third, the energy/capital ratio decreases with increasing economic activity, and finally, energy quality is higher with income.

Given the importance of this input, several studies analyze whether shocks to the supply or price of energy have effects on aggregate production and inflation in an economy. Hamilton (2008) shows that several authors since the 1970s have reported the negative effect of oil shocks on economic activity and inflation. Since the seminal works on this topic, evidence of this effect has continued to grow. Peersman and Van Robays (2012) find that the real GDP of eleven industrialized countries undergoes transient fluctuations in response to shocks in oil prices. For emerging countries, Ji et al. (2015) find for the BRICS that the Russian economy is more vulnerable to oil supply shocks, while the other countries of the bloc are more vulnerable to demand shocks for the good.

Although the energy markets encompass different categories of goods besides oil, such as natural gas, electricity, and coal, it is observed that the variables of the oil market, such as price, consumption, and production, are more used to identify energy shocks. However, recent papers formally question its use and find new insights by replacing (Melichar, 2016) or adding (Sarwar et al., 2017) other energy proxies. Unlike shocks in the oil market, which can simultaneously and similarly impact a set of countries, given that there are internationally defined prices and trade and transport policies, electricity market shocks are more restricted and depend on how the economy exploits its electricity matrix.

For the G7 countries, Narayan et al. (2008) find that, except for the US, electricity consumption has a significantly positive impact on the real GDP of the countries of the bloc in the short term. Similarly, Arčabić et al. (2021) report a cointegration relationship between electricity consumption and economic activity for nine out of fourteen European Union countries. Marques et al. (2014) show a causal relationship between electricity generation and economic growth in Greece. According to He et al. (2010), tariff shocks cause contractionary effects on economic activity in the Chinese economy. For Brazil, Divino and Brandão (2020) verify that fiscal and monetary policy shocks affect the variables of the electricity sector.

Despite the numerous empirical evidence of a relationship between energy, production, and other economic variables, some works suggest caution in this analysis and ask whether energy shocks are exogenous. For example, Barsky and Killian (2001) propose that much of the rise in oil prices observed in 1973-74 was generated by monetary expansion. Or even, if the negative effects on production attributed to energy shocks are not generated by the increase in interest rates as a measure to contain inflation (Bernanke et al., 1997).

Structural autoregressive vectors (SVAR) are the most used models to identify and quantify the effects of energy shocks (Kilian and Zhou, 2022b; Van de Ven and Fouquet, 2017; Ji et al., 2015; Baek, 2021; Mele, 2019). However, other models, such as VAR-GARCH-on-average (Azad and Serletis, 2020) and Quantum ARDL (Benkraiem et al., 2018), are also used.

The present work intends to contribute to this theme by estimating the effects of two exogenous shocks in the electricity market, one in the quantity supplied and the other in energy tariffs, for the Brazilian economy. For this, we use SVAR models and the identification method proposed by Antolín-Díaz and Rubio-Ramírez (2018) that adds a set of narrative information to the traditional sign restrictions.

The Brazilian electrical system is the 9th largest in the world and the largest in Latin America (ANEEL, 2019). The main feature that distinguishes Brazil from most countries is the strong dependence on the hydraulic source for electricity generation (Cavaliero and Da Silva, 2005) whose supply capacity is strongly reduced in periods with low rainfall, such as in 2001. Another characteristic is the strong susceptibility of the sector to discretionary government policies, such as Law 12,783/2013 which imposed a reduction in tariffs in exchange for the advance of the renewal of concessions, but ended up exposing the regulated agents to serious economic losses. These are two prominent cases of exogenous shocks in the Brazilian electricity sector and will be used to construct the set of narrative information necessary for the identification strategy.

Several works report that this method of identification can produce better results (see, for example, Zhou, 2020; Kilian and Zhou, 2022a; Boer et al., 2021). Antolín-Díaz and Rubio-Ramírez (2018) formalize and improve this method of identification. Despite the robustness of the new technique, so far there are few applications beyond oil and monetary policy shocks. This work seeks to contribute to this literature with an application for the Brazilian electricity market.

The results show that generation and tariff shocks harm economic activity and increase inflation, public debt, and interest rates. The supply shock has a brief effect, while the economic recovery is slower after the tariff shock. Results are in line with related literature and are confirmed in robustness checks.

The rest of the work is organized into five sections. The next section presents the literature related to the topic. The third and fourth sections describe the methodology and data, respectively. In the fifth section the results are presented and in the last section the main conclusions.

2 LITERATURE REVIEW

A substantial body of literature studies the effects of energy shocks on economic activity. The price and consumption of oil are the most commonly used proxies to estimate the shock. For eleven industrialized countries, Peersman and Van Robays (2012) find that shocks in oil prices lead to a temporary increase and a transient decline in real GDP, respectively. For the UK, Van de Ven and Fouquet (2017) find that the transition from biomass to coal reduced the contractionary effects of supply shocks and raised the expansionary ones of demand shocks. Both works use the SVAR method.

Developing countries may show significant differences in the effects of energy shocks due to greater economic fragility and lower price bargaining power (Sarwar et al., 2017). Ji et al. (2015) use the SVAR model to analyze these effects in the BRICS countries in the period from 1994 to 2012. The work uses industrial production, price index, and exchange rates for each country, besides oil production and prices. The results show that, except for Russia, the countries of the bloc are more affected by demand shocks induced by global economic expansion than supply shocks.

Using VAR-GARCH-on-average, Azad and Serletis (2020) find that oil price uncertainty has a negative effect on real production in India, Indonesia, Mexico, Russia, and Turkey and a positive one for Brazil and China. For Brazil, Mele (2019) finds a long-term relationship between oil consumption and real GDP through the VECM model. Baek (2021) finds similar results for Indonesia using the SVAR model for oil prices, industrial production, inflation, and exchange rates.

