Climate Change and The Brazilian Economic Cycle

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Abstract

This paper investigates the impact of climate change on the Brazilian economic cycle. Using a small-scale Dynamic Stochastic General Equilibrium (DSGE) model, the study incorporates climate variables to analyze the effects of climate variations on macroeconomic and fiscal variables. This study evaluates climate change and its possible increase in the weight of the climate-related parameter. It is not a study on climate shocks because the climate data are within the Phillips curve, in which there is an inflation shock, and it cannot be said that this shock is derived solely from climate. The results highlight the sensitivity of economic variables to climate fluctuations and suggest that monetary and fiscal policies should consider these impacts to mitigate risks and promote economic stability. The model simulations reveal how climate change can affect price stability, highlighting the need for proactive and adaptive policy management in the face of changes.

Keywords: Climate Change, Economic Cycle, Monetary Policy, Fiscal Policy.

JEL Classification: C13, E32, F41, Q54

1. Introduction

Climate change refers to long-term variations in global temperature and weather patterns that occur due to natural or anthropogenic causes. Scientific evidence reveals that, since the industrial revolution, human activity has been the main source of these changes, as a consequence of the significant increase in the concentration of gases in the atmosphere, such as carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and others. In turn, climate change, through the increase in the intensity and frequency of extreme weather events, has been causing widespread adverse impacts, as well as material and human losses. Extreme weather events are occurring simultaneously, causing sequential impacts that are increasingly difficult to manage. The economic and social impacts of climate change are unevenly distributed, affecting the poorest and the economic sectors that depend most heavily on climate stability (IPCC, 2022).

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In Brazil, studies on the impacts of extreme weather events on the economic cycle are still scarce, with regard to the necessary responses of fiscal and monetary policies to these events. Natural disasters in the country, typically regional due to its vast territorial extension and diversity of biomes, highlight the need for a more in-depth analysis of how climate change, such as rising temperatures, can affect the economy. This relevance is amplified by the crucial role of commodities, especially agricultural ones, in Brazilian economic growth, subject to fluctuations triggered by commodity cycles. The strong influence of these commodities on the Gross Domestic Product (GDP) highlights the urgency of incorporating climate impacts into economic policy strategies. Climate shocks, such as heat waves and droughts, have become more frequent and intense in recent years, suggesting a trend of greater relevance of these shocks as drivers of economic fluctuations, particularly in countries with economies based on agriculture, where such changes can generate significant fluctuations in the agricultural sector and affect the economy as a whole.

Agriculture in Brazil has undergone significant transformations in recent decades, with notable advances in technical aspects such as soil correction, artificial irrigation and genetic improvement of seeds. Such innovations have allowed agricultural exploitation of areas previously considered unsuitable, with some regions achieving up to three harvests per year, thanks to efficient irrigation control. This phenomenon highlights the capacity of the agricultural sector to adapt and expand its production frontier, even in challenging conditions. However, these advances have come at high costs. Despite the success of these highly controlled areas, they do not represent the entire Brazilian agricultural scenario. Much of the country's agriculture still depends on climate conditions, especially rainfall patterns. This dependence highlights the vulnerability of a substantial portion of the Brazilian agricultural sector to climate cycles, just as the impact of rising temperatures can be persistent to the point of increasing production costs in areas with controlled irrigation, affecting food inflation. This situation highlights the importance of adequate responses by government authorities to extreme climate events, which tend to be more frequent, generating adverse effects (e.g. food insecurity, recessions, currency devaluation, etc.), requiring the inclusion of climate change proxies in traditional economic models.

The recent increase in climate anomalies has redefined these models, revealing intrinsic connections between climate change, as well as macroeconomic and fiscal variables. According to Cevik and Gwon (2024), the ramifications of these climate disruptions extend far beyond the ecological sphere, instigating a cascade effect through global supply chains and, ultimately, affecting inflation dynamics , for example. However, natural disasters related to extreme weather events, which have increased in frequency and intensity, require coordinated responses from monetary and fiscal policies due to the significant impacts of these disasters. The hypothesis of this study is that the supply shock caused by climate change requires an effective response from monetary and fiscal policies, since fiscal action can mitigate some of the adverse short-term effects, but if not carefully calibrated, it can lead to additional inflationary pressures in the medium and long term.

Thus, the overall objective of this paper is to analyze the impact of extreme weather events on the economy, as well as the economic policy interventions needed in response to these climate changes. In terms of specific objectives, we propose the implementation of a Dynamic Stochastic General Equilibrium (DSGE) Model to explore not only how supply shocks altered by climate change impact agricultural inflation, but also the response of monetary and fiscal authorities to these shocks. The approach includes an adaptation of the New Keynesian Phillips Curve, which now considers both changes in international commodity prices and climate oscillations caused by the El Niño and La Niña phenomena .

In terms of justification of the topic, this study stands out in the existing literature on the subject in Brazil by integrating relevant climate variables, allowing the assessment of the effects on aggregate supply through the analysis of upward trends in consumer prices. The result is a set of simulations of certain economic variables for a medium-term horizon, providing a basis for investigating the economic effects resulting from climate change and formulating effective policy responses.

In a context of intensification of the inflationary process due to the supply shock caused by extreme weather events, this study contributes to the literature on the subject in three ways. First, it reveals that fiscal stimuli exacerbate volatility in the level of economic activity, according to the behavior of the output gap. Second, this study highlights that the monetary response must be adequately calibrated to mitigate the adverse effects of climate shocks, with particular attention to the most vulnerable sectors, such as agriculture. Inflation in the first year after the climate shock increases by 2.22%, so that the interest rate in the scenario of a supply shock caused by extreme weather events would need to be 1.83% higher in the period. However, due to the increase in government spending aimed at mitigating the effects of disasters caused by climate change, the interest rate would need to be even higher, at 6.2%, to pay the public debt created to finance these additional expenses. The DSGE model used demonstrated the complexity of the interaction between fiscal and monetary policies, climate and macroeconomic dynamics, providing a detailed overview of the potential economic impacts and guidance for effective public policies. Finally, it broadens the understanding of the mechanisms by which climate shocks affect emerging economies, with significant economic policy implications, by combining macroeconomic modeling with climate variables, a relatively new approach that is increasingly relevant given the global climate emergency.

The remainder of this paper is organized as follows. The next section provides evidence on the impact of climate change on macroeconomic variables, based on the existing literature on the subject. Section 3 details the structure of the DSGE model and the data used, respectively. Section 4 presents the results obtained and analyzes the short-term effects of climate change. Finally, the last section presents the concluding remarks and the policy implications of the results obtained in this study.

2. Theoretical Framework

2.1 Impacts of Climate Change in Brazil

Between 2001 and 2017, most of the world experienced an increase in the frequency and intensity of natural disasters related to extreme weather events, in parallel with significant global warming, with 17 of the 18 years recording high average temperatures. This period also saw a jump in the annual frequency of natural disasters from 222 in 1980 to over 700 in 2016 (Delgado *et al.* , 2021).

Latin America and the Caribbean are one of the most vulnerable regions in the world to the impacts of climate change, which poses major challenges for governments. The World Meteorological Organization (WMO) reports that the impacts of climate-related events, including heat waves or floods, have claimed more than 312,000 lives in the region and affected more than 277 million people between 1998 and 2020. The Intergovernmental Panel on Climate Change (ICC*)* Panel on Climate Change (IPCC) estimates that the planet has warmed by 1.1°C since the pre-industrial era due to human activity. At the same time, rising global temperatures are increasing fiscal risks from natural disasters. The IPCC states that the window to limit global temperature rise to 1.5°C in order to comply with the Paris Agreement will close soon, but there is time to transition to green and climate-resilient economies **.** It is therefore essential that ministries of finance and planning, or equivalent bodies, play an active role in creating greater economic resilience for the communities most affected by these natural disasters. Identifying and managing fiscal risks generated by extreme weather events is essential, given that countries in Latin America and the Caribbean have faced an increasing number of such events (IDB, 2021).

