Measuring national policy impacts in a region: SAMBA+REG

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Abstract

This article presents an empirical methodology for analyzing the propagation of aggregate shocks across regions. While focusing on the specific case of Brazil and Ceará, the proposed methodology can be easily adapted to examine other regions as well. We develop a dynamic model, termed SAMBA+REG, which complements the Central Bank of Brazil's dynamic stochastic general equilibrium model (SAMBA) by incorporating regional elements. This theoretical framework allows us to explore how aggregate shocks impact a specific region. We conduct simulations using fiscal and monetary shocks and the results align with the existing literature. SAMBA+REG not only facilitates the evaluation of the effects of central government economic policies on a regional economy, but also offers insights into various strategies for state governments to respond effectively to these policies.

Keywords

SAMBA. DSGE models. Regional economics.

Resumo

Este artigo apresenta uma metodologia empírica para analisar a propagação de choques agregados entre regiões. Embora focando especificamente no caso do Brasil e do Ceará, a

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metodologia proposta pode ser facilmente adaptada para examinar outras regiões também. Desenvolvemos um modelo dinâmico, chamado SAMBA+REG, que complementa o modelo DSGE do Banco Central do Brasil (SAMBA) ao incorporar elementos regionais. Esse arcabouço teórico nos permite explorar como choques agregados impactam uma região específica. Realizamos simulações de choques fiscais e monetários, e os resultados estão alinhados com a literatura existente. O SAMBA+REG não apenas facilita a avaliação dos efeitos das políticas econômicas do governo central em uma economia regional, mas também oferece insights sobre várias estratégias para os governos estaduais responderem de forma eficaz a essas políticas.

Palavras-Chave
SAMBA. Modelos DSGE. Economia regional.

Classificação JEL
R13. C68.

1. Introduction

There is some difficulty for public managers, especially regional managers, in understanding the transmission and measurement of the impacts of some Central Government policies, such as an increase in interest rates or government consumption within the local economy. Filling this gap in the national and international literature specialized in the theme, this work seeks to operationalize an instrument that allows state policy makers to anticipate some rebates of national policies on the variables and local actions.

Brazil is a country of continental size that has a considerable concentration of income and production among its federative units; this is so much that a large part of the states contributes with only a small fraction of national GDP. In 2020, for example, while the state of São Paulo accounted for 31.2% of GDP that year, states such as Amapá, Acre and Roraima accounted for only 0.2% of national production, according to data from IBGE regional accounts.[1] Given this heterogeneity, it is not difficult to admit that central government policies affect the economy of these federations differently. In this way, it would then be appropriate for policy makers to have at their disposal an effective tool to evaluate their economic, social, and governmental policies vis-à-vis the actions of the central govern.

[1] In 2018, these shares were: São Paulo accounted for 31.6% of GDP and Amapá, Acre and Roraima still accounted for only 0.2% of GDP.

There is a research effort that suggests that modern macroeconomic analysis tools should be used to analyze these kinds of regional issue. Rickman (2010), for example, proposed that macroeconometric treatment based on dynamic stochastic general equilibrium (DSGE) and vector autoregressive models (VAR) can contribute with quick answers and empirical evidence to the inherent problems of regional economics.

DSGE models have unified the methodology of macroeconomic analysis, allowing both classical and Keynesian economists to engage in dialogue using this same framework. DSGE models have incorporated various microeconomic enhancements, which also involve microeconomists in the field of research. Subsequently, econometricians turned their attention to DSGE models, bringing significant advances and making the empirical results of these models more precise and robust. After demonstrating their potential for macroeconomists, microeconomists, and econometricians, it is now time to seek the participation of regional economists to present their contributions. With this in mind and focusing on Brazilian specialized literature, the present article aims to start establishing a regional methodology for evaluating economic policies based on DSGE models.

This type of modeling began with the work of Lucas Jr. (1976), Kydland and Prescott (1982), and Long and Plosser (1983), all of them in the area of business cycles. This modeling had its foundations based on macroeconomic issues, and the flexibility in its theoretical construction allows one to explain several stylized facts of the economy. This strand of models seeks to explain the behavior of macroeconomic aggregates using theories strictly based on microeconomic fundamentals. In these models, the economy is a dynamic stochastic system of general equilibrium that reflects the collective decisions of rational individuals made in relation to a set of variables that consider both the present and the future. These individual decisions are coordinated through markets, so they end up in macroeconomics itself.

In DSGE models, the economy is seen as being in constant equilibrium in the sense that, given the information available, people make optimal decisions for them and, therefore, do not incur systematic errors; that is, agents act rationally, and the occurrence of errors is attributed to unanticipated shocks in the economy. Analyzing the attractiveness and convenience of the various models of computable general equilibrium, dynamic and static, for the interpretation of regional phenomena, as well as their ability to achieve success in regional policy forecasts and evaluations, Rickman (2010) advised that there would be potentially promising gains by extending the DSGE approach to these issues, in addition to the traditional econometric techniques of global or restricted vectors autoregressive (VARs).

Macroeconomic models often study the effect of shocks using impulse--response (FIR) functions. The empirical device presented here allows us to disaggregate the relevant variables of the macro-model to observe how aggregate shocks propagate within a specific region, and in the rest of Brazil (this is known in the literature as a specific model for regional approach). Thus, the final model not only can support simulations of effects of economic policies of the Central Government on regional economies, but it also brings greater and better conditions for decision-making and clarifying a more accurate idea of the economic impacts generated by macroeconomic policies at the local level.

Given the existing literature, this article proposes a dynamic regional model that works together with a DSGE model for Brazil. The proposal is to explore the Stochastic Analytical Model with Bayesian Approach (SAMBA) of the Central Bank of Brazil (BCB) described in Castro et al. (2011 and 2015), a model already established in the academic environment, as a starting point and complementing its theoretical structure with specific regional characteristics. In fact, we built this national aggregate model in a way that works in fine harmony with the regional model, which we named SAMBA+REG.

The results generated in the empirical exercises of SAMBA+REG are very realistic and adequately explain how national shocks may affect regional economies. We perform two simulations using data from the economy of Ceará. The first comes from a fiscal shock, an expansionary fiscal policy with a rise in government spending, and the second from a monetary shock, a contractionary monetary policy with increased interest rates.

In addition to this introduction, a brief review of the literature on the subject is presented in the second section. In the third section we present the regional structure and the closing equations coupled to Samba. In the fourth section, we present the estimated values of the model parameters and perform simulation exercises. In the last section, we make our final considerations.

2. Review of the literature

The use of DSGE models has spread among the central banks of the world, due to their flexibility and power to explain stylized facts of macroeconomics and to provide important economic rationale due to its rigorous theoretical construction and economic microfoundation. This already consolidated approach, as explained in Smets and Wouters (2003), manages to combine theoretical consistency with a predictive capacity as much satisfactory as that of traditional time-series models. Rickman (2010) argues that the application of DSGE models could be extended to understand issues at the regional level.

Given this perception on the subject, studies with a greater focus on regional issues followed, which were variants of DSGE models for small open economies. Christiano, Trabandt and Walentin (2011), for example, built a DSGE model for a small open economy that incorporates unemployment and financial constraints for the purpose of analyzing Sweden's economy. Adolfson et al. (2008) and Marcellino and Rychalovska (2014) did the same for the EURO Zone. Cakici (2011) examined the effects of financial integration on business cycles in a small open economy and found that a greater degree of integration amplifies the effects of shocks on monetary policy. In turn, De Paoli (2009) investigated optimal monetary policy in a small and open economy, revealing that the optimal monetary policy rule may differ according to the elasticity of substitution between domestic and foreign products.