Recent works question the use of oil prices as an energy proxy. Melichar (2016) reports that models with diesel, natural gas, heating oil, and electricity prices better predict the economic activity index for many of the 50 American states than the baseline model with the price of oil, especially in the short and medium term. The work uses a VAR model and imposes that economic activity has no contemporary effect on energy prices as an identification strategy.

Sarwar et al. (2017) estimate a Solow model with the oil price and electricity consumption for a panel of 210 countries from 1960 to 2014. The authors find, in general, a bidirectional relationship between GDP and the other variables, despite the heterogeneous effects on income and participation of renewable sources. For Nigeria, Galadima and Aminu (2019) use SVAR with sign restrictions and show that natural gas consumption responds significantly to real GDP and money supply shocks.

There are several empirical works dedicated to the study of the relationship between economic activity and electricity consumption. Narayan et al. (2008) estimate the effects of electricity consumption shocks on economic activity in G7 countries from 1970 to 2002 with SVAR models. Except in the US, electricity consumption has a positive and statistically significant impact on countries' real GDP in the short term.

Arčabić et al. (2021) analyze the long-term relationships between electricity consumption, GDP, and inflation for 20 European Union countries through the ARDL model with structural changes. The results point to cointegration in at least nine of the fourteen EU15 countries. Similar studies are conducted by Zachariadis and Pashourtidou (2007) for Cyprus and Hamdi et al. (2014) for Bahrain. Both observe bidirectional effects between electricity consumption and economic activity. For Turkey, Azgun (2011) and Soytas and Sari (2007) show that electricity consumption shocks do not influence economic activity, while real GDP and value-added innovations affect total electricity consumption. Different from other works, where there is a bidirectional relationship. All these works use VAR class models, such as SVAR and VECM.

Marques et al. (2014) analyze the relationship between electricity generation (renewable, hydroelectric, and thermoelectric sources) and industrial production in Greece from 2004 to 2013 through a VECM model. The results point to a short-term causal relationship between conventional fossil sources and economic growth but do not find a causality of renewable sources with economic activity in the short and long term.

Agurto et al. (2021) estimate the impacts of tariff shocks on the Chilean business cycle in the short and medium term through DSGE models. The results show that shocks of different signals modify the investment in generation and affect the business cycle. For China, He et al. (2010) use computable general equilibrium (CGE) models and show that tariff shocks may have a contractionary effect on economic activity. For Brazil, Divino and Brandão (2020) find that fiscal and monetary shocks affect the dynamics of the Brazilian electricity sector, albeit indirectly. In addition, there is a high rigidity in the Brazilian electricity tariff, which can be explained by regulatory measures.

The related literature mostly uses SVAR models that require a set of restrictions for identification, such as sign restrictions. The class of restrictions used in this work adds to the traditional sign restrictions a set of narrative information. The method proposed by Kilian and Murphy (2014) to identify energy shocks involves a combination of sign restrictions and limits on the price elasticities of demand and supply implicitly. Zhou (2020) explicitly incorporates narrative sign restrictions and evaluates the posterior distribution of the structural models. The results are similar to those of Kilian and Murphy (2014) for the US.

Following Kilian and Murphy (2014), the work of Antolín-Díaz and Rubio-Ramírez (2018) shows a procedure that explains the narrative sign restrictions (NSR). They restrict the structural shocks and/or historical decomposition around historical events ensuring that these shocks agree with the narrative report. The method is applied to measure the effect of oil shocks on the American economy. The results show that oil demand shocks have a much smaller initial impact on economic activity in absolute value than in the specification without NSR. Moreover, the response of economic activity to aggregate demand shocks is stronger and more persistent.

Kilian (2022) argues that externally validating the model by comparing historical decomposition with external evidence was an early way of using narrative sign restrictions. Kilian and Zhou (2022a) use a combination of zeros and NSR restrictions motivated by theory and external evidence. They show that the depreciation of the dollar is important to explain the increase in the price of oil between 2003 and 2008. Thus, persistent exogenous fluctuations in the exchange rate can produce considerable appreciations or depreciations in the price of oil.

Although recent studies show the advantages of using NSR to identify shocks in energy markets, it is observed that the method is mostly applied to the oil market. We intend to contribute to this literature using this class of restrictions to estimate the economic effects of shocks in the Brazilian electricity market.

3 METHODOLOGY

3.1 The model

The methodology proposed by Antolín-Díaz and Rubio-Ramírez (2016, 2018) is used. Let $1 \leq t \leq T$. The structural autoregressive vector (SVAR) can be expressed as

$$y_t' A_0 = \sum_{l=1}^{p} y_{t-l}' A_l + c + \varepsilon_t' \tag{1}$$

Where y_t is an $(n \times 1)$ vector of (endogenous) variables, A_l is an $(n \times n)$ matrix of autoregressive parameters, A_0 is an invertible matrix of parameters that express the instantaneous relationships among the variables in y_t, c is a $(1 \times n)$ vector of deterministic terms, p is the length of the delay, and ε_t is a $(n \times 1)$ vector of structural shocks. Conditional on past information and initial conditions, ε_t is Gaussian with zero mean and covariance matrix I_n, the $(n \times n)$ identity matrix. The model in (1) can be rewritten as

$$y_t' A_0 = x_t' A_+ + \varepsilon_t' \tag{2}$$

Where $A_+' = [A_1' \cdots A_t' c']$ is $(m \times n)$ and $x_t' = [y_{t-1}', \ldots, y_{t-p}', 1]$ is $(m \times 1)$, and $m = np + 1$. Let $B = A_+ A_0^{-1}$, $u_t' = \varepsilon_t' A_0^{-1}$, and $E[u_t u_t'] = \Sigma = (A_0 A_0')^{-1}$. The solution or the reduced form of (2) gives the vector autoregressive model (VAR) given by $y_t' = x_t' B + u_t'$.