The average annual occurrence of these events in the Latin America and Caribbean region has increased by more than 50% in recent decades, rising from 0.20 events between 1980 and 2000 to 0.30 between 2001 and 2019. For countries that faced at least one extreme event in each of these periods, the average occurrence increased from one event every eight years (1980-2000) to one event every five years (2001-2019). Brazil and Mexico, for example, have faced extreme weather events almost every year (on average), while Panama and Suriname have faced none (IDB, 2021). Brazil stood out for recording, on average, one extreme weather event almost every year. In addition, the warming of the atmosphere resulting from the greater concentration of greenhouse gases leads to an acceleration of the water cycle, which can make extreme events such as droughts and floods more frequent (Stern, 2007).

Obviously, in Brazil, extreme weather events did not occur throughout the country, given its continental size. This climate disparity is noticeable when analyzing the Drought Monitor for February 2024 (ANA, 2024). It can be seen that the South Region shows almost no signs of drought, a fact very different from the other regions. When a single climate indicator is used for the entire country, this difference between regions can result in an average index that does not capture the two extremes of the measurement.

Persistent changes in climate conditions can affect the country's main sources of wealth generation. Brazil is one of the world's largest producers and exporters of commodities, especially agricultural and mineral commodities. This class of goods represents 70% of all Brazilian shipments abroad. In the agricultural sector, soybeans lead exports, alongside iron ore and oil in the extractive sector (Lima, 2020). Brazilian agriculture is recognized as competitive and a generator of jobs, wealth, food, fiber, and bioenergy for Brazil and other countries, accounting for 21% of the sum of all wealth produced in the country, which corresponds to 1/5 of all jobs and 43.2% of Brazilian exports. Internally, the sector has contributed to maintaining a decline in the real price of the basic food basket (Antonini, 2009). It is in this context that the importance of incorporating climate change into an analysis of the behavior of the Brazilian economy becomes evident.

In addition to resulting in the loss of lives, the economic damage caused by natural disasters can be significant and put the population's lives in a negative spiral, since, by affecting the reduction in revenue due to this shock, a government response is required both in terms of aid and infrastructure reconstruction. At the end of the period, the economy lost revenue and increased unplanned public spending that was not aligned with the government's medium-term fiscal planning. Alejos (2018) estimates that the occurrence of at least one extreme weather event per year is associated with an increase in the fiscal deficit of 0.8% of GDP in lower-middle-income countries and 0.9% of GDP in the low-income group.

In economic models focused on environmental issues, temperature data are used for climate analysis. In the agricultural sector, these analyses are enriched with precipitation data to assess agricultural productivity patterns. Soil moisture is determined by the interaction between rainfall and temperatures, where precipitation promotes increased agricultural productivity by stimulating crop growth, while rising temperatures can lead to greater evapotranspiration, decreasing water availability and, consequently, soil productivity (Gallic , 2020).

This article uses data from the abnormal warming of surface waters in the equatorial Pacific, known as El Niño , which is a phase of the El Niño -Southern Oscillation (ENSO) phenomenon. Its historical impacts have been known since the colonization of Peru in 1525, but have been recurring for thousands of years. Ancient civilizations such as the Incas already adapted their practices, building cities on hills and storing food to face its consequences. However, global interest in this specific warming grew significantly after the devastations of 1982-1983, driving studies that allowed accurate climate predictions during the 1997-1998 event. Under normal conditions, trade winds promote the accumulation of warm water in the western Pacific, but during El Niño , changes in atmospheric and oceanic circulation lead to a significant increase in sea temperatures, changes in air currents and global climatic and ecological impacts, such as heavy rains in Peru and droughts in Indonesia and Australia. The intensity and occurrence of El Niño are monitored by the Southern Oscillation Index and the Sea Surface Temperature Anomaly, reflecting significant changes in atmospheric pressure and ocean temperature, influencing global climatic and ecological patterns (Kiyuna , 2002).

The temperature anomaly is the difference in temperature in relation to the historical average. The measurement occurs in regions called Niño (or Nino) in the Equatorial Pacific, namely, Niño 1+2 (0-10S, 90-80W), Niño 3 (5N-5S, 150-90W), Niño 4 (5N-5S, 160E-150W) and Niño 3.4 (5N-5S, 170-120W), the latter encompassing parts of Niño 3 and 4. The El Niño effect climate patterns observed globally during the winter and summer seasons in the Southern Hemisphere. Between June and August, heavy rainfall is observed in southern Brazil and high temperatures from the Southeast to the Northeast; from December to February, rains are concentrated in the South region, while the Southeast experiences heat and the Northeast faces dry conditions. During these periods, both Indonesia and northern Australia generally experience drier weather, and there is a significant increase in rainfall over large areas of the equatorial Pacific Ocean. Consequently, during El Niño events , irregular rainfall is common in many areas, with temperatures rising in most parts of the world, or temperatures decreasing in the southern United States.

Based on the known effects, and the fact that El Niño causes changes across the globe, the use of these data in the economic modeling of this study was justified. In addition to impacts on agriculture, there may also be migratory effects. With temperatures ranging from -20°C in the Arctic to 30°C at the Equator, and with global temperatures expected to rise by between 1.4°C and 4.5°C by 2100, it is clear that the impacts of climate change will vary significantly across the world. Considering the vast expanse of land in the northern latitudes, if there were the possibility of free movement of populations and economic activities across the planet, the economic impact of global warming could be considerably mitigated. It is estimated that a 10% drop in crop yields increases migration by 2% (Feng *et al* ., 2011). However, there are real obstacles to mobility: migrants face barriers: trade and transportation are expensive; physical infrastructure is vulnerable; and the dissemination of knowledge linked to economic sectors occurs in a limited way. Therefore, the economic burden resulting from climate change is also related to these spatial obstacles (Desmet , 2024).

2.2 Macroeconomic Models and Climate Change

Climate change impacts not only agriculture, but also the industrial and service sectors. A study conducted in the Philippines found that the industrial sector suffered a 1.8% reduction, and the service sector a 0.7% reduction, due to the loss of labor productivity or the increased costs of maintaining adequate working environments, such as the need for air conditioning due to rising temperatures. In addition, the research found that temperature shocks threaten economic activity and inflate prices, affecting sectors ranging from agriculture to manufacturing and services, highlighting the importance of a joint approach by government authorities to mitigate these challenges. The analysis emphasizes the need for coordinated fiscal and monetary policies to address the inflationary impact of these climate shocks. Immediate non-monetary interventions are crucial to manage the short-term effects, given the latency in monetary policy responses. In the face of inflationary persistence and subsequent consequences, it becomes essential that the central bank adjusts interest rates proactively to stabilize the economy (Armas *et al* , 2024).

Studies suggest that poorer and warmer regions suffer more severe economic impacts due to high temperatures. However, Berg *et al.* (2023) reveal that economic growth in several less developed countries has responded positively to historical variations in global temperature. Although these results acknowledge that these relationships between economic growth and temperature may change in the future with increasing global warming, due to potential tipping points or adaptations , it is likely that these short-term gains are being absorbed by inflation passed on to consumers. There are challenges in using the relationship between short-term climate change and agricultural profits to infer the impacts of global warming. Immediate fluctuations in climate can cause temporary adjustments in prices, obscuring the true long-term effect of these changes (Deschênes , 2007).