Recently, studies have been developed for Japan with a more specific regional focus. Tamegawa (2012), for example, presents a DSGE model for regions and simulates the effects of fiscal policy on the economy with two small regions that interact through trade. One obstacle is that the model does not allow an agent to coordinate the monetary policy. Later, Tamegawa (2013) built a DSGE model for small Japanese regions with low participation in the national economy. The model seeks to evaluate the effects of government policies on regional economies based on several subnational shocks. The results reveal that regional tax expansions are greater than those observed in nationwide DSGE models, particularly due to the increase in regional production with no increase in interest rates, enabling a crowding-in effect of investment.

Okano et al. (2015) developed a DSGE model to examine the Japanese region of Kansai to discover the causes of its long-term economic stagnation. This model incorporates monetary and fiscal policy and includes local and central governments. However, the regions were modeled as if they were closed economies, which is not very realistic because it makes the interdependence between regions inadmissible.

In relation to the works of Tamegawa (2012), Tamegawa (2013), and Okano et al. (2015), the proposed theoretical framework presented here differs in the following aspects: in contrast to the Tamegawa (2012) model, our model incorporates an agent coordinating monetary policy. This feature is important because monetary policy tends to generate rebates in consumption, investments, productive structure, and subnational finance. Unlike Okano et al. (2015) and Tamegawa (2012), which model regional economies as closed, our model treats the regional economy as a small open economy, that is, the region trades with both the rest of Brazil and abroad, but is unable to fix prices based on market power. It should be noted that the hypothesis of the closed economy limits the analysis since, in this scope, only local action would have effects on the dynamics of the economy. Finally, Tamegawa (2013) does not consider the existence of Ricardian and non-Ricardian households, which makes it impossible to infer about the impacts of fiscal or monetary policies in households restricted to the financial and credit markets. As a considerable part of the Brazilian population has credit restrictions or no savings available and being a greater portion of population in states such as Ceará, not considering this hypothesis makes the model quite distant from reality.

Novel studies have made significant advancements in addressing specific regional issues through the utilization of DSGE models. These models aim to address a wide range of questions, such as environmental challenges, the coronavirus pandemic, and the implications of the Great Recession. However, one limitation of these studies is the potential lack of flexibility of the model to analyze other pertinent questions.

Exploring The Great Recession, Beraja et al (2019 a, b) use a New Keynesian DSGE model of a monetary union that combines both regional and aggregate data to explore the implications of regional business cycles for understanding aggregate business cycles. The authors argue that drawing inferences from regional variation alone is not enough and that a formal model is needed to properly analyze the data. The methodology presented in the paper allows for the estimation of the model using both regional and aggregate data, which can provide insights into the relationship between regional and aggregate business cycles.

For the same purpose, Jones, Midrigan, and Philippon (2022) use aggregate and state-level data from the United States to investigate how significant shocks to household credit limits were in generating macroeconomic dynamics across regions and the overall economy. The authors employ a DSGE model to isolate the effects of these shocks and propose a novel methodology that utilizes these data to assess the likelihood function required for Bayesian estimation, incorporating data from numerous regions.

Pan et al (2020) also use a multi-area DSGE model to analyze the effects of environmental expenditures on local and external regions in China. The model is represented by four economic agents: the representative household, intermediate goods producers, final goods producers, and the government. It is observed that environmental expenditures have negative effects on consumption and investment in local areas, but generate some positive influences on the economy of external regions. Furthermore, the shock of environmental expenditures in a local area can well explain the volatility of social investment and real output in China, but shocks of environmental expenditures in external regions had little contribution to the volatility of investment and production in local areas.

Dubrovskaya et al (2022) also presents an extended version of the dynamic stochastic general equilibrium model for the conditions of the regional economy. Interaction modeling was carried out between the two regions. At the same time, the links between interregional commodity flows and flows of labor and capital resources were taken into account. The model considers the institutional characteristics of the regions by including human capital in the form of education and healthcare care in the parameters. The levels of sensitivity of the response functions to the parameters of the economies of specific regions and their dependence on each other in terms of the mobility of labor and capital, as well as the intensity of trade, were evaluated. The model tries to replicate the Russian economy and their parameters was only calibrated, not estimated.

Our work is related to this literature and aims to analyze the effect of aggregate shocks on regional economies. We believe that we have addressed some open gaps and worked with a highly flexible model capable of mimicking the effect of various types of shocks in a particular region. To our knowledge, this is the first model to use a widely accepted aggregate approach at the national level and the first to analyze Brazilian and subnational economies as a case study.

3. SAMBA+REG

The basic idea of SAMBA+REG is to provide an instrument to measure the rebates, at the regional level, of various shocks generated by the outside or by the central government. With this premise, we first need a robust macroeconomic model of the aggregate economy. Therefore, we chose SAMBA and it is convenient to explain the reasons for this choice. First, SAMBA has in its structure several types of rigidity that naturally become aggregate models for short-term fluctuation analyses. The choice of a short-term model is not ad hoc, as a medium or long-term analysis can miss the timing of several more immediate bounces. Furthermore, SAMBA already incorporates several types of shocks in its structure that can be analyzed, which becomes an advantage in terms of simulation and understanding of the transmission mechanisms of these shocks. The entire basement of SAMBA is described in detail by Castro et al. (2015), and here we will focus on the regional part of the model.

3.1. Theoretical Structure of SAMBA+REG

As already explained, SAMBA+REG "regionalizes" SAMBA. However, working with regional economies in the context of a dynamic general equilibrium is not an easy task. It is necessary to characterize how the flows of inputs, outputs, and tax revenues and spending take place. For example, it is appropriate to model how the regional economy absorbs products imported from the rest of the world and the rest of Brazil, as well as exports goods and services to Brazil and the rest of the world. It is also appropriate to observe what tax revenues with products were obtained from other states, as well as the tax revenue provided by local products. Central government transfers also need to be segmented into transfers to the region under review, to the rest of Brazil, etc.

In addition, there are relevant issues, such as labor migration and capital mobility, that need to be adequately modeled in the regional scheme. Similarly, it is necessary to consider the possibility of substitution between inputs in the regional production process. If one supposes that central government policies dramatically change the price of the inputs across the regions, then we need to know for sure how these changes will reflect on the aggregate composition of the capital used in the economy. For example, it is possible that certain policies cause human capital drain, capital recomposition from other regions, increased migration, unemployment, etc.

The SAMBA+REG purposely relaxes some of these theoretical rigors because, as SAMBA is a short-term general equilibrium model, it is expected that several simplified equilibrium hypotheses employed here will sustain in short time horizons. Next, we describe the hypotheses that underpin the model and seek to reinforce why they are used in our analysis.

Regional GDP: The GDP of Brazil Y_t is the sum of the GDP of a given Region Y_{RR} and the GDP of the rest of Brazil, Y_{RB}:

$$Y_t = Y_{RR,t} + Y_{RB,t} \tag{1}$$

To couple this identity with SAMBA, it is necessary to work with a log-linearized equation around the steady state, because, by construction, SAMBA has this structure. Let $y_{RR,t} = ln(Y_{RR,t}) - ln(Y_{RR}^*)$, where Y_{RR}^* is a position of steady state of $Y_{RR,t}$. Like this, all the variables in the model are percentage deviations from the steady state. In this case, in log-linearized fashion, the steady state is zero for all variables. The transformation of (1) gives:

$$y_t = \left(\frac{Y_{RR}^*}{Y^*}\right) y_{RR,t} + \left(1 - \frac{Y_{RR}^*}{Y^*}\right) y_{RB,t} \tag{2}$$

The expression in (2) suggests that the logarithm of the gap (with respect to steady state) of Brazil's GDP is equal to the relative GDP long-term participations of the region and the rest of Brazil times their respective logarithmic deviations around their steady-state positions. This expression is a presumption that the regional contribution to the GDP of Brazil is constant in the short term, and this is, in fact, the truth for several states. Ceará, for example, has maintained its share of GDP around 2% for decades. Therefore, in the absence of shocks, because they are based on structural parameters, this participation is expected to also remain constant in the short term.