3.1.1 Impulse-response functions

For a given set of values of the structural parameters collected in $\Theta = (A_0, A_+)$, the impulse-response functions (IRFs) of the *i*-th variable to the *j*-th structural shock on the horizon k corresponds to the *ij*-th element of $L_k(\Theta)$ defined as

$$L_0(\Theta) = (A_0^{-1})' \tag{3}$$

$$L_k(\Theta) = \sum_{l=1}^{k} (A_l A_0^{-1})' L_{k-l}(\Theta) \text{ for } 1 \leq k \leq p \tag{4}$$

$$L_k(\Theta) = \sum_{l=1}^{k} (A_l A_0^{-1})' L_{k-l}(\Theta) \text{ for } p < k < \infty \tag{5}$$

3.1.2 Structural shocks and historical decomposition

Given Θ, structural shocks in *t* are given by:

$$\varepsilon_t'(\Theta) = y_t' A_0 - x_t' A_+ \tag{6}$$

Historical decomposition calculates the contribution of structural shocks to the unexpected change observed in variables between two periods. Formally, the contribution of the *j*-th structural shock to the unexpected change observed in the *i*-th variable between periods t and $t + h$ is

$$H_{i,j,t,t+h}(\Theta, \varepsilon_t, \ldots, \varepsilon_{t+h}) = \sum_{l=0}^{h} e_{i,n}' L_l(\Theta) e_{j,n} e_{j,n}' \varepsilon_{t+h-l} \tag{7}$$

Where $e_{j,n}$ is the *j*-th column of I_n, for $1 \leq i, j \leq n$ and for $h \geq 0$.

3.2 The identification problem and sign restrictions

The structural form in (1) is not identified and restrictions must be imposed on the structural parameters to solve this problem. Antolín-Díaz and Rubio-Ramírez (2016, 2018) propose a new method of narrative sign restrictions, expanding the methods of identification by signs proposed by Faust (1998), Canova and Nicolo (2002), Uhlig (2005), among others. This new method restrains the structural parameters by ensuring that, around a series of key historical events, structural shocks and/or historical decomposition agree with the established narrative.

3.2.1 Traditional Sign Restrictions

Rubio-Ramírez, Waggoner and Zha (2010) and Arias, Rubio-Ramírez and Waggoner (2018) highlight that traditional signal restrictions can be characterized by function

$$\Gamma(\Theta) = (e_{1,n}' F(\Theta)' S_1', \ldots, e_{n,n}' F(\Theta)' S_n')' > 0 \tag{8}$$

Appropriate choices of S_j and $F(\Theta)$ will lead to sign restrictions in the IRFs or in the structural parameters. To impose restrictions on IRFs, they must be stacked vertically in $F(\Theta)$ according to the different periods that the restrictions will apply. Define the S_j matrix as an $(s_j \times r_j)$ matrix of 0s, 1s, and -1s that selects the periods and variables with the sign restrictions r_j to identify the structural shock j. Restrictions can be placed directly on the structural parameters, making $F(\Theta) = \Theta$ and S_j as an $(s_j \times r_j)$ matrix of 0s, 1s, and -1s to select the entries of Θ that will be restrained.

3.2.2 Restrictions on the signals of structural shocks

Assume that narrative sign restrictions of the *j*-th shock in the episodes s_j that occur on the dates $t_1, \ldots, t_{s_j}$ are all positive. Then, the restrictions can be expressed as

$$e_{j,n}'\varepsilon_{t_v}(\Theta) > 0 \text{ for } 1 \leq v \leq s_j \quad (9)$$

Negative effects can be imposed using a negative sign on the left side of the equation (9). In addition, one can restrict shocks to be negative in some periods and positive in others.

3.3 Restrictions on historical decomposition

The second class of narrative sign restrictions makes it possible to add information about the relative magnitude of the contribution of the *j*-th shock to the unexpected change in the *i*-th variable between some periods. Antolín-Díaz and Rubio-Ramírez (2018) formalize this idea in two different ways.

In the first, called Type A restrictions, it is specified that a given shock is the most (least) important factor of the unexpected change in a variable during some periods. That is, for a given period the absolute value of its contribution to the unexpected change in a variable is greater (lesser) than the absolute value of the contribution of any other structural shock. In the second, called Type B restrictions, it is specified that a given shock is the main (insignificant) determining factor of the unexpected change in a given variable during some periods.

If the contribution of the *j*-th shock is greater than the sum of all other contributions, it will be greater than any individual contribution, so Type B is more restrictive than Type A. And if the contribution of the *j*-th shock is lesser than any individual contribution, it must also be lesser than the sum of all other contributions in absolute value, so Type B is more restrictive than Type A.

3.3.1 Type A restrictions on historical decomposition

To enforce the restriction that the *j*-th shock is the most important to the unexpected change in the $i_1, \ldots, i_{s_j}$-th variables in the periods $t_1, \ldots, t_{s_j}$ for $t_1 + h_1, \ldots, t_{s_j} + h_{s_j}$, i.e., that its cumulative contribution is greater in absolute value than the contribution of any other shock to the unexpected change in these variables during these periods, the narrative sign restrictions can be imposed as

$$\left|H_{i_v,j,t_v,t_v+h_v}\left(\Theta, \varepsilon_{t_v}(\Theta), \ldots, \varepsilon_{t_v+h_v}(\Theta)\right)\right| - max_{j' \neq j}\left|H_{i_v,j',t_v,t_v+h_v}\left(\Theta, \varepsilon_{t_v}(\Theta), \ldots, \varepsilon_{t_v+h_v}(\Theta)\right)\right| > 0 \quad (10)$$

For $1 \leq v \leq s_j$. If, instead, the shock is the least important,

$$\left|H_{i_v,j,t_v,t_v+h_v}\left(\Theta, \varepsilon_{t_v}(\Theta), \ldots, \varepsilon_{t_v+h_v}(\Theta)\right)\right| - min_{j' \neq j}\left|H_{i_v,j',t_v,t_v+h_v}\left(\Theta, \varepsilon_{t_v}(\Theta), \ldots, \varepsilon_{t_v+h_v}(\Theta)\right)\right| < 0 \quad (11)$$

Equations (10) and (11) can be used together.