The literature on climate impacts and their economic effects is not new. Many models have emerged and demonstrated the urgency of incorporating climate variables, but it is also necessary to measure the effectiveness of these models. Newell *et al.* (2021) studied 800 econometric models, and the results obtained suggest a loss of 1% of global GDP due to a climate shock, but that it could be 5 to 12 times greater by 2100.

Kotz *et al.* (2024) analyzed how climate change, in particular rising temperatures, has impacted global and food inflation, as well as economic productivity, and the results obtained indicate that these changes may threaten price stability. Fixed-effects regression models were used on more than 27,000 observations of monthly consumer price indices around the world to quantify the impacts of climate conditions on inflation. Higher temperatures increase inflation persistently over 12 months in both high-income and low-income countries. The effects vary across seasons and regions, depending on the climate, with additional impacts arising from daily temperature variability and extreme precipitation. Evaluating these results against projected temperature increases by 2035 implies upward pressures on food inflation and global inflation of 0.92–3.23 and 0.32–1.18 percentage points per year, respectively, on average globally (range of uncertainty across emissions scenarios, climate models, and empirical specifications). Pressures are greatest at low latitudes and show strong seasonality at high latitudes, peaking in summer. Finally, the extreme heat of summer 2022 increased food inflation in Europe by 0.43–0.93 percentage points, which projected warming by 2035 would amplify by 30–50%.

Keen (2011) developed a DSGE model to measure monetary policy responses to inflation using the asset channel. Data on environmental disasters were used to assess the loss of value of household assets (where the disaster destroys an economically relevant portion of the economy's productive capital stock) and the impact on the firm, since a disaster temporarily interrupts production, which was modeled as a transitory negative technological shock. Monetary policy transmission channels are influenced by capital destruction and temporary negative technological shocks resulting from natural disasters. In addition, the DSGE model used incorporates nominal price and wage rigidities, as well as using a generalized Taylor rule for monetary policy. Inspired by the event of Hurricane Katrina, in which the United States Federal Reserve (FED) was expected to change the direction of its monetary policy but did not, the results obtained suggest that, in the face of a disaster, the monetary authority should increase its target for the nominal interest rate. In the face of higher inflation and an increase in the real interest rate due to the destruction of the capital stock, the adoption of a restrictive (contractionary, tight) monetary policy is more appropriate than an expansive (or stimulative) monetary policy, in accordance with the Taylor principle (1993), in which the nominal interest rate tends to adjust more quickly in response to changes in inflation than to changes in the level of output. This principle holds even when directly incorporating a variable representing climate change into the Taylor rule.

Gallic and Vermandel (2020) investigate the importance of climate shocks on the economic cycle using a DSGE model. With a climate-dependent agricultural sector, the study documents the propagation of climate shocks in a small, open economy and estimates the model to assess the impacts on the economic cycle. Among the results obtained, it is worth noting that climate shocks explain about 35% of the fluctuations in GDP and agricultural production in New Zealand, resulting in a significant welfare cost.

Other recent papers using a variety of DSGE models highlight how droughts, storms, and floods affect not only economic well-being and growth, but also public debt and fiscal positions. While natural disasters require adjustments in adaptive policies and investments, including international support and resilient infrastructure, climate shocks challenge economically fragile states due to their vulnerability and limited adaptive capacity, affecting food security and intensifying conflicts (Cantelmo , 2023; Jaramillo, 2023; Fuje , 2023; Delgado, 2021; Corugedo , 2023; Fernández-Villaverde, 2018; Wright, 2016).

Regarding one of the contributions to the Brazilian case, this article will focus on the interest rate and exchange rate transmission channels, given that in Brazil monetary policy has many obstructed channels, such as the credit channel, which is composed of approximately 40% of directed credit and has rate controls. There are also other problems, such as the public debt being concentrated in post-fixed assets linked to the Central Bank's own rate, in which the entity changes the rate to control the economy and the central government itself becomes the most affected (Barboza, 2015).

3. Methodology

In this study, we use a small-scale semi-structural aggregate DSGE model used by the Central Bank of Brazil (Lima *et al* ., 1999; Bogdanski *et al* ., 2000; BCB 2020), considering climate change and its interactions with fiscal and monetary policies, with the following extensions made by Teles and Teixeira (2022): (1) a fiscal bloc where a spending shock affects the path of aggregate demand; (2) the incorporation of the structural fiscal result in the explanation of the path of the neutral interest rate; (3) estimation of potential output and the output gap based on Blagrave *et al.* (2015). Furthermore, the inclusion of the fiscal block, as per points (1) and (2) mentioned above, allows for a more precise assessment of how fiscal policy may affect economic variables in the medium term, in response to the impacts of climate change. This DSGE model, which considers free price inflation without disaggregations, has been used by the Central Bank of Brazil (BCB) in its Inflation Reports (2017, 2020). Its micro fundamentals are described in Appendix A; however, the following modifications stand out:

a) Substitutions in data sources:

1. the Central Bank Commodities Index (IC-BC) was replaced by the CRB (Commodities Research Bureau);
2. change of the region of measurement of climate data. Replaced from NINO 3.4 to the NINO 1+2 region, which is the region closest to Latin America and brings the climate volatility observed empirically in the country; and
3. Use of the historical series of the Structural Result prepared by the Independent Fiscal Institute (IFI) to explain the equilibrium interest rate.

b) Equation changes:

1. The equation that estimates the Phillips curve had the climate variable changed and the equation that defined it;
2. The output gap information equation was used, following Teles and Teixeira (2022), in which the deviation from the fiscal result trend was disaggregated into Ricardian and non-Ricardian expenditure deviations;
3. The model parameters have been recalibrated.

Data on macroeconomic, fiscal and climate variables between the last quarter of 2003 and the last quarter of 2023 were used. This period is characterized by improvements in the agricultural sector, such as soil correction, artificial irrigation, increased use of transgenic seeds and technology applied in the field. Since the 1970s, Brazil has adopted an agricultural model focused on vertical integration and increased productivity. This period was characterized by improvements in grain production through technological advances. Globally, transgenic seeds occupy only 2.4% of the agricultural area, with 80% of this concentration in the USA, Argentina and Brazil, where the USA leads with half of the world's transgenic cultivation. Cotton, particularly in India and China, is cultivated to improve resistance to climate variations and pests. Brazil, accounting for 26% of the global agricultural biotechnology area, stands out in the cultivation of soybeans, corn and cotton, with expansion of these crops in 2017 due to profitability, market demand and seed availability (Ferro, 2021). At the same time, significant improvements in the soil were achieved through practices such as liming, aiming to correct soil acidity, essential to increase agricultural productivity. This process, essential for the optimal development of crops such as corn, resulted in favorable chemical changes in the soil, increasing pH, exchangeable calcium levels and base saturation, while reducing exchangeable aluminum, thus improving mineral nutrition and plant growth. These interventions not only increased production capacity but also facilitated more sustainable agriculture, maintaining soil quality and health in the long term (Caires, 2002).

Given this scenario of a country dependent on commodities (mainly agricultural), it makes sense to include climate variables in government decision-making. And as global temperatures continue to rise, it is necessary to measure this effect on monetary policy, in addition to including a fiscal response scenario in situations of climate-related disasters.