Prices: From the log-linearized national GDP deflator, q_t^Y, it can be assumed that the same is given by thecontribution of the other two log-deviations of prices, the regional and the remaining of Brazil, which are:

$$q_t^Y + y_t = \left(\frac{P_{RR,t}^* Y_{RR,t}^*}{P^* Y^*}\right)(p_{RR} + y_{RR}) + \left(1 - \frac{P_{RR}^* Y_{RR}^*}{P^* Y^*}\right)(p_{RB,t} + y_{RB,t}) \quad (3)$$

Here, we assume that, based on these prices, we can arrive at an approximation of the regional inflation given by $\pi_{RR,t} = p_{RR,t} - p_{RR,t-1}$. We also admit that the level of price of the rest of Brazil follows a first-order autoregressive process:

$$p_{RB,t} = \rho_{p_{RB}} p_{RB,t-1} + \varepsilon_t^P \quad (4)$$

where the ε_t^P term is a white noise.

Number of People Employed: Regarding the labor market, the number of people employed in Brazil can be described as follows:

$$N_t = N_{RR,t} + N_{RB,t} \quad (5)$$

As for GDP, log-linearization around steady-state also generates:

$$n_t = \left(\frac{N_{RR}^*}{N^*}\right) n_{RR,t} + \left(1 - \frac{N_{RR}^*}{N^*}\right) n_{RB,t} \quad (6)$$

Technology, Capital, and Investment: The Okun law suggests a negative relationship between unemployment and product, and this theoretical relation can be established regionally through a simple neoclassical production function with constant returns to scale:

$$Y_{RR,t} = A_{RR,t} K_{RR,t}^{\alpha} N_{RR,t}^{1-\alpha} \quad (7)$$

where $A_{RR,t}$ is the regional TFP, $K_{RR,t}$ is the stock of regional physical capital, $N_{RR,t}$ is the number of people employed in the region and, α is a regional parameter establishing the share of capital in the product.

Log-linearization of (7) around the steady state generates:

$$y_{RR,t} = a_{RR,t} + \alpha k_{RR,t} + (1-\alpha)n_{RR,t} \tag{8}$$

It should be noted that (8) ensures the countercyclical behavior recommended by Okun's law. As $y_{RR,t}$ was defined in (2) and $n_{RR,t}$ was defined in (6), equation (8) requires modeling two new endogenous variables of the regional model: capital and technology. Both variables can be modeled in a standard way. We assume that regional technology is governed by an AR (1) process with:

$$A_{RR,t} = (1-\rho_A)A^*_{RR} + \rho_A\left(A_{RR,t-1}\right) + \varepsilon^A_t; \varepsilon^A_t \sim N(0, \sigma^2_A) \tag{9}$$

As usual, we assume $A^*_{RR} = 1$ so, the log-linearization around the steady state generates:

$$a_{RR,t} = \rho_A a_{RR,t-1} + \varepsilon^A_t; \varepsilon^A_t \sim \text{Log}\,\text{N}(0, \sigma^2_A) \tag{10}$$

Capital also can be modeled in a standard way, e.g. through an investment function,

$$K_{RR,t+1} = (1-\delta)K_{RR,t} + I_{RR,t} \tag{11}$$

where δ is the depreciation rate of physical capital (noting that there is no reason to expect this rate to be different from the national one). Using the fact that $I^*/K^* = \delta$, the log-linearization of (11) generates:

$$k_{RR,t+1} = (1-\delta)k_{RR,t} + \delta i_{RR,t} \tag{12}$$

The above expression introduces a new endogenous variable to the regional model, i_{RR}, which requires specific modeling. Investment is a key variable for the regional economy because investment decisions are based on the rate of return of the regional capital. These capital return rates can be specific to each region, and their differentiation based on regional theories often adds complexity to the models, delivering a set of difficult-to-solve equations.

Seeking to circumvent this limitation, the proposal is to model the investment simply based on the (*ex-ante*) aggregate real rate of interest, $\hat{R}_t$, and on a risk premium that is function of the expectative of the productivity gains of the region, A_{RR}, over the national productivity gains, Z_D, i.e.

$$I_{RR,t} = \chi_{ia}\left[\hat{R}_t + E_t\left(Z_{D,t+1}\right) - E_t\left(A_{RR,t+1}\right)\right] \tag{13}$$

where $\chi_{ia} < 0$ represents a specific regional parameter that describes how regional investment responds to nominal interest rates, expectations of domestic inflation, and expected productivity gains. Note that, as χ_{ia} is negative, the investment responds negatively to the real interest rate, but positively to the expectation of relative regional productivity gains.

In addition, we discuss the effect of federal government spending on local investments. As Junior, Oliveira, and Jacinto (2006) point out, public spending can be considered productive or unproductive. They are unproductive from the moment the public sector applies resources in areas that compete with the private sector and additional benefits are not generated for the society. On the other hand, public spending becomes productive when it starts to have a relevant effect on the local production function or generating benefits and utility to the residents of the region.

It is not clear how local investment responds to federal public spending. It is expected that an increase in federal transfers to the region will have a positive effect on the level of investments because these transfers ease the budget constraint, enabling an increase in consumption, which in turn, would require more investments. Additionally, there is the possibility that the increase in government spending could temporarily boost income in other parts of Brazil. If a portion of this economic expansion is directed towards the region, for instance through the tourism sector, it is also expected that this will promote an increase in local investments. If federal spending is directly channeled to regional infrastructure, such as through the construction of railways (Transnordestina) or structural works (Transposition of San Francisco), obviously the effect of the expansion of spending will be positive on the investments.

On the other hand, it could be contended that any attempt to assess the impact of government spending on local investment may be subjective and depend on the nature and effectiveness of spending in the region. Furthermore, if there is a confirmed crowding-out effect of spending on national-level investments and if this effect extends to the region, it is likely that the consequences on local investments could be adverse.

Although it can be argued against and in favor of all discussion and economic rationality, and given the absence of studies at the regional level that explore this connection, we suggest that the local investment function described in (13) is also explained by a component associated with federal government spending; for example, we propose that (13) give way to:

$$I_{RR,t} = \chi_{ia}\left[\hat{R}_t + E_t\left(Z_{D,t+1}\right) - E_t\left(A_{RR,t+1}\right)\right] + \chi(G_t) \tag{14}$$

The log-linearization of (14) generates:

$$i_{RR,t} = \phi_{ia}E_t\left(a_{RR,t+1} - z_{D,t+1}\right) + \phi_{ir}\hat{r}_t + \phi_{ig}g_t \tag{15}$$

By hypothesis, z_D, which is aggregate TFP, is correlated with a_{RR}, since if there is an increase in national TFP, this will flow to regional productivity.

It is interesting to observe (15) with a little more attention. ϕ_{ia} is positive ϕ_{ir} is negative, and ϕ_{ig} may be both. They are parameters that depend, respectively, on the steady-state relationships of the investment together with the actual interest rate, TFP and the expenses of the federal government. Also, note that if productivity gains are not expected, then the investment responds negatively to the real interest rate of the economy, but this response is not necessarily equal to the aggregated one, because ϕ_{ir} is a specific regional parameter.