3.3.2 Type B restrictions on historical decomposition

If the *j*-th shock is the main contributor, i.e., its contribution is greater in absolute value than the sum of the absolute contributions of all other shocks to the unexpected change in these variables during these periods, the narrative sign restrictions are

$$\left|H_{i_v,j,t_v,t_v+h_v}\left(\Theta, \varepsilon_{t_v}(\Theta), \ldots, \varepsilon_{t_v+h_v}(\Theta)\right)\right| - \sum_{j' \neq j}\left|H_{i_v,j',t_v,t_v+h_v}\left(\Theta, \varepsilon_{t_v}(\Theta), \ldots, \varepsilon_{t_v+h_v}(\Theta)\right)\right| > 0 \quad (12)$$

On the other hand, if its contribution is insignificant in absolute value than the sum of the contributions of all other shocks to the unexpected change in these variables during these periods, the narrative sign restrictions can be imposed as

$$\left|H_{i_v,j,t_v,t_v+h_v}\left(\Theta,\varepsilon_{t_v}(\Theta),\dots,\varepsilon_{t_v+h_v}(\Theta)\right)\right| - \sum_{j'\neq j}\left|H_{i_v,j',t_v,t_v+h_v}\left(\Theta,\varepsilon_{t_v}(\Theta),\dots,\varepsilon_{t_v+h_v}(\Theta)\right)\right| < 0 \quad (13)$$

As in Type A restrictions, equations (12) and (13) can be used together.

4 DATA AND NARRATIVE INFORMATION

In the period analyzed, two shocks in the Brazilian electricity market stand out: the generation (supply) shock of 2001 and the tariff shock of 2013. The macroeconomic effects of these two shocks are the object of study of this work.

Brazilian electricity generation is heavily dependent on hydraulic sources, unlike the world average, which is essentially dependent on fossil fuels (Cavaliero and Da Silva, 2005). Figure 1 in the Appendix shows that in 2001 the hydroelectric participation corresponded to 83% of the installed generation capacity, while the other sources add up to 17%. In this context, the country faced in 2001 a severe drought that reduced the level of reservoirs to the lowest values in years (see Figure 2 in the Appendix).

Figure 3 in the Appendix shows the time series of Brazilian electricity generation in TWh, highlighting the exogenous fall in June/2001 caused by the drought and consequent supply crisis. To avoid a worsening of the crisis, the federal government rationed consumption by 20% for households and 15% to 25% for industry and commerce, depending on the importance of economic activity (Cavaliero and Da Silva, 2005).

According to Hunt et al. (2018), the 2001 supply crisis is greater than the previous ones in size, duration, geographical scope, and complexity. The crisis led to the second reform of the sector in 2004, the first of which took place from 1993 to 1998. An auction system was established for distribution utilities to contract 100% of the expected load to serve regulated customers (Hochberg and Poudineh, 2021).

On September 11, 2012, the federal government published the provisional measure (MP) 579/2012, converted into Law 12,783/2013, establishing new guidelines for the concession of electricity generation, transmission, and distribution services. The MP aimed to stimulate economic activity by reducing electricity tariffs. For this, the government required the anticipation of the maturities of the electricity generation and transmission concessions, so that the tariff reflected only the operating costs of the companies, in addition to reducing the sectoral costs (Resende and Cardoso, 2019).

These changes resulted in a 16.7% reduction in the tariff, below the initial target of 20.2%. Figure 4 in the Appendix shows the temporal evolution of the general average (non-sectoral) tariff of Brazilian electricity. The vertical bar indicates the fall in the tariff in February/2013 as a consequence of Law 12,783/2013.

According to Brandão et al. (2021), an unforeseen consequence of the MP 579/2012 was that several generation companies refused to accept its terms. Generator contracts expired and distributors were exposed to higher wholesale electricity prices during the hydrological crisis that began in 2013. This situation led to financial difficulties for them, as tariffs did not cover the unexpected increase in expenses. These factors contributed to the subsequent increase in the tariff in the following years, aiming to cover the losses resulting from Law 12,783/2013.

The series used are the electricity generation in TWh[1] available at the National Electric System Operator (ONS), the general average electricity tariff from the Brazilian Electricity Regulatory Agency (ANEEL), the rate of change of real GDP[2] accumulated per year, the IPCA inflation rate accumulated per year, the gross debt/GDP ratio of the general government, and the Selic interest rate accumulated per year. The macroeconomic series are available at the Central Bank of Brazil (BCB). The sample period runs from January/1998 to August/2022.

To estimate the economic effects of generation and tariff shocks, we estimate two models. The first one includes electricity generation and the indicators for economic activity, inflation, public debt, and interest rates. The second one includes the electricity tariff and the same four macroeconomic variables above.

The related literature is not unanimous regarding the transmission mechanism of energy shocks. Kilian (2009) argues that understanding the cause of the underlying movement is important in the identification process. However, the most commonly used economic variables to describe the transmission channel of energy shocks are GDP and inflation rate. Fiscal and monetary policies also play an important role in the transmission mechanism of shocks. Both shocks have effects on economic activity and, consequently, on the debt-to-GDP ratio.