3.1 Description of the Macrofiscal DSGE Model with Climate Change

The DSGE model consists of five blocks: (i) a New Keynesian IS curve, which defines the path of the output gap; (ii) a New Keynesian Phillips curve, which describes the evolution of market price inflation; (iii) a

Taylor rule, which shows the response of monetary policy to divergences from the inflation target; (iv) an equation that models the evolution of inflation expectations; and (v) an uncovered interest parity equation, which relates the exchange rate to the domestic and foreign interest rate differential.

3.1.1 - New Keynesian IS Curve

Unlike traditional DSG E models in which the hybrid New Keynesian IS Curve is based on the Euler equation for aggregate consumption, in the present study the New Keynesian IS Curve is described as follows:

$$h_t = \beta_1 h_{t-1} - \beta_2 \hat{r}_{t-1} + \beta_3^r \widehat{rp}_{t-1} + \beta_4 \widehat{ie}_t + \beta_5 h_t^* + \varepsilon_t^y \quad (1)$$

$$\hat{r}_t = r_{t,t+4}^{ex} - \pi_{t,t+4}^{e} - r_t^{eq} \quad (2)$$

$$r_t^{ex} = \frac{0{,}5 i_t + E_t i_{t+1} + E_t i_{t+2} + E_t i_{t+3} + 0{,}5 E_t i_{t+4}}{4} + \varepsilon_t^{ie} \quad (3)$$

$$r_t^{eq} = r_{t-1}^{eq} + \varsigma(s_t) + \varepsilon_{req} \quad (4)$$

where $h_t$is the domestic product gap; $\hat{r}$ is a measure of the real interest rate gap, obtained by the difference between the expected real interest rate and the natural interest rate (r^{eq}), where $\pi^e$is the inflation expectation and $r^{ex}$is the Selic rate expectation; $s_t$is the fiscal indicator known as the structural fiscal result, published by the Independent Fiscal Institute (IFI); $\widehat{rp}_{t-1}$it is the cyclical component of the structural fiscal result lagged in a period; $\widehat{ie}$it is the degree of uncertainty in the economy; and h^*it is a proxy for the world output gap.

Thus, the New Keynesian IS curve addresses variations in aggregate demand, where the output gap is influenced by both monetary and fiscal policies, which can increase or decrease demand, and by external shocks and economic uncertainties that can reduce investment. Another adjustment to the model when composing the fiscal block is the inclusion of the variation in total expenditures as a component of the neutral interest rate.

Table 1 – Observable variables used in the IS Curve – Output Gap

Variable	Description	Data Source
i	Interest rate – Selic target	Central Bank of Brazil
π^e	Inflation Expectations	Central Bank of Brazil
$\widehat{ie}$	Economic Uncertainty Index	Getulio Vargas Foundation
$\widehat{rp}$	Cyclical Component of the Structural Fiscal Result	Independent Fiscal Institute
s_t	Structural Fiscal Result	Independent Fiscal Institute
r^{ex}	Future Interest Rate	Brazilian Stock Exchange

The variables used in this block underwent transformations to ensure compatibility and accuracy of the data in the model. The annual interest rate, which is collected monthly and converted to a quarterly average, was divided by four. The deviation from the mean of the Economic Uncertainty Index was calculated by subtracting the historical average from the current value. Inflation expectations were considered for four quarters ahead, while the future interest rate was obtained from futures contracts and divided by four.

In particular, the structural fiscal result should be understood as the conventional fiscal result free from transitory influences, that is, the result that would be observed with GDP at its potential level, oil prices equal to the long-term equilibrium value, and without non-recurring (atypical, extraordinary) revenues and expenses. The indicator seeks to measure the discretionary and recurring effort of the consolidated public sector to achieve the country's long-term solvency. The calculation of the structural primary result can be considered as a purification of conventional fiscal statistics, since an indicator is extracted that seeks to express the discretionary effect of fiscal policy on solvency, that is, a fiscal result free from the cyclical effects of the level of economic activity and non-recurring fiscal events that tend to affect it. In short, the structural primary result provides a better understanding of how expansionary or contractionary the discretionary action of fiscal policy is in each period.

The inclusion of this modified IS curve in the model is justified because climate shocks affect the supply and not the demand for products, altering the quantity of food available to the population and their respective prices.

Following Teles and Teixeira (2022) (see Appendix C), two equations of the New Keynesian hybrid IS curve were used. The first (1) to capture the output gap and the second (5) to measure the level of activity in the economy, in which the cyclical component of the structural fiscal result was replaced by Ricardian and non-Ricardian expenditures, calculated based on data published in the National Treasury Result. Monthly data on the central government's primary result were collected, divided by the monthly GDP estimate published by the Central Bank of Brazil, and the accumulated value by quarters. After having the entire result as a percentage of GDP, expenses were separated between transfers to Ricardian and non-Ricardian families, where it is assumed that expenses with Social Security Benefits, Continuous Benefit Benefits of LOAS/RMV, Extraordinary Credits (except PAC), Bolsa Família Program and Auxílio Brasil, Health, Education and Social Assistance are non-Ricardian transfers, while the other expenses are Ricardian transfers. So that in response to a climate event, the government can react by making transfers via Ricardian and non-Ricardian spending, as is empirically observed. In which the IS Curve equation is as follows:

$$fpib_t = \beta_1 fpib_{t-1} - \beta_2 \hat{r}_{t-1} + \beta_3^r \left(g_t^{ric} - g_{t-1}^{ric}\right) + \beta_3^{nr}\left(g_t^{nric} - g_{t-1}^{nric}\right) + \beta_4 \widehat{ie}_t + \beta_5 h_t^* + \varepsilon_t^y \quad (5)$$

Table 2 – Observable variables used in the IS Curve – Activity level

Variable	Description	Data Source
$fpib$	GDP Quarter on Quarter (QOQ)	IBGE
g^{ric}	National Treasury Result	National Treasury
g^{nric}	National Treasury Result	National Treasury

According to Gali *et al.* (2007), it is important to consider non-Ricardian agents, who spend all their income, when analyzing the effects of spending expansions on consumption in the IS curve. These agents do not save, which causes their reactions to spending policies to have a greater impact on consumption and short-term production. Therefore, it is essential to separate spending between Ricardian and non-Ricardian agents when estimating the model and constructing policy scenarios.

Changes in the sustainability of public debt, represented by the structural fiscal balance, affect the neutral interest rate. Basic thinking about the level of public debt and the neutral real interest rate is shaped by Barro's (1974) Ricardian equivalence formulation. Ricardian equivalence theory suggests that issuing public debt causes households to demand more assets to save and pay future taxes, without affecting the neutral real interest rate in the long run. However, in practice, Ricardian equivalence does not always hold, especially in incomplete market models such as that of Aiyagari (1994).

In this model, some agents face borrowing constraints, and so additional public debt is purchased mostly by unconstrained agents, while everyone pays the necessary taxes. This difference between who buys the debt and who pays the taxes results in an increase in the neutral long-term real interest rate.

To incorporate the fiscal block into the model, the first step is to collect data on the treasury's results and decompose the fiscal variables into trend, seasonality, cyclical component and shocks. This is necessary because the macroeconomic effects of changes in the trend are different from the effects of temporary shocks, for example. In this sense, temporary shocks affect demand through shifts in the IS curve.