Regional Aggregate Demand: In a regional context, the region's production can be channeled to consumption, investment, government spending, and trade with other states and abroad. Thus, we have the following regional aggregate demand function:

$$Y_{RR} = C_{RR} + I_{RR} + G_{RR} + NX_{RB} + NX_{RW} \tag{16}$$

Here, NX_{RB} and NX_{RW} are the net exports to the rest of Brazil and to the rest of the world, respectively. The log-linearization around the steady state of the above identity returns:

$$y_{RR,t} = \left(\frac{C^*_{RR}}{Y^*_{RR}}\right)c_{RR,t} + \left(\frac{I^*_{RR}}{Y^*_{RR}}\right)i_{RR,t} + \left(\frac{G^*_{RR}}{Y^*_{RR}}\right)g_{RR,t} + \left(\frac{NX^*_{RB}}{Y^*_{RR}}\right)nx_{RB,t} + \left(\frac{NX^*_{RW}}{Y^*_{RR}}\right)nx_{RW,t} \tag{17}$$

Trade Interregional and International: Government consumption and spending will be modeled later. Here, we follow Junior (2013) and assume that net exports to the rest of Brazil depend on regional income and the remainder of the Brazil income, that is,

where φ_{RB} and φ_{RR} are positive parameters that represent respectively the sensitivities of net exports to the rest of Brazil in relation to the income of the rest of Brazil and the regional income, respectively. Log-linearizing (18), we have:

$$nx_{RB,t} = \varphi_{RB}\left(\frac{Y_{RB}^*}{NX_{RB}^*}\right)y_{RB,t} - \varphi_{RR}\left(\frac{Y_{RR}^*}{NX_{RB}^*}\right)y_{RR} \tag{19}$$

Similarly, assume the following:

$$NX_{RW} = \lambda_{RW}Y_{RW} - \lambda_{RR}Y_{RR} \tag{20}$$

where λ_{RW} and λ_{RR} are positive parameters that conceive the sensitivities of net exports to the rest of the world in relation to the rest of the world income and regional income, respectively. The log-linearization of (20) generates:

$$nx_{RW,t} = \lambda_{RW}\left(\frac{Y_{RW}^*}{NX_{RW}^*}\right)y_{RW,t} - \lambda_{RR}\left(\frac{Y_{RR}^*}{NX_{RW}^*}\right)y_{RR,t} \tag{21}$$

Regional Consumption: See that from the aggregate demand equation in (17) there is a need to model regional consumption, which can be extremely important and different depending on the region under analysis.

In the SAMBA framework, the set of equations that define the behavior of consumption is given by three equations. These three equations are structural equations, and we reinforce that they are described in terms of log-deviations in relation to steady state. The first of these defines the log-deviations in relation to the steady state of the optimizing households (O), that is, of the Ricardian households, or even of the households that have access to the financial markets and credit. This equation is given by:

$$\begin{aligned} c_t^O = {} & \frac{\tilde{\kappa}}{1+\tilde{\kappa}}c_{t-1}^O + \frac{1}{1+\tilde{\kappa}}E_t c_{t+1}^O - \frac{1-\tilde{\kappa}}{\sigma(1+\tilde{\kappa})}(r_t + s_t^B - E_t\pi_{t+1}^c) \\ & + \frac{\rho_Z - \tilde{\kappa}}{1+\tilde{\kappa}}z_t^Z - \frac{(1-\rho_C)(1-\tilde{\kappa})}{\sigma(1+\tilde{\kappa})}z_t^C \end{aligned} \tag{22}$$

In terms of log-deviations of the variables, the expression above suggests that the present consumption, c_t^o, depends positively on past consumption, c_{t-1}^o, the expectation of consumption in the next period, $E_t c_{t+1}^o$, of the expectation of inflation in the next period $E_t \pi_{t+1}^c$, and of the technological permanent shock (or the tendency of growth rate of economy), z_t^Z; the present consumption also depends negatively of the nominal interest rate, r_t, of the domestic risk premium, s_t^B, and of a shock in household preferences, z_t^C.

The parameters that weight such variables are $\tilde{\kappa}$, ρ_Z, ρ_C and σ. In SAMBA, $\tilde{\kappa} \equiv \kappa(Z^Z)^{-1}$, where κ is a parameter that governs the persistence of consumption, imposing a certain inertia on the dynamics of aggregate consumption; the term Z^Z is the steady state growth rate of technological progress; σ is the inverse of the intertemporal elasticity of substitution,[2] and; ρ_Z and ρ_C are, respectively, auto regressive parameters associated with shocks in the growth rate of technological progress and in the preferences of households.

On the other hand, the log-deviation of consumption in relation to the steady state of non-Ricardian, or rule-of-thumb (RT), is given by:

$$c_t^{RT} = w_t + n_t - \frac{T}{1-T}\tau_t \tag{23}$$

In other words, the consumption of non-Ricardian households depends positively on the real wage rate and the number of people employed in the economy, and negatively on the tax burden, τ_t. The relevant parameter in this expression is the average tax rate, T. Finally, the aggregate consumption is given by:

$$c_t = \widetilde{\varpi_C} c_t^{RT} + (1 - \widetilde{\varpi_C}) c_t^O \tag{24}$$

where, $\widetilde{\widetilde{\omega_C}} \equiv \varpi_{RT}\left(\widetilde{C^{RT}}/\tilde{c}\right)$ describes the weight of consumption of non-Ricardian households in the total consumption and $\left(\widetilde{C^{RT}}/\tilde{c}\right)$ is the relative consumption of steady state of non-Ricardian households in the total consumption. Thus, aggregate consumption is given by the weighted average of the steady-state consumption of each group of households.

[2] See that the intertemporal discount factor $\tilde{\beta} \equiv \beta(Z^Z)^{1-\sigma}$ is the same for the region.

For modeling the regional consumption of non-Ricardian households, we assume that the real wage and the tax burden are equal between regions, but the number of people engaged in production is specific to each region. Similarly to investment, a wage premium can be added based on the expectation of productivity gains. More precisely, it can be defined that $w_{RR,t} = w_t + \varphi_{wa} E_t(a_{RR,t+1})$. Thus, the regional consumption equation of non-Ricardian households is:

$$c_{RR,t}^{RT} = w_t + \phi_{wa} E_t\left(a_{RR,t+1}\right) + n_{RR,t} - \frac{T}{1-T}\tau_t \tag{25}$$

This expression suggests that the detachment from the steady state of consumption of non-Ricardian households depends on the detachment of the population of the region engaged in production, the detachments of the wage rate and the expectation of productivity gains, and the detachment of the tax burden. Regarding the Ricardian households installed in the region, we assume that the persistence of the consumption habit and the steady-state growth rate of technological progress does not differ from the rest of Brazil, e.g., aggregate remains the same even for the region.

We also admit that the intertemporal elasticity of substitution and changes in preferences are similar over regions and, in addition, the nominal interest rate, inflation expectation and domestic risk premium continue to influence the consumption decisions of optimizing households in the region in an analogous way to the aggregate. Meanwhile, we do not expect that the decision-making of Ricardian agents differs between regions. This is equivalent to saying that the decision-making of the Ricardian households in the region is strictly the same as those of the Ricardian households of SAMBA, e.g.:

$$c_{RR,t}^{O} = c_t^{O} \tag{26}$$

In the end, like the national aggregate consumption, the regional aggregate consumption is given by a weighted average,

$$c_{RR,t} = \varpi_{RR} c_{RR,t}^{RT} + (1 - \varpi_{RR}) c_{RR,t}^{O} \tag{27}$$

where $\varpi_{RR} = \omega_{RR}^{RT} \left(C_{RR}^{RT^*} / C_{RR}^{*}\right)$, and ω_{RR}^{RT} is the weight of consumption of non-Ricardian households in region in the total regional consumption. It is important to note that the social structure of a state/region may differ from the rest of the country, and that there may be significant differences between these parameters when observing the same in terms of country aggregates and regions. In the case of Brazil, poor states, for example, tend to have a much higher than the ϖ_C national, which can generate significant changes in national and state consumption standards.