Blanchard (2019) argues that high public debt leads to equilibrium situations where investors believe the debt is risky and demand a higher risk premium, raising the interest rate. A higher risk premium further increases debt and default risk, which can lead to a further negative effect on economic activity.

5 RESULTS AND DISCUSSION

First, we examine the implications of the baseline models for Jun/2001 and Feb/2013. Panels A and B of Figure 5 show the posterior distributions of the shocks on the left and the counterfactual paths, assuming no other shock was observed, on the right. Although most of the distributions corroborate with events, there is a posterior probability that the generation shock will be negative and the tariff shock positive, around 0.005% and 8.86%, respectively.

The counterfactual path resulting from the exclusion of all structural shocks, except generation (Panel A) and tariff (Panel B) shocks, implies that the shocks were rather unimportant in explaining the unexpected fall in generation and tariff in June/2001 and Feb/2013, respectively. That is, the falls were due to some other structural shock.

Thus, the sets of structural parameters implied by the identification of models with traditional signal restrictions retain many parameters that go against the argument that in June/2001 a major generation shock greatly reduced supply and in Feb/2013 a major tariff shock greatly increased the tariff. To eliminate such parameters, the narrative sign restrictions below are imposed. The first two restrictions refer to the first model and the last two to the second one.

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[1] Sources: hydrological, conventional thermal, thermonuclear, wind and solar.

[2] The monthly GDP is an estimate produced by the Central Bank of Brazil (BCB) combining several indicators of economic activity and prices. This is done because the Brazilian GDP, officially calculated by the Brazilian Institute of Geography and Statistics (IBGE), is released only quarterly.

NSR 1: The generation shock should assume a negative value in June/2001.

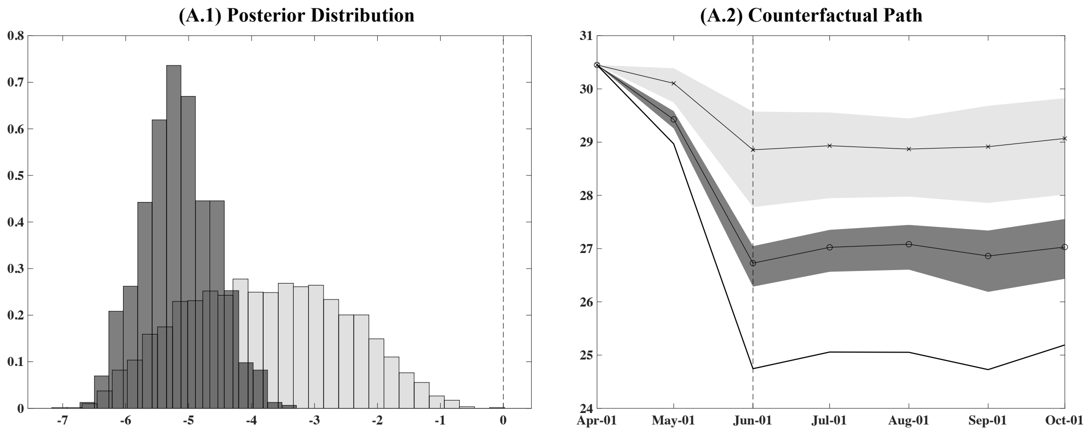
NSR 2: For the period specified by NSR 1, the generation shock is the main driver of the unexpected movements in electricity generation. That is, the absolute value of the contribution of the generation shock is larger than the sum of the absolute contribution of any other structural shock.

NSR 3: The tariff shock should assume a positive value in February/2013.

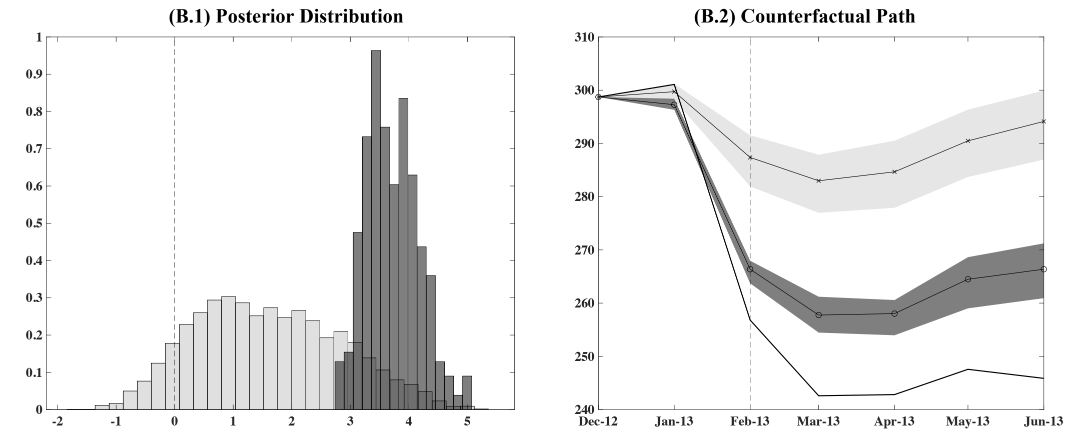
NSR 4: For the period specified by NSR 3, the tariff shock is the main driver of the unexpected movements in the electricity tariff. That is, the absolute value of the contribution of the tariff shock is larger than the sum of the absolute contribution of any other structural shock.

Figure 5 – Posterior distribution and counterfactual paths with and without NSR.

Panel A



Panel B



Note: Panels A and B plot on the left side the posterior distribution of the generation shock for June/2001 in Panel A and the tariff shock for February/2013 in Panel B, using the traditional sign restrictions in light grey and incorporating the NSR in dark grey. On the right side, the unmarked line represents the electricity generation in Panel A and the electricity tariff in Panel B; the median (with a 68% confidence interval) of the counterfactual paths resulting from the exclusion of all structural shocks, except the shock under study, is represented by the line with a cross marker in the model with traditional sign restrictions and with a circle marker in the model which incorporates the NSR.