To perform the decomposition of the fiscal variable, an auxiliary model proposed by Teles and Teixeira (2022) is used with the following system of equations:

$$y_t = \mu_t + \tau_t + \beta^{T} x_t + \varepsilon_t \quad (6)$$

$$\mu_{t+1} = \mu_t + \delta_t + \upsilon_{0t} \quad (7)$$

$$\delta_{t+1} = \delta_t + \upsilon_{1t} \quad (8)$$

$$\tau_{t+1} = -\sum_{s=1}^{s-1} \tau_t + \upsilon_{2t} \quad (9)$$

where $y_t$is the series to be decomposed, $\mu_t$is the trend, $\tau_t$is the seasonality, $x_t$are the variables that describe the cyclical component of the activity, and $\varepsilon_t$is the shock. Thus, the trend is modeled as a combination of a random walk and potential growth subject to shocks, and the sign of β indicates the cyclicality of the fiscal variable under analysis . Monetary policy is expected to be contractionary due to the climate impact, while fiscal policy will have to be expansionary to support the affected population.

The model considers the output gap as an unobservable variable , whose trajectory is influenced by four economic activity variables : Gross Domestic Product (GDP) from IBGE; Level of Utilization of Installed Capacity (Nuci) from FGV; unemployment rate from IBGE; and stock of formal jobs from Novo Caged [3]. The specification of the observation equations for these variables seeks to capture the common cyclical component , normalized by the variance of GDP. The cyclical component of the GDP and formal employment stock variables is obtained by applying the Hoddrick -Prescott (HP) filter with a lambda parameter value of 1,600, while for Nuci and unemployment rate , the average of the pre-Covid period is subtracted . The model adds economic structure to the gap estimate, relating it to free price inflation , inflation expectations and the IS curve. Thus, the estimated path of the gap is influenced by both activity indicators and the behavior of the other variables in the model.

$$fpib_t - fpib_{t-1} = h_t + \sigma^h \varepsilon_t^{pib} \quad (10)$$

$$\left(\frac{fnuci_t}{\Upsilon nuci}\right) = h_t + \sigma^h \varepsilon_t^{nuci} \quad (11)$$

[3] The "New Caged " is a system used by the Brazilian government, which replaces the collection of data from the General Registry of Employed and Unemployed Persons (Caged) with eSocial , unifying and simplifying the provision of labor, social security and tax information by employing firms.

$$\left(\frac{femp_t}{\Upsilon emp}\right) = h_{t-1} + \sigma^h \varepsilon_t^{emp} \quad (12)$$

$$\left(\frac{fcaged_t}{\Upsilon caged}\right) = h_{t-1} + \sigma^h \varepsilon_t^{caged} \quad (13)$$

3.1.2 – New Keynesian Phillips Curve

The New Keynesian Phillips Curve is modified to account for the effects of climate change on prices. Specifically, free price inflation can be affected by inertial or expectation components, external shocks, gap shifts, and climate factors. Thus, this block is given by:

$$\pi_t^L = \alpha_{1L}\pi_{t-1}^L + \alpha_{1I}\frac{\sum_{i=1}^4 \pi_{t-1}^{IPCA,sa}}{4} + (1-\alpha_{1L}-\alpha_{1I})\pi_{t,t+4}^e + \alpha_2\hat{\pi}^* + \alpha_3\widehat{\Delta e}_{t-2} + \alpha_4 fpib_t + \alpha_5 Clima_{t-1} + \varepsilon_t^{\pi^L} \quad (14)$$

$$\hat{\pi}_t^* = \omega_a\hat{\pi}_t^{*agri} + \omega_m\hat{\pi}_t^{*metal} + \omega_e\hat{\pi}_t^{*energia} \quad (15)$$

where $\pi^L$is the inflation of free prices; $\pi^{IPCA,sa}$is the inflation measured by the Broad Consumer Price Index - IPCA seasonally adjusted; $\hat{\pi}^*$is imported commodity inflation , which depends on inflation in agricultural, metal and energy commodities; $\widehat{\Delta e}$is the deviation of the exchange rate variation;$Clima_t$ is a variable of climate anomalies, measured by the El Niño of the region, being closer to Latin America and the Caribbean. By incorporating the climate within the block of free price inflation, theoretical and empirical support is found for the model proposed by Kotz (2024), in which climate change directly affects inflation.

The inclusion of climate variables in economic models is justified by the significant influence that climate conditions can have on the economy, especially in sectors such as agriculture and food production. The Central Bank of Brazil (BCB) recognizes the importance of these factors and incorporates climate variables into its models to improve the accuracy of projections of inflation and other economic variables.

Niño 1+2 climate index was used to adjust the model to the region studied. Every three to seven years or so, the surface waters of the tropical Pacific Ocean become extremely warm since the International Dateline to the west coast of South America. This process causes changes in local and regional ecology and is clearly linked to abnormal global climate patterns (Trenberth, 2024). Niño 1+2 (0-10S, 90W-80W) was used : The

Niño 1+2 region is the smallest and easternmost of the Niño SST regions, and corresponds to the coastal region of South America, where El Niño was first recognized by local populations. This index tends to have the largest variance of the Niño SST indices. This region best fits the study region for the model.

This equation constitutes the main contribution of this work. The equation suggested by the Central Bank of Brazil (BCB) used a structure with dummy variables , where three dummy variables were added, divided by three, and the same value was subtracted in the following equation. In this study, we propose the use of climate data with a lag, specifically data from NINO 1+2, which reflect a greater sensitivity to the current climate in Brazil, unlike NINO 3.4, which is calculated with mean deviation and not with the direct measurement of water temperature, as is the case with NINO 1+2. The weight of the parameter associated with climate was recalibrated from approximately 0.001 in the BCB model to 0.21, after re-estimations. This resulted in an equation that presents greater volatility and sensitivity to climate data, as is empirically observed.

To find consumer inflation, administered price inflation (π^{adm}) was modeled and its sum with free price inflation resulted in the inflation rate:

$$\pi_t^{adm} = \alpha_6 * \pi_{t-1,t+4}^{e} + (1 - \alpha_6) * \pi_t^{meta} + \alpha_7 * \left(\pi_t^{petro} + \widehat{\Delta e}_t - \pi_t^{meta*}\right) + \varepsilon_t^{\pi^{adm}} \quad (16)$$

$$\pi^{IPCA} = \alpha_8 \pi_t^L + \alpha_9 \pi_t^{adm} + \epsilon_t^{\pi^{IPCA}} \quad (17)$$

Some of the data used in this equation were already presented in the previous construction, and were added:

Table 3 - Observable variables used in the Philips Curve

Variable	Description	Data Source
$\boldsymbol{\pi^L}$	Quarterly inflation of free prices	Central Bank of Brazil
$\boldsymbol{\pi^{IPCA,sa}}$	Quarterly inflation measured by IPCA	Brazilian Institute of Geography and Statistics
$\boldsymbol{\hat{\pi}^*}$	CRB – *Commodity Research Bureau*	Bloomberg
$\boldsymbol{\Delta e}$	Exchange rate variation in the quarter	Central Bank of Brazil
$\boldsymbol{Clima_t}$	Child 1+2 (0-10S, 90W-80W)	NOAA - Physical Sciences Laboratory
$\boldsymbol{\pi^{meta}}$	Inflation target announced by the National Monetary Council	Central Bank of Brazil
$\boldsymbol{\hat{\pi}^{petro}}$	Brent Oil in US$	Yahoo Finance
$\boldsymbol{\pi^{adm}}$	Quarterly inflation of administered prices	Central Bank of Brazil

Quarterly inflation of market prices was obtained from the accumulated monthly series for quarterly composition. Quarterly inflation measured by the seasonally adjusted IPCA was accumulated from the seasonally adjusted monthly series to obtain the quarterly rate. The CRB commodity index was calculated using the quarterly difference of the index. Agricultural inflation was decomposed by subtracting the Non-Agricultural and Livestock CRB from the CRB index, and energy inflation was obtained by subtracting the Non-Energy CRB from the CRB index. Metal inflation was determined by subtracting both the Non-Energy CRB and the Non-Agricultural CRB from the CRB index. The exchange rate variation was calculated from the average between the purchase and sale rates, with the quarterly variation calculated thereafter. The inflation target was divided by 4 to obtain the quarterly rate, starting from the annual value. The quarterly variation of the Brent oil price was calculated based on the monthly closing prices. Finally, quarterly inflation of administered prices was seasonally adjusted and accumulated from the monthly series to obtain the quarterly composition.