Regional Government: It remains to determine the behavior of subnational government spending. First, note that government spending is the sum of tax collection, , and direct transfers from the Central Government to the state, F_{RR}, e.g.:

$$G_{RR,t} = T_{RR,t} + F_{RR,t} \tag{28}$$

Here, we assume that the regional government collects a fraction of the income of the region, as well as taxes the products sold outside the state and brought to the region. This simplification is close to what happens with the Tax of Circulation of Goods and Services (ICMS), which is responsible for the greater participation in the tax revenues of states, and its taxation is by differential rates, depending on when a product is purchased in a state different from where it is consumed. Additionally, the amount collected from goods imported from the rest of the world and consumed in the region is considered. Taking the definitions of equations (19) and (21), the state collection can be better outlined in the following way:

$$T_{RR,t} = \tau_{RR}Y_{RR,t} + \tau_{RB}Y_{RB,t} + (1 - \tau_{RR} - \tau_{RB})\lambda_{RR}Y_{RR,t} \tag{29}$$

Its log-linearization gives:

$$t_{RR,t} = \tau_{RR}\left(\frac{Y_{RR}^*}{T_{RR}^*}\right)y_{RR,t} + \tau_{RB}\left(\frac{Y_{RB}^*}{T_{RR}^*}\right)y_{RB,t} + (1 - \tau_{RR} - \tau_{RB})\lambda_{RR}\left(\frac{Y_{RR}^*}{NX_{RW}^*}\right)y_{RR,t} + \psi_{RR,t}$$

By rearranging the above expression and gathering parameters, one has the following:

$$t_{RR,t} = \Gamma_{RR}y_{RR,t} + \Gamma_{RB}y_{RB,t} + \Gamma_{RW}y_{RR,t} + \psi_{RR,t} \tag{30}$$

It is also considered that the collection $\psi_{RR,t}$ follows an AR process (1), e.g.

$$\psi_{RR,t} = \rho_{\psi_{RR}}\psi_{RR,t-1} + \varepsilon_t^{\psi_{RR}}; \varepsilon_t^{\psi_{RR,t}} \sim \mathrm{Log\,N}\left(0, \sigma^2_{\psi_{RR,t}}\right) \tag{31}$$

From log-linearization of (28), we have:

$$g_{RR,t} = \left(\frac{T^*_{RR}}{G^*_{RR}}\right) t_{RR,t} + \left(\frac{F^*_{RR}}{G^*_{RR}}\right) f_{RR,t} \tag{32}$$

In the above equation, it is assumed that in the steady state, taxation is equal to the expenditure; that is, the regional government has a balanced budget and, by simplification, does not issue debt.

Finally, it is necessary to define the transfers of the central government, which, by hypothesis, are exogenous and evolve as an AR (1) process:

$$f_{RR,t} = \rho_{f_{RR}} f_{RR,t-1} + \varepsilon_t^{f_{RR}}; \varepsilon_t^{f_{RR}} \sim \mathrm{Log\,N}\left(0, \sigma^2_{f_{RR}}\right) \tag{33}$$

4. Methodology

4.1. Data Set

The data set used in the investigation contains observable national, foreign, and regional variables for the state of Ceará. They were obtained from several sources and different treatments were performed, as detailed in Table 1. The data have a quarterly frequency and comprise the period from the first quarter of 2003 to the first quarter of 2020, totaling a database with 24 observable series and 69 points in time. The choice of the series used in the estimation depended on the availability of the data, their relevance to the estimation of parameters, and the need to explain the trajectory of the variables of interest. As expected, a large set of data for estimation reduces the identification problem, but can also cause stochastic singularity problems, which does not allow the estimation of parameters.

The objective in choosing the series for estimation is to link the observed variables with the endogenous variables of the model. In a log-linearized model, this is a simple task, as there is a similarity between the idea of steady-state deviations in the model and the observed cyclical fluctuations data around its long-term trend. In the preparation of the series for estimation, we tried to extract the tendency of nonstationary series and standardize the stationary ones. The treatment of the series followed Pfeifer (2014).[3]

Thus, the trending series were logaritmized, and the trend component was extracted through the one-sided Hodrick-Prescott (HP) filter[4], which makes use of current and passed values in the data filtering process and is compatible with the solution model used. The cyclic component of the series was extracted from their mean, so the variable is centered at zero. Thus, for a generic variable x, we have the following:

$$x_{obs} = \hat{x} - \bar{\hat{x}}, \tag{a}$$

where $\hat{x}$ represents the cyclic component of the series (log-linearized).

For variables with negative values, the following transformation was performed before taking the logarithm and applying the HP filter:

$$x = 1 + |min(x_{data})| + x_{data} \tag{b}$$

Finally, for variables in rates, the filter is not used, and the following treatment is performed:

$$x = log(1 + x_{obs}/100)\,;\, x_{obs} = x - \bar{x} \tag{c}$$

3 As the treatment given to the series and the *span* of data are different from those of Castro et al. (2015), the differences in terms of moments and deviations between these studies are somewhat compromised.

4 It was used as smoothing parameter $\lambda = 1600$, which is suggested for quarterly data.

Table 1 - Detailing of the data series used in the estimation.

Description	Source	Treatment
Domestic Variables		
Gross Domestic Product (s.a.)	IBGE	a
Household Consumption (s.a.)	IBGE	a
Gross Formation of Fixed Capital (s.a.)	IBGE	a
Government Consumption (s.a.)	IBGE	a
Imports of Goods and Services (s.a.)	IBGE	a
Relative Import Prices	Funcex	a
Relative Export Prices	Funcex	a
IPCA inflation (%)	IBGE	c
Inflation target (%)	IBGE	a
Managed Prices Inflation (%)	IBGE	a
Nominal Interest Rate - Selic (%)	BCB	a
Real Salary*	IBGE	a
Number of persons employed (s.a.)	IBGE	a
Primary Surplus/GDP - Public Sector 12 months	BCB	b
Real Effective Exchange Rate (%)	BCB	a
Country Risk Award - EMBI	JP Morgan	c
Foreign Variables		
World Product (s.a.)	IMF	a
U.S. Interest Rate	Fed St. Louis	a
World Inflation	OECD	c
Investor Risk Aversion Index -VIX	CBOE	c
Regional Variables - State of Ceará (CE)		
Retail Sales Volume Index - Total - Ceará - (s.a.)	BCB	a
Regional Economic Activity Index - Ceará - (s.a.)	BCB	a
Salaried Employed Personnel (Jan/2001=100) - Ceará**	BCB, PNADC e CAGED	a
Tax Collection (R$) - Total - Ceará	CONFAZ	a

Source: Various sources. Own elaboration. Note: (s.a) with seasonal adjustment. *Real salaries have different methodologies. The rates of the shorter period series were used to extrapolate the data throughout the period under analysis. **The series of salaried employed personnel in the Ceará State of BCB begins in the first quarter of 2003 and ends in the third quarter of 2014, while PNADC begins in the first quarter of 2012 and ends in the first quarter of 2020. The PNADC series was considered as the basis, and we use the variation rates of the BCB series for updating at the beginning of the period. The last four quarters were updated with those of the CAGED variation rates.

4,2. Parameters Estimation

Just like Castro et al. (2015), the model was estimated using Bayesian techniques. An and Schorfheide (2007) showed that the Bayesian estimation of the parameters of a DSGE model is a "bridge" between calibration and frequentist estimation. This procedure allows the use of available information, in the form of a *priori* distributions and observed data, to properly update pre-established *priors*. This allows the *posteriori* distribution of parameters to be computed in a less costly way and, theoretically, more accurately. In practical terms, this results from the improvement in the adjustment of maximum likelihood functions, which are essential for estimating large DSGE models and which strongly influence the form of the subsequent distribution of parameters. In addition, the techniques allow one to estimate parameters that were previously difficult to identify.