The dark grey histograms in panels A and B of Figure 5 show that the posterior distributions of the structural generation (tariff) shock have negative (positive) support with 100% probability when the NSRs are used. Moreover, in these cases, the counterfactual paths of the series show that the electricity sector structural shocks are the main contributors to the unexpected fall in generation and tariffs.

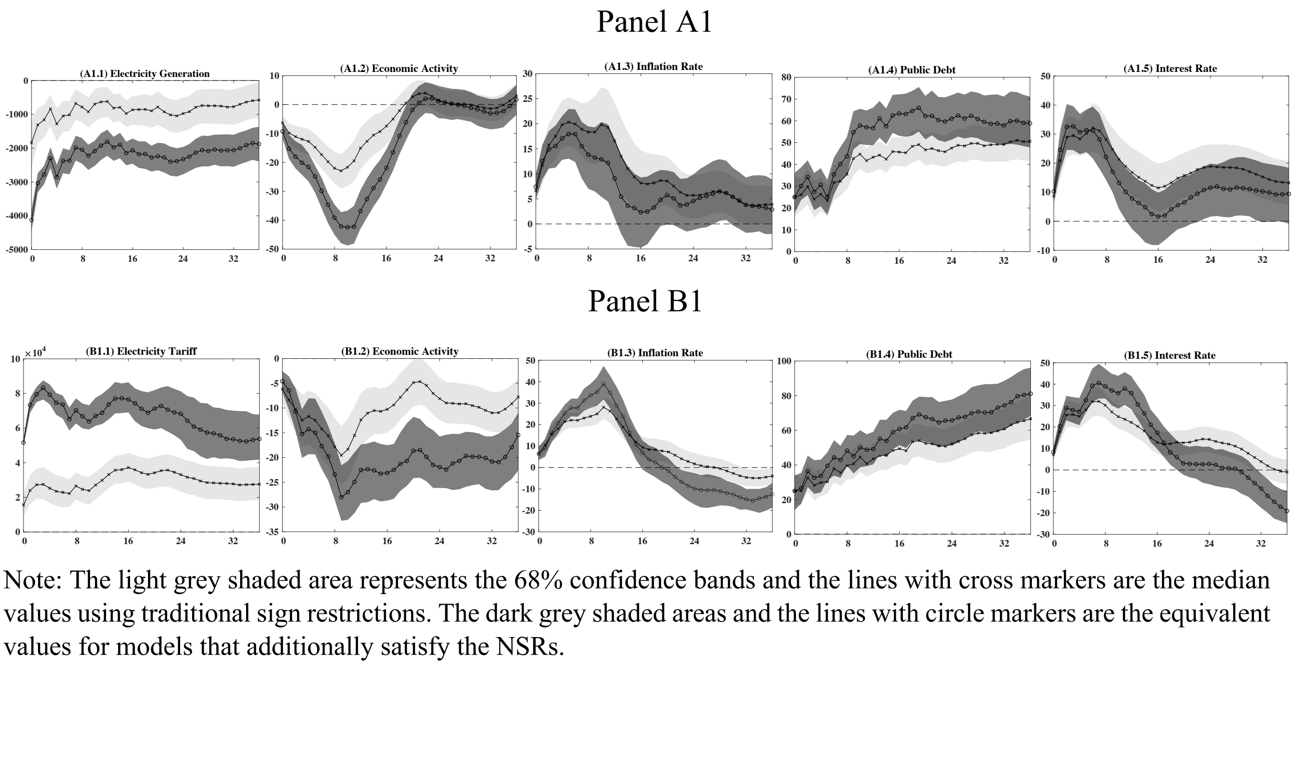
Thus, by agreeing to the set of restrictions imposed, there is a high probability that structural generation and tariff shocks will reduce economic activity and raise inflation, public debt, and interest rates. Figure 6 compares the IRF of the generation shock (Panel A1) and tariff shock (Panel B1) on the macroeconomic variables with and without the NSR.

The addition of narrative information accentuates the negative impact of the generation shock on economic activity, which begins to recover after 12 months. Inflation, public debt, and interest rates respond positively to shock in the initial period. The positive effects on inflation and interest rates are smaller when incorporating NSR1 and NSR2 compared to traditional sign restrictions (Panel A1).

Generation has a direct impact on electricity consumption, for example, the supply crisis of 2001 led to rationing of consumption. The literature that deals with the relationship between the electricity market and economic activity mostly uses consumption as a proxy for this market. However, it is argued that, in the Brazilian case, shocks in consumption are usually the result of supply crises. For this reason, in the structural model presented, the consumption variable is not used, but the generation variable.

This approach is advantageous in identifying the effect since consumption shocks are endogenous to electricity generation. Thus, the results presented above are in line with the main results in the literature, since the negative generation shock compromises consumption with a negative effect on economic activity (Narayan et al., 2008; Arčabić et al., 2021; Hamdi et al.; 2014). The transience of these effects is also observed in Zachariadis and Pashourtidou (2007) and Marques et al. (2014). Although the relationship between generation capacity or consumption and economic activity literature is not unanimous (see for example Azgun, 2011; and Soytas and Sari, 2007), the results found in this study are supported by most of the findings in the literature.

Figure 6 – IRFs with and without restrictions of narrative signals.



Note: The light grey shaded area represents the 68% confidence bands and the lines with cross markers are the median values using traditional sign restrictions. The dark grey shaded areas and the lines with circle markers are the equivalent values for models that additionally satisfy the NSRs.