The CRB – Commodity Research Bureau index is a basket of 19 commodities, including energy, agriculture, precious metals and industrial metals contracts. The Index acts as a representative indicator of the commodities markets. It was preferred to use the CRB rather than the Central Bank's IC-BR because the Index is a global reference in relation to commodities and because it has a more representative weight in agricultural commodities. The index aggregates the prices of: Aluminum, Cocoa, Coffee, Copper, Corn, Cotton, Crude Oil, Gold, Heating Oil, Lean Hogs, Live Cattle, Natural Gas, Nickel, Orange Juice, RBOB Gasoline, Silver, Soybeans, Sugar and Wheat. These commodities are classified into 4 groups, with different weightings: Energy: 39%, Agriculture: 41%, Precious Metals: 7%, Base/Industrial Metals: 13%. For this work, the metallic commodities were added .

3.1.3 – Taylor’s Rule

The Central Bank's reaction function, represented by the Taylor rule, responds to deviations in inflation expectations from the target, in addition to smoothing and natural interest rate components, and is given by,

$$i_t = \theta_1 i_{t-1} + \theta_2 i_{t-2} + (1 - \theta_1 - \theta_2)\left[r_t^{eq} + \pi_t^{meta} + \theta_3\left(\pi_{t,t+4}^e - \pi_t^{meta}\right)\right] + \varepsilon_t^i \quad (18)$$

3.1.4 – Inflation Expectations

The expectations equation seeks to maintain coherence between the model and the expectations measured by the Focus report, being given by ,

$$\hat{\pi}_{t,t+4}^e = \varphi_1 \hat{\pi}_{t-1}^e + \varphi_2 [E_t\left(\frac{\sum_{i=1}^4 \pi^{IPCA}}{4}\right) - \pi^{meta}] + \varphi_3 \left(\frac{\sum_{i=1}^4 \pi^{IPCA} - \pi^{meta}}{4}\right) + \varepsilon_t^e \quad (19)$$

where $\hat{\pi}^e$ is the median inflation expectation from the Focus report, $E_t(\sum_{i=1}^{4}\pi^{IPCA}/4) - \pi^{meta}$ is the inflation expectation consistent with the model, and $(\sum_{i=1}^{4}\pi^{IPCA} - \pi^{meta}/4)$ is the deviation of inflation from the target.

3.1.5 – Uncovered Interest Parity

The fifth block is given by the uncovered interest rate parity, which relates the exchange rate variation to the difference in domestic and foreign interest rates adjusted by the Credit Default Swap (CDS), being given by,

$$\Delta e_t = \Delta e^{ppc} - \delta\left(i_t^{dif} - i_{t-1}^{dif}\right) + \varepsilon_t^{e} \quad (20)$$

$$i_t^{dif} = 4 * \left(i_t - (i_t^{*} + CDS_t)\right) \quad (21)$$

$$\Delta e^{ppc} = \frac{\pi^{metass} - \pi^{*ss}}{4} \quad (22)$$

It was necessary to incorporate the following data into this equation:

Table 4 - Observable variables used in Uncovered Interest Parity

Variable	Description	Data Source
π^{metass}	Inflation target announced by CMN and softened	Central Bank of Brazil
CDS_t	Credit Default Swaps for 5-year Brazilian debt securities	Bloomberg
i_t^{*}	US Treasury Federal Funds Effective Rate	St. Louis Fed

The inflation target announced by the National Monetary Council (CMN) was smoothed and divided by 4, after calculating a 4-period average to obtain a quarterly rate. The Credit Default Swap (CDS) for 5-year Brazilian debt securities was transformed into the quarterly average. The effective federal funds rate of the US Treasury was calculated from the quarterly variation of the annual rate, and then divided by 4 to obtain the quarterly rate.

3.2 Scenario Building

Considering that the occurrence of climate effects is increasingly frequent, and that Brazil depends on domestic agriculture to reduce the cost of the basic food basket, in addition to being dependent on the export of agricultural commodities for the trade balance, it is necessary to design scenarios where this climate impact becomes consistent and that monetary and fiscal responses are increasingly precise so as not to penalize the population twice (with the impact of a natural disaster and then with a lack or excess of intervention in the economy, resulting in inflation – which harms the neediest segment of the population). And as an emerging country, inflation is already higher than in developed economies, still being vulnerable to the occurrence of disasters that occur in other countries.

In this study, the analysis focuses on the projection of 20 quarters of the following variables: GDP growth, output gap, inflation measured by the 12-month IPCA and SELIC interest rate. The Kalman Filter was used for these estimates. These projections were constructed for three proposed scenarios:

1. Standard projection without manual changes to the model;
2. Projection using the previous scenario, but with the climate variable with the calibration multiplied by two (considering that the climate could have twice the impact in the future, with the persistent increase in temperature);
3. Same as scenario 2, but with a fiscal expenditure of R$125 billion in response to the climate shock. It is assumed that after a shock the government will be encouraged to support the local economy, either through Ricardian transfers (reconstruction of cities, for example) or through non-Ricardian expenditure (direct aid to the population). In this scenario, non-Ricardian expenditure will account for 26% of the total injected into the economy. The value of R$125 billion was adopted because similar fiscal expenditure was found during the COVID-19 pandemic.

Scientific evidence shows that global temperatures are rising rapidly. Reports from the Intergovernmental Panel on Climate Change (IPCC) indicate that emissions of greenhouse gases, primarily carbon dioxide (CO_2), have caused a continuous warming of the Earth's atmosphere. This warming has direct and indirect effects on global weather patterns , including increasing the frequency and intensity of extreme weather events such as droughts, heat waves, floods, and storms .

The increased frequency of extreme weather events observed in recent decades suggests that climate impacts on the economy are likely to be more severe in the future. For example, more intense and frequent episodes of El Niño and La Niña have caused significant variations in agricultural production and food prices , resulting in inflationary volatility . Persistent increases in global temperatures may intensify these phenomena , justifying an adjustment in the models to reflect these future conditions .

Climate projections indicate that if current trends continue , global average temperatures could rise by as much as 3 ° C or more by the end of the century . This increase is substantial and could exacerbate negative impacts on agriculture, making climate shocks more frequent and intense. Therefore, by doubling the climate parameter , we are more realistically incorporating possible future scenarios and their economic effects .

For monetary and fiscal responses to be effective and not excessively penalize the population , it is crucial that economic models use parameters that accurately reflect future climate conditions . Underestimating climate impacts can lead to inappropriate policies , resulting in inflation and unemployment, especially harming the most vulnerable segments of the population . Doubling the climate parameter in the model helps to anticipate these effects and plan more effective economic interventions .

4. Results Obtained

4.1 Output Gap

In the projections extracted from the model, it is possible to see that there is a positive gap, but that it is decreasing over time, even in the baseline scenario. In other words, Brazil may still have inflationary pressures due to the economy being overheated, but it is approaching its potential level. The growth dynamics are reflected in the output gap, which decreases over time and presents great volatility in the scenario of extra fiscal spending.