This version of SAMBA+REG has 102 equations to be solved (or 102 endogenous variables, 83 of the aggregate model, and 19 of the regional model)[5] and 27 stochastic shocks (four are regional shocks, and the other 23 are shocks from the SAMBA itself). SAMBA's shocks are **Fiscal**: shock in the tax burden, the primary surplus/GDP target, and government spending; **Monetary**: inflation target, interest rate, and managed prices; **International** shocks: demand for imports, demand for exports, real exchange rate, inflation of the rest of the world, relative price of imports, international interest rate, and GDP of the rest of the world; **Structural** shocks: domestic risk premium, country risk premium, price mark-up, export price mark-up, wage mark-up, international investor risk aversion, and shock in household preferences for consumption; **Technological** shocks: permanent change of TFP, transitory change in TFP, and shock in the technology of the investment. **Regional** shocks are exogenous changes: in the region's prices, regional productivity, state revenues, and federal transfers.

Note that the model is solved simultaneously, that is, the SAMBA+REG model is a model where regional equations are added to the SAMBA before the model is solved. Thus, what is being done is reinforcing the structure of SAMBA, because, mathematically, a greater number of structural equations are being included in the model, whose equilibrium must necessarily be met.

[5] Specifically, the log-linearized equations of the regional side are: 2, 3, 4, 6, 8, 10, 12, 15, 17, 19, 21, 22, 25, 26, 27, 30, 31, 33 and 32.

The Bayesian estimation of SAMBA+REG is done in two stages, and, only when the parameters are properly valued, the simulations are elaborated. The steps to conduct the simulation are described below:

(i) With the data processed and the priors established, based on Castro et al. (2015), the SAMBA parameters are estimated;

(ii) With the parameters estimated in step 1, we fixed them, and the estimation of the regional parameters of SAMBA+REG is initiated;

(iii) With the estimated and fixed parameters of SAMBA+REG, the simulations are performed (here they are used in the form of FIRs).

The idea behind this two-step estimation is that SAMBA would be a reliable model of the national economy and that the rest of the regional structure would necessarily have to adapt to the structure already imposed by the base model. Thus, SAMBA+REG carries all the resources and particularities of SAMBA, such as rigidity of prices and salaries, regulated prices, persistence in consumption habits, etc., in addition to regional structural equations.

Table 2 presents the estimated values for the 27 regional parameters based on the average of the respective posterior distributions drawn for them.[6]

First, it is interesting to note that the estimates presented in Table 2 are in line with several structural and stylized facts of the Ceará economy. The historical relationship between the GDP of Ceará and the GDP of Brazil, for example, is about 2%, but has been growing timidly. Estimates indicate a value of 1.91%, which is a value quite compatible with reality. The proportion of the Ceará population in relation to that of Brazil is around 4.5%. In the estimates, the value found was 4.44%, which fits the data quite well. Another estimated parameter that attracts attention is the share of capital income in the product, . This figure, which can be seen as an approximation of gross operating surplus/GDP – and its share (remuneration) – is in line with that found for this parameter at national level.

[6] The distributions were calculated using the Metropolis-Hastings algorithm, in line with Castro et al. (2011, 2015).

Table 2 - Posterior Average Values for Ceará Parameters Through Bayesian Estimation

Parameter	Description	Prior			Posterior		
		Dist.	Mean	SD	Mean	Credible	Interval
Y^*_{RR}/Y^*	Ceará GDP / Brazil GDP Ratio (in SS)	beta	0,020	0,001	0,0191	0,0184	0,0196
N^*_{RR}/N^*	Ceará's work force / Brazil's work force Ratio (in SS)	beta	0,045	0,001	0,0444	0,0438	0,0450
$P^*_{RR}Y^*_{RR}/P^*Y^*$	Ceará's deflator / Brazil's deflator Ratio (in SS)	beta	0,020	0,001	0,0217	0,0211	0,0222
ρ_{PRB}	Autoregressive parameter for the rest of Brazil prices	beta	0,900	0,050	0,9771	0,9652	0,9940
ρ_A	Autoregressive parameter of Ceará's TFP	beta	0,900	0,050	0,9877	0,9794	0,9969
α	Capital share in the product of Ceará	beta	0,4448	0,050	0,4902	0,4660	0,5185
φ_{ia}	Investment sensitivity to relative TFP	beta	0,400	0,050	0,7126	0,7106	0,7142
φ_{ir}	Investment sensitivity to interest rate	beta	0,400	0,050	0,2182	0,2016	0,2386
φ_{ig}	Investment sensitivity to Ceará government consumption	beta	0,000	0,050	0,1036	0,0797	0,1277
C^*_{RR}/Y^*_{RR}	Consumption / GDP Ratio (in SS)	beta	0,525	0,050	0,4151	0,4002	0,4283
G^*_{RR}/Y^*_{RR}	Government spending / GDP Ratio (in SS)	beta	0,297	0,050	0,5777	0,5677	0,5868
NX^*_{RB}/Y^*_{RR}	NX for the rest of Brazil / GDP Ratio (in SS)	beta	0,003	0,001	0,0034	0,0026	0,0040
NX^*_{RW}/Y^*_{RR}	NX for the rest of the World / GDP Ratio (in SS)	beta	0,011	0,001	0,0105	0,0100	0,0112
ϕ_{RB}	Income elasticity of NX from other states to Ceará	norm	0,500	0,050	0,6254	0,6112	0,6417
ϕ_{RR}	Income elasticity of NX from Ceará to other states	norm	0,500	0,050	0,6685	0,6539	0,6901
λ_{RW}	Income elasticity of NX from the rest of the world to Ceará	norm	0,500	0,050	0,4072	0,3937	0,4159
λ_{RR}	Income elasticity of NX from Ceará to the rest of the world	norm	0,500	0,050	0,5344	0,5148	0,5551
φ_{wa}	RT family consumption sensibility to expec. of productivity gains	beta	0,500	0,050	0,4305	0,4184	0,4393
ω^{RT}	Weight of RT families in SS consumption	norm	0,600	0,050	0,7623	0,7501	0,7732
Υ_{RB}	Revenue from the rest of Brazil / GDP Ratio	beta	0,800	0,050	0,9197	0,9058	0,9330
Υ_{RW}	Revenue from the rest of the world / GDP Ratio	beta	0,020	0,010	0,0043	0,0020	0,0068
F^*_{RW}/G^*_{RR}	Federal Transfers / Government Spending Ratio	beta	0,300	0,050	0,2487	0,2350	0,2630
ρ_{fRR}	Autoregressive parameter of federal transfers	beta	0,900	0,050	0,8987	0,8733	0,9190
$\rho_{\psi RR}$	Autoregressive parameter of state taxation	beta	0,900	0,050	0,9518	0,9241	0,9789

Source: Own elaboration. Note: SS: steady state.

Another point to be highlighted is the steady-state relations from the perspective of demand. Consumer participations, government spending, and trade balance as a fraction of the output of the economy were considered close to what occurs at the national level. It is important to note that households restricted to the credit market are the majority in lower income states, as is the case in Ceará. This fact can also be found observing the ω^{RT} estimated: This value is 76,23% and represents the weight given to non-Ricardian households in the regional steady state of consumption.

The parameter ϕ_{ig} was estimated with a *prior* zero-value and with support [-0,4; 0,4], and our result for the parameter was 0.1036 for the Ceará economy. This reinforces the importance of public spending and investments in the region for the attraction of private investments, which contribute to a business environment that promotes the generation of employment and income.

The auto-regressive parameters, ρ_{pRB}, ρ_{A}, ρ_{fRR} and $\rho_{\psi RR}$, are also compatible with theoretical modeling since these terms are expected to maintain a considerable degree of persistence over time.

5. Simulations

The following are two exercises with FIRs generated by shocks in interest rates and central government spending. The effect of these shocks is analyzed in the macroeconomic variables of Brazil and Ceará. The simulations carried out consider shocks of 1% in the standard deviation in interest rates and government spending. They were performed using Matlab and Dynare. It is important to note that this is a *coeteris paribus* exercise, e.g., it reveals the net effect of shock disturbance, ignoring all other shocks (positive and negative) that have possibly been affecting and that prevail in the economy.