At first, although Law 12,783/2013 caused the tariff to fall, the expectation of an increase in the tariff harms economic activity even at the beginning of the decrease. Then, there is a sharp increase in tariffs to compensate for the losses incurred by the system operators. Thus, a positive sign restriction on the tariff shock is considered in the structural model presented.

The addition of the NSR does not significantly change the negative impact of the tariff shock on economic activity in the initial period, but accentuates the contractionary effect in the following periods. Inflation, public debt, and interest rates respond positively to the tariff shock in the initial period in the models with and without NSR. From the sixteenth month onwards, a negative effect on inflation and the interest rate cannot be ruled out (Panel B1). These results corroborate those of He et al. (2010), Divino and Brandão (2020), and Agurto et al. (2021). They also report that a strong increase in the electricity tariff has a contractionary effect on economic activity.

5.1 Robustness checks

To verify the robustness of the results, two tests are performed: (a) an alternative economic activity variable, and (b) we use data at a quarterly frequency instead of monthly. Although industrial production is a proxy for economic activity (see for example Ji et al., 2015; Peersman and Van Robays, 2012; Hamilton,1983), this index in Brazil undergoes a methodological change in its calculation in April 2004. Using data from this point considerably reduces our sample. For this reason, we use the capacity utilization rate as an alternative measure of economic activity.

Figure 7 in the Appendix shows the response of macroeconomic variables to supply and tariff shocks in panels A2 and B2, respectively. It is observed that both shocks lead to a fall in economic activity at the initial moment. However, unlike the baseline model, the capacity utilization rate recovers, on average, more quickly after both shocks. The other variables did not present significant changes in their results.

A possible explanation lies in the responses of the industrial sector to these types of shocks, which can lead to a faster recovery of installed capacity. For example, during the 2001 supply crisis, several companies hired private generators or generated their electricity, a practice called distributed generation (DG). Furthermore, the rationing rate imposed by the federal government varied depending on industrial activity (Cavaliero and Da Silva, 2005).

The second robustness check estimates the models with and without NSR using quarterly data. This data frequency allows us to use GDP instead of its monthly estimate. Figure 8 in the Appendix shows the response of macroeconomic variables to generation and tariff shocks in panels A3 and B3, respectively. The results are generally similar to those with the monthly series. Economic activity responds negatively in the initial period, although, in the case of the tariff shock, a positive effect cannot be ruled out from the seventh quarter onwards. Therefore, the robustness checks confirm the results presented initially, since there are no significant differences between them.

6 CONCLUSION

This work analyses the macroeconomic effects of shocks in the Brazilian electricity market, using the procedure proposed by Antolín-Díaz and Rubio-Ramírez (2018) that adds a set of narrative sign restrictions (NSR) to traditional sign restrictions as a strategy for identifying shocks. The

Brazilian electricity market has different characteristics that help to identify these shocks, such as the strong dependence on the hydraulic source that makes the country susceptible to supply shocks, such as the one that occurred in 2001 due to very low rainfall, and the lack of alternatives at that time such as thermoelectric, solar, and wind energy that became available long after that event. In addition, the sector is vulnerable to discretionary government policies, such as Law 12,783/2013 which exogenously reduced tariffs, exposing the sector to serious economic losses.

Narrative sign restrictions (NSR) generate impulse response functions with different intensities than those obtained through traditional sign restrictions. The negative responses of economic activity to an energy supply shock are more profound when using NSRs. Responses to tariff shocks are larger and more persistent in this scenario. A question that naturally arises is whether the estimates of these responses with narrative restrictions are more accurate. One reason to believe so is that the counterfactual paths of electricity generation and electricity tariff are much closer to reality.

The results show that generation and tariff shocks have a negative effect on economic activity and a positive effect on inflation, public debt, and interest rates in the period immediately after the shock. A possible explanation for the faster recovery of the economy after the supply shock, when compared to the tariff shock, can be the agile adaptation of the private sector, especially the industry, which started to use alternative means of generating its energy, in addition to the re-establishment of supply with the new rainfall cycle. Robustness checks with another economic activity variable and different frequencies of data corroborate the results found, which are in line with the main findings in the literature.

The results of this work are relevant for policymakers, companies, and others involved in the management of the electricity sector, as they show that the reduction in energy availability can have negative effects on economic activity, in addition to increasing prices in the economy. Therefore, its effects can spread over employment, income, and household consumption, an issue that can be addressed in future work. Furthermore, the imposition of tariffs (prices) by the government that are far from the reality of the energy market can generate an even worse and more lasting result.

Declarations of interest

None.

Data availability

The data that support the findings of this study are openly available in the database of the Institute of Applied Economic Research (Ipea) at http://www.ipeadata.gov.br/ and in the Time Series Management System of Central Bank of Brazil (BCB) at https://www3.bcb.gov.br/sgspub/.

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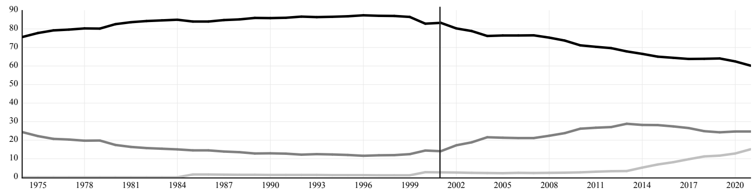
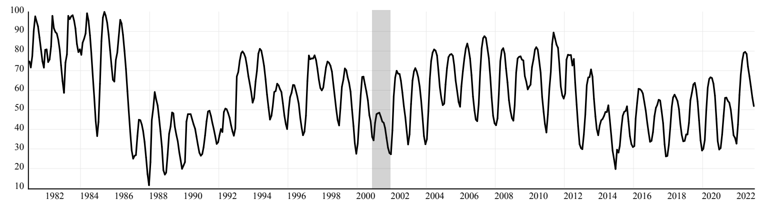
APPENDIX

Figure 1 – Percentage of installed electricity generation capacity by source.



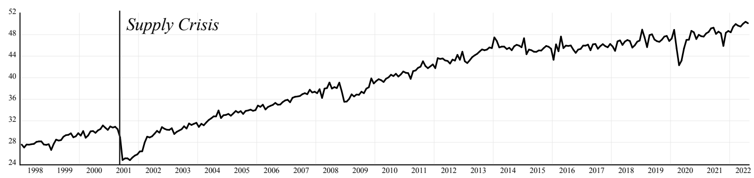
Note: the black, dark grey and light grey lines represent, respectively, the hydraulic, conventional thermal, and the sum of the thermonuclear, wind, and solar sources. The vertical bar highlights the year 2001.

Figure 2 – Percentage of storage of reservoirs.



Note: The vertical bar indicates the year 2001.

Figure 3 – Electricity generation (TWh).



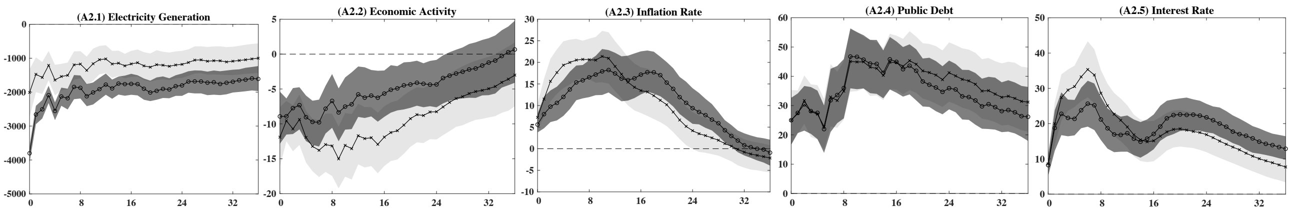
Note: The vertical bar indicates the fall in generation associated with the supply crisis (June/2001).

Figure 4 – Overall average electricity Tariff (R$/MWh).

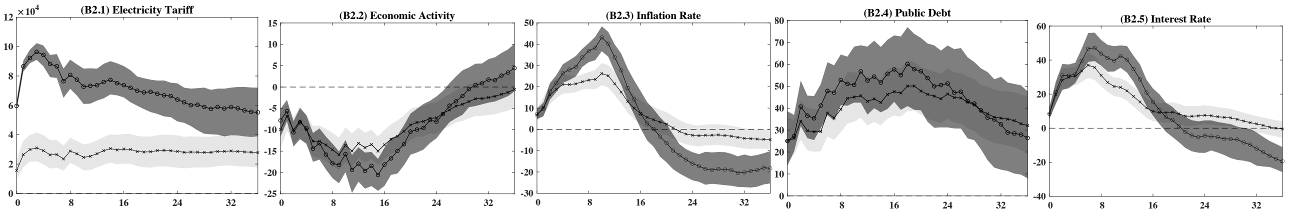
Note: The vertical bar indicates the fall in the tariff associated with Law 12,783/2013 (February/2013).

Figure 7 – IRFs with and without NSR of the Robustness Test 1.

Panel A2



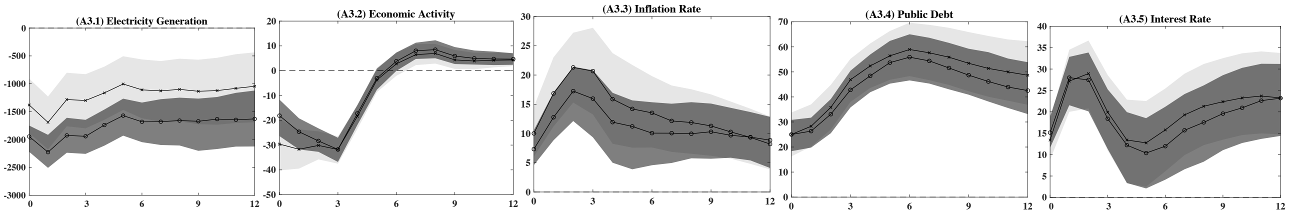
Panel B2



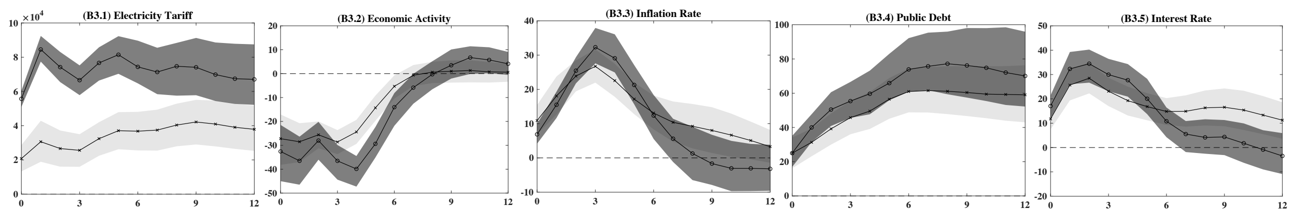
Note: The light grey shaded area represents the 68% confidence bands and the lines with cross markers are the median values using traditional sign restrictions. The dark grey shaded areas and the lines with circle markers are the equivalent values for models that additionally satisfy the NSRs.

Figure 8 – IRFs with and without NSR of the Robustness Test 2.

Panel A3



Panel B3



Note: The light grey shaded area represents the 68% confidence bands and the lines with cross markers are the median values using traditional sign restrictions. The dark grey shaded areas and the lines with circle markers are the equivalent values for models that additionally satisfy the NSRs.