The table below presents the output gap projections for the three modeled scenarios:

Table 5 – Projection of the output gap

	Scenario 1	Scenario 2			Scenario 3		
Quarter	**Gap**	**Gap**	**Delta 1 - 2**	**% delta**	**Gap**	**Delta 1 - 3**	**% delta**
March-24	0.6663	0.6663	-0.0000	0%	0.7247	0.0584	9%
June-24	0.4896	0.4906	0.0010	0%	0.5721	0.0825	17%
September-24	0.3573	0.3595	0.0022	1%	0.4701	0.1127	32%
December-24	0.2881	0.2921	0.0040	1%	0.4090	0.1209	42%
March-25	0.1991	0.2049	0.0058	3%	0.3504	0.1513	76%
June-25	0.1260	0.1334	0.0074	6%	0.2666	0.1406	112%
September-25	0.1212	0.1297	0.0084	7%	0.2090	0.0878	72%
December-25	0.1022	0.1098	0.0076	7%	0.1671	0.0649	63%
March-26	0.0982	0.1044	0.0063	6%	0.1191	0.0209	21%
June-26	0.0949	0.0982	0.0034	4%	0.0811	-0.0138	-15%
September-26	0.1054	0.1052	-0.0002	0%	0.0581	-0.0474	-45%
December-26	0.1314	0.1276	-0.0038	-3%	0.0376	-0.0938	-71%
March-27	0.1140	0.1070	-0.0070	-6%	0.0388	-0.0752	-66%
June-27	0.1011	0.0909	-0.0102	-10%	0.0419	-0.0593	-59%
September-27	0.1040	0.0912	-0.0128	-12%	0.0459	-0.0581	-56%

December-27	0.1004	0.0860	-0.0144	-14%	0.0277	-0.0726	-72%
March-28	0.0739	0.0583	-0.0156	-21%	0.0100	-0.0639	-86%
June-28	0.0924	0.0764	-0.0160	-17%	0.0286	-0.0638	-69%
September-28	0.1090	0.0927	-0.0163	-15%	0.0230	-0.0860	-79%
December-28	0.1100	0.0932	-0.0168	-15%	0.0339	-0.0761	-69%
Accumulated			**-0.0671**			**0.1300**	

The data show that fiscal stimulus generates volatility in the output gap, with a significant reduction over time. Over the five years, the output gap increased by 0.13% in the scenario with an increase in the climate parameter and extra fiscal spending, while in the scenario without fiscal spending, the gap decreased by 0.671%. And since the gap percentage was low, any slight change in the rate causes great volatility in the percentage variation.

4.2 Inflation

The dynamics of inflation measured by the IPCA show interesting results, especially when climate change is taken into account. These variations have a strong impact on the economy in the very short term, as evidenced by the first two years after the shock. The scenario with fiscal spending shows that the economy returns to equilibrium earlier than in the scenarios without fiscal intervention, but with a high possibility of inflation resuming in the medium term.

The projections extracted from the model show the impact of climate shocks in three different scenarios. Table 7 presents these projections for the IPCA accumulated in 12 months:

Table 6 – Projection for accumulated IPCA in 12 months

	Scenario 1	Scenario 2			Scenario 3		
Quarter	**IPCA**	**IPCA**	**Delta 1 - 2**	**% delta**	**IPCA**	**Delta 1 - 3**	**% delta**
March-24	3,0491	3,2537	0.2047	7%	3,2440	0.1950	6%
June-24	3,4245	3,9548	0.5303	15%	3,8063	0.3818	11%
September-24	3,4817	4,1218	0.6401	18%	3,7484	0.2667	8%
December-24	3,5088	4,3573	0.8485	24%	3,5413	0.0326	1%
March-25	4,0650	4.8638	0.7988	20%	3,5293	-0.5356	-13%
June-25	3,8450	4,4376	0.5926	15%	3,0319	-0.8132	-21%
September-25	3,9302	4,5126	0.5824	15%	2,6732	-1.2571	-32%
December-25	3,5775	3.7727	0.1952	5%	2.9767	-0.6008	-17%
March-26	3,5727	3,6916	0.1189	3%	3,2229	-0.3498	-10%
June-26	3,2321	3,0363	-0.1958	-6%	3,4681	0.2360	7%
September-26	3,0368	2.6224	-0.4144	-14%	4.0148	0.9779	32%
December-26	3,2429	3,0541	-0.1888	-6%	4,4756	1,2326	38%
March-27	3,2621	3,1066	-0.1554	-5%	4.3666	1,1045	34%
June-27	3,3103	3,1930	-0.1173	-4%	4,1594	0.8491	26%

September-27	3,3913	3,3720	-0.0193	-1%	4,3293	0.9379	28%
December-27	3,4421	3,4494	0.0073	0%	3,8414	0.3993	12%
March-28	3,1923	2.9685	-0.2237	-7%	3,6782	0.4859	15%
June-28	3,3814	3,3671	-0.0142	0%	3,5226	0.1412	4%
September-28	3,3548	3,3430	-0.0118	0%	3,4596	0.1047	3%
December-28	3,0253	2.7325	-0.2928	-10%	3.8745	0.8492	28%
Accumulated			**2,8851**			**4.6381**	

In scenario 2, where the climate parameter is doubled, inflation is significantly higher in the first and second years. Specifically, in the first year, a price increase of 2.22% is observed, followed by 2.16% in the second year. This sharp increase in prices is clear evidence of the adverse impact of climate change on the economy, causing significant inflationary pressure.

On the other hand, in scenario 3, where there is fiscal intervention, the inflation rate presents a different dynamic. Initially, inflation is lower in the first year compared to the baseline scenario, reflecting the mitigating influence of fiscal spending. However, in the second year, inflation falls below the baseline scenario, possibly due to weakened economic activity, before rising again. At the end of the five years, cumulative inflation is higher by 4.6381%, indicating that, despite the mitigating effects in the short term, fiscal spending can lead to inflationary pressure in the long term.

The data reveal that climate change can cause volatility in inflation, especially in the fiscal spending scenario. This behavior is consistent with the theory that supply shocks initially increase prices due to shortages of agricultural products and other goods directly affected by the climate. Fiscal intervention can help mitigate some of the short-term adverse effects, but can lead to additional inflationary pressures if not carefully calibrated.

The results of this study are in line with the findings of Kotz (2023), who observed that higher temperatures increase food inflation and overall inflation persistently over 12 months, in countries of different income levels. This research reinforces the idea that economies that frequently face climate shocks need well-adjusted monetary and fiscal policies to avoid an inflationary spiral and maintain economic stability. Furthermore, the results obtained are in line with Cevik and Gwon (2024), reinforcing the premise that the trajectory of inflation is not immune to the forces of climate change.

4.3 Interest rate

Interest rates are a crucial tool of monetary policy, influencing economic activity by reducing the cost of credit and encouraging investment and consumption. In a climate change scenario, the response of interest rates can be a vital indicator of how monetary policy should be adjusted to maintain economic stability and control inflation.

The projections extracted from the model show the impact of climate shocks in three different scenarios. Table 8 presents these projections for the SELIC rate:

Table 7 – Projection for the SELIC interest rate

	Scenario 1	Scenario 2			Scenario 3		
Quarter	**SELIC**	**SELIC**	**Delta 1 - 2**	**% delta**	**SELIC**	**Delta 1 - 3**	**% delta**
March-24	11.78	11.79	0.01	0%	11.82	0.04	0%
June-24	11.32	11.35	0.02	0%	11.41	0.09	1%
September-24	10.97	11.02	0.05	0%	11,11	0.14	1%
December-24	10.71	10.79	0.08	1%	10.87	0.17	2%
March-25	10.51	10.62	0.11	1%	10.68	0.16	2%
June-25	10.37	10.52	0.15	1%	10.54	0.17	2%
September-25	10.26	10.43	0.17	2%	10.44	0.18	2%
December-25	10.17	10.36	0.19	2%	10.35	0.18	2%
March-26	10.08	10.28	0.20	2%	10.27	0.19	2%
June-26	10.00	10.19	0.19	2%	10.21	0.20	2%
September-26	9.93	10,10	0.17	2%	10.18	0.25	3%
December-26	9.87	10.01	0.15	2%	10.17	0.30	3%
March-27	9.82	9.94	0.12	1%	10.17	0.35	4%
June-27	9.77	9.86	0.09	1%	10.18	0.41	4%
September-27	9.71	9.78	0.07	1%	10.18	0.46	5%
December-27	9.66	9.71	0.05	0%	10.19	0.53	5%
March-28	9.62	9.65	0.03	0%	10.19	0.57	6%
June-28	9.59	9.60	0.01	0%	10.19	0.59	6%
September-28	9.57	9.56	-0.01	0%	10.18	0.61	6%
December-28	9.55	9.53	-0.02	0%	10.16	0.61	6%
Accumulated			**1.83**			**6.20**	

The data reveal that climate change can cause a significant increase in the SELIC rate, especially in scenario 3, where there is fiscal spending and the public debt balance changes. This behavior is consistent with economic theory, where supply shocks, such as climate shocks, initially increase prices, leading to higher inflation. To control this inflation, the Central Bank needs to raise the interest rate. In scenario 2, where the climate parameter is doubled, the SELIC rate is 1.83% higher at the end of five years. In scenario 3, with fiscal intervention, the SELIC rate is 6.20% higher compared to the base scenario, highlighting the impact of public debt.

The results of this study are in line with the findings of Keen (2011), who observed that the Central Bank needs to keep interest rates high for longer to control inflation in climate shock scenarios. Furthermore, the study by Cantelmo (2023) highlights the importance of public investment in resilient infrastructure to achieve significant welfare gains. This study suggests that aid is more efficient when targeted to finance resilience before disasters occur, rather than being disbursed after the events.

The results also show some of the current behavior of the Central Bank of Brazil (BCB), in which it changes interest rates in small and consistent movements. This is different from what is expected in theory, where the monetary authority could give an abrupt shock to the rate and balance inflation in a short period. However, this is not what the historical data used in the model express, and this is why the interest rate needs to remain high for a longer period. Here, the BCB is concerned with the expectations of economic agents and its credibility in communication.

The analysis of the results demonstrates the need for a coordinated strategy that not only addresses the immediate consequences of climate shocks, but also considers their long-term effects on the economy. The Brazilian experience illustrates how fiscal measures can have ambiguous impacts, highlighting the importance of prudent fiscal planning and a monetary policy that can dynamically adapt to economic conditions altered by climate change.

These findings indicate the complexity of the interaction between fiscal and monetary policies in response to climate change and highlight the importance of appropriately calibrating these policies to mitigate adverse effects and promote economic stability.

5. Final Considerations and Policy Implications

Climate-related natural disasters have not only increased in frequency and intensity, but also have significant economic impacts that require agile and effective policy responses. This study delves into the increasing frequency of such anomalies, elucidating their role as a non-negligible factor in supply chain volatility. The data highlight a consistent pattern: anomalies lead to sharp fluctuations in production capacity, which, together with supply chain frictions, precipitate pronounced shortages and upward price pressures. This study assesses climate change and its possible increase in the weight of the climate-related parameter. It is not a study of climate shocks because the climate data are within the Phillips curve, in which there is an inflation shock and it cannot be said that this shock is derived solely from climate. However, by comparing scenarios with modified climate parameter weights, the likely trajectories of the indicators in response to this variation are presented.

The results of this study indicate that climate change has significant and long-lasting impacts on the Brazilian economy. The analysis focused on the effects on inflation, measured by the IPCA, the output gap and the SELIC interest rate, highlighting the volatility induced by supply shocks and the necessary fiscal and monetary responses. In scenario two, where we simulate an economy where the climate parameter had doubled, inflation is significantly higher, especially in the first two years. Specifically, in the first year, prices increase by 2.22%, and in the second year, the increase is 2.16%, compared to the baseline scenario. These data reinforce the theory that climate change can cause substantial inflationary pressure in the short term. In scenario three, which includes a fiscal response, inflation presents a different dynamic. Initially, inflation is lower in the first year, falling to 0.87%, possibly due to the weakening of economic activity. However, over five years, accumulated inflation is 4.6381% higher than in the baseline scenario. This indicates that while fiscal intervention may mitigate inflationary effects in the short term, it may lead to additional inflationary pressures in the long term.

The SELIC interest rate also reacts significantly to climate change . In the scenario with the climate parameter doubled, the SELIC rate accumulates an increase of 1.83% over five years. In the scenario with fiscal spending, the interest rate accumulates an even larger increase, of 6.2%, due to the need to finance the increase in public debt. This result highlights the complexity of maintaining economic stability in the face of climate change , requiring prolonged adjustments in interest rates to control inflation. These findings are in line with economic theory that predicts that supply shocks, such as climate shocks, initially raise prices, leading to higher inflation and requiring tighter monetary policy to control it.

In summary, the fiscal response to the supply shock resulting from climate change causes a resurgence of inflation, requiring monetary policy intervention via the Taylor Rule. Additionally, the model incorporates a component that simulates the interactions of this economy with the global scenario, emphasizing the need for balance in domestic and foreign markets.

This study represents an initial attempt to incorporate climate shocks into economic equations. Although it focused on the effects on inflation and interest rates, it is necessary to investigate how these variations may impact other economic variables, such as asset values, employment, credit and migration movements. It is also suggested that further research include drought variables and latitude data in the sample, as well as dividing GDP into sectors in order to assess only the effect on the agricultural sector. The analysis of the results demonstrates the need for a coordinated strategy that not only addresses the immediate consequences of climate change , but also considers its long-term effects on the economy. The Brazilian experience illustrates how fiscal measures can have ambiguous impacts, highlighting the importance of prudent fiscal planning and a monetary policy that can dynamically adapt to economic conditions altered by climate change.

The study suggests that climate change requires a careful monetary and fiscal policy response. Fiscal intervention can mitigate some of the short-term adverse effects, but if not carefully calibrated, it can lead to additional inflationary pressures in the long run. This behavior is consistent with the findings of Keen (2011), who observed that the Central Bank needs to keep interest rates high for longer to control inflation in climate shock scenarios. Furthermore, the study by Cantelmo (2023) highlights the importance of public investment in resilient infrastructure to achieve significant welfare gains, suggesting that aid is more efficient when targeted to finance resilience before disasters occur, rather than being disbursed after events.

This study expands the understanding of the mechanisms by which climate change affects emerging economies, with significant policy implications, and offers a vital contribution to the literature by combining macroeconomic modeling with climate issues, a relevant approach given the global climate emergency. From a policy perspective, the study highlights the importance of incorporating climate risks into economic policy strategies to strengthen economic resilience to environmental shocks. The results of this study reiterate the urgency of an interdisciplinary approach in economic research, emphasizing the integration of economics and environmental sciences. The research highlights the importance of preparing the Brazilian economy for a future in which extreme climate events may become more common, reinforcing the need for a public policy agenda that prioritizes sustainability and economic resilience.

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Appendix