5.1. Fiscal Shock

The following graphs show the FIRs generated by a shock of one standard deviation in the proportion of government spending on GDP. The effect of this shock can be seen at the national level (black lines) or at the regional level (red lines). The steady state of the model, which by construction is equal to zero, is described by the dashed horizontal line fixed at zero (which is a direct result of log-linearization of the model).

In relation to the shock of one standard deviation related to national government spending, as seen in Figures 1 and 2, we initially observe a growth movement in the trajectories of all variables analyzed, except in the consumption of optimizer households and national investments. Given the positive effect of government spending on income, demand heats up and prices rise; the Central Bank seeks to control the excess of demand by raising interest rates, which causes the drop in investments. This is the well-known crowding-out effect of public spending, which suggests a recomposition of aggregate demand. However, it should be noted that this effect of increased spending at the regional level is crowding in, that is, an expansionary fiscal policy at the national level positively impacts regional investment, corroborating the result found in Tamegawa (2013).

Transfers can relieve the budget constraint, which allows for increased consumption, which, in turn, would require more investments. There is also the possibility that the increase in government spending will increase, even momentarily, the income of the rest of Brazil, and, if part of this income is channeled to the region, through the tourism sector, for example, this is also expected to promote an increase in local investment. These are transmission channels that would explain this particularity of Ceará's economy in the face of the national economy regarding the impact on investments.

However, when observing the graph of investment dynamics, it is observed that the crowding-in and crowding-out effects are only temporary. In approximately six quarters, investment levels are growing again above their steady-state value in Brazil and, in the case of Ceará, below. It is interesting that the model suggests a subsequent decline of the regional variables, all of which fall back to values below their potential. It is also observed that this decline is more intense in the Ceará variables than in the national ones; that is, in the long term, the negative effects of the increase in spending on national investment begin to have repercussions on the economy of Ceará, indicating that in the medium/long term, the national crowding-out effect dominates the regional crowding-in effect. This effect was expected given the relative participation of Ceará in the national economy. Another point that draws attention with respect to the crowding-in effect is that all components of aggregate demand are heated. Thus, with no reallocation of the positive effects of federal government spending (as there is no contemporary decrease of investment), regional and national inflation necessarily rises.

Another critical issue reported by the model is how the interest rate influences consumption. By hypothesis, the behavior of optimizing consumers does not differ between regions, see Equation (23), and the effects of expansionary fiscal policy on these agents are quite simple (note that the abscesses of graph for this variable is on a scale 10^{-3}), however, the weight of the participation of agents in economy is extremely relevant for an analysis. As a considerable proportion of Ceará households have limited access to the credit market, the role of the consequent increase in the interest rate on consumption appears to be low. Because of this, the convergence process for steady-state consumption of these agents is slower than that of Brazil as a whole, and this is reflected in aggregate consumption.

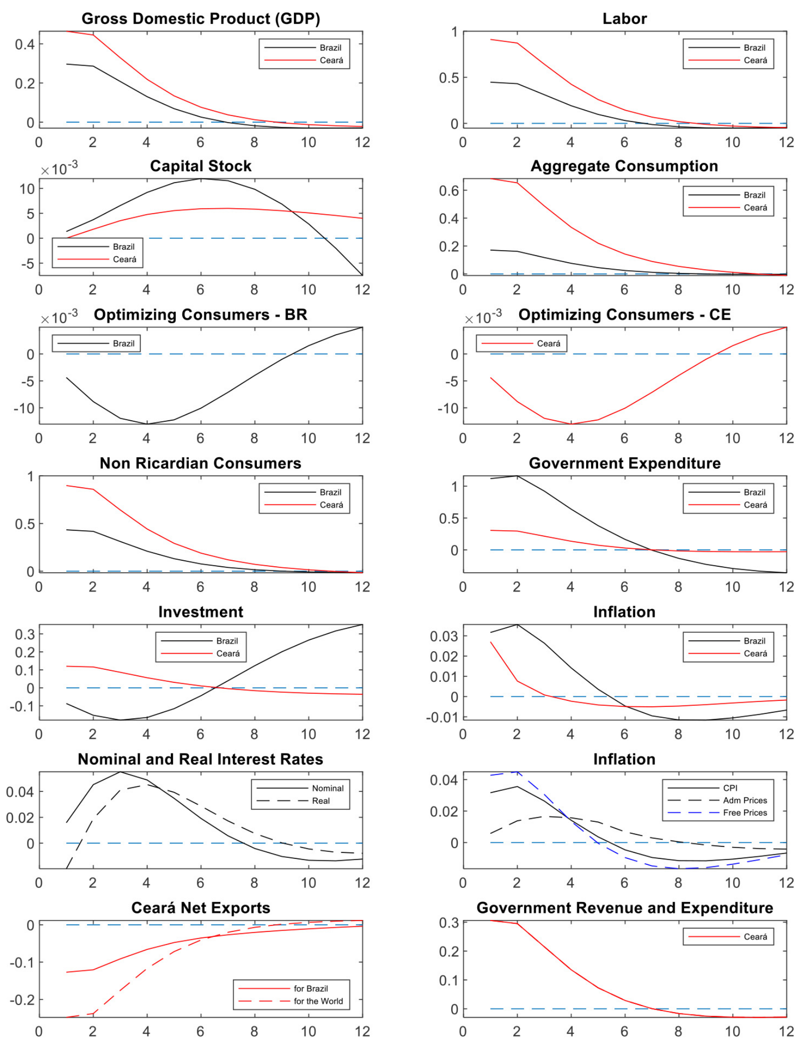

Figure 1 - Impulse-response functions of a shock in government spending

Source: Own Elaboration.

The initial increase in GDP, both within and outside the region, has an impact on regional tax collection. As, by hypothesis, the local government equalizes spending on revenue, government expenditures also have a momentary elevation. Again, in the medium/long term, the national crowding-out effect dominates the regional crowding-in one, and the state tax collection accomplishes this dominance.

Finally, the rise in the region's internal prices, along with the substantial increase in income (from Brazil and Ceará), caused net exports to contract, both for the rest of Brazil and the rest of the world. This reflects the increased demand for imported goods. The impact on imports of products from abroad is even stronger because of the influence of the exchange rate on the relative price of imports, which is also affected by the subsequent rise in the interest rate.

5.2. Monetary Shock

Among several other analyses, the SAMBA+REG model allows one to investigate the effect of monetary policies on the national economy and its rebates on the regional economy (Ceará). In general, exogenous shocks are investigated through the BCB's role in establishing the nominal interest rate, which usually guides the other interest rates of the economy. Here, as is the case, an exercise is conducted considering the increase of 1 standard deviation in the interest rate (Selic) in relation to its steady-state value. Figures 3 and 4 show the effects of this elevation. The analysis of the effect of this contractionary monetary policy is evident in the dynamics of output: a fall in national GDP and GDP of Ceará with a persistent recessionary effect. The GDP of the Ceará economy has a similar dynamic but suffers a greater decline than the national one.

A comparative analysis of the production dynamics between Brazil and Ceará brings some caveats: the first is that the initial response to the recessive period, both for Brazil and Ceará, seems to come from a labor factor. The analysis of demand components also reveals an interesting process: The short-term effect on interest has a negative impact on all components, whether in Brazil or in Ceará. After a certain period, the investment starts to contribute positively to mitigate the recessionary shock in Brazil; however, this phenomenon does not occur in Ceará.

As a direct effect of the increase in interest rates, investments fall and follow what is expected in the macroeconomic literature that points to a decline in this variable when there is an increase in the interest rate, with a greater impact for national investment. There is also a drop in inflation, which is already expected, as the regime of inflation target makes use of the interest rate as the principal instrument to combat the increase in the level of prices.

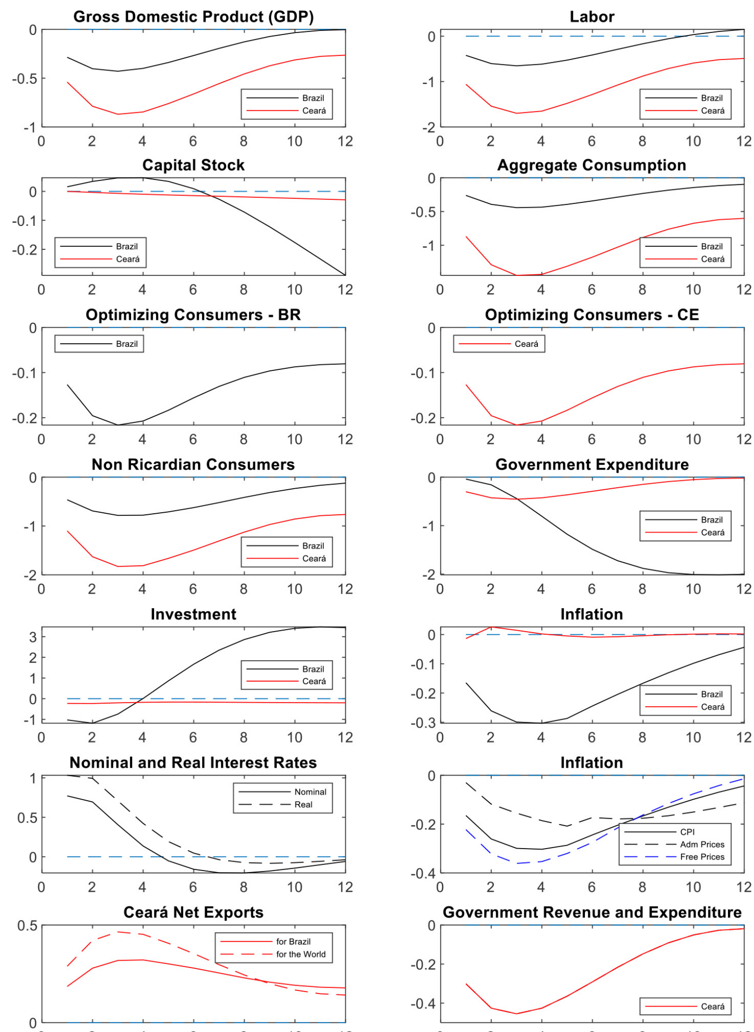

Figure 2 - Impulse-Response Functions of an Interest Rate Shock

Source: Own Elaboration.

Regarding investment, inflation, and government spending, the effect of monetary policy is much smaller in Ceará than in Brazil, because the state deviates much less from its steady-state position than the nation. Therefore, net exports have a relevant role in minimizing the negative effects of interest on the Ceará economy. Note that the drop in production is much larger in Ceará than in Brazil. This suggests that our imports should decrease more intensely than exports, consequently leading to an increase in net exports. This applies to both national and international net exports.

The state's revenue also declines as the dynamics of production decreases with a contractionary monetary policy. However, the size of the government is much lower in Ceará than in Brazil. This means that the regional government of Ceará plays a crucial role in guiding the economy toward its long-term trajectory. By actively managing policies, investments, and mitigating the negative effects of external factors such as interest rates, the regional government can have a significant impact on the economic development and stability of Ceará, ensuring that it moves towards its desired long-term goals and growth goals.

It is important to highlight that the simulations presented here are in line with the specialized literature that studies the effects of monetary policy on regions, suggesting that there are differences in monetary policy shocks between the aggregate economy and regional economies, as found in Araújo et al. (2004), Bertanha and Haddad (2008) and Serrano (2015). In an application to the American economy, Pizzuto (2020) finds that a tightening of monetary policy leads to a persistent decrease in the real income of individuals in the region and in employment, with thus etheric effects between regions.

6. Final Comments

There is a certain lack in the literature of empirical methodologies that can measure the impacts of national policies on regional economies. Because of this, local governments are partial unable to foresee shocks of actions generated by the central government in their economy, and the effects of such shocks are always assessed *ex-post*. This work seeks to fill this gap. Here, an empirical instrument unpublished in the Brazilian literature capable of measuring and simulating these rebates in an *ex-ante* way is proposed.

To this end, a dynamic regional model has been developed that operates in combination with a DSGE for the Brazilian economy to investigate the effects of fiscal and monetary shocks on the local economy. Since the regional model works in conjunction with the SAMBA model of the Central Bank, the model is called SAMBA+REG.

The parameters of the model were estimated using Bayesian techniques, using data from Brazil, Ceará, and international data. Through FIRs, the impacts on regional macroeconomic variables caused by two types of shock were simulated, on interest rates, and on government spending. It is important to point out that it would be entirely possible to make analyses with all regional and national shocks, which in total are 27 distinct types of shock, and that this model can be applied considering any state of Brazil.

According to the results of the simulations, we observe that interest rate shocks cause responses with different magnitudes on the national and regional economies and have a more pronounced impact on household consumption to contain an expansion in demand. As expected, the economy's output, the number of jobs, government spending, tax collection, and investments decline.

When it comes to a shock in federal government spending, there is at first an improvement in all macroeconomic variables, but there is an increase in interest rate with a concomitant fall in investment, which characterizes a crowding-out effect at the national level. The opposite happens for regional investments, meaning that the increase in public spending is crowding-in. Thus, it is possible to infer those expenses transmitted as public investments are an important driver of product improvement. However, it should be emphasized that these impacts captured here occur noticeably in the short term.

Finally, it was possible to identify heterogeneous effects of shocks on the consumption of Ricardian and non-Ricardian households. It should be noted that the preliminary results produced here show consistency regarding the impacts of shocks on macroeconomic variables according to what is expected in the literature, and this is an important instrumental for simulations of various policies that may serve as a horizon, both for the decision-making of regional governments and for the choice of the best countercyclical policy to be adopted; that is, it will be possible to create a strategy to soften the regional economic cycle.

Although our results are already consistent with previous analyses conducted using different methodologies, it is essential to recognize the limitations of our work. First, it is known that macroeconomic policies have heterogeneous sectoral effects, directly influencing the dynamics of regional economies. As our model does not explore the issue of regional productive structure, this aspect is not adequately addressed and could be improved. Secondly, the theoretical microfoundation on the regional side is still quite rudimentary and could be significantly enhanced.

However, the advances in this research are also evident. The DSGE modeling brings to regional analysis the role of uncertainty and forward-looking intertemporal optimization, making agents' savings and investment decisions much more elegant from the perspective of the model's theoretical microfoundation, compared, for example, to CGE models. The DSGE modeling also deals with real and nominal frictions, which is much more realistic and suitable for short-term analyses. Moreover, the DSGE modeling is well suited for monetary policy analysis, and a considerable number of central banks around the world utilize this framework for this purpose.

Considering these advancements and limitations, we believe that future studies incorporating elements of CGE and/or Input-Output modeling alongside the DSGE model, and leading to what is known as DSGE Multisectoral models, [7] could substantially contribute to the analysis of regional economies. Other extensions may include, for example, incorporating state public investments or even adding the stock of human capital in the regional production function. Finally, in addition to these potential model derivations, improvements in parameter estimates can enhance the robustness of the findings as well as contribute to a better understanding of how regional economies operate.

[7] DSGE Multisectorial Models have been timidly explored in foreign literature; see, for example, Bukowski and Kowal (2010), Antosiewicz and Kowal (2016), Antosiewicz et al (2016), Miranda-Pinto and Young (2019), and Varga et al (2022).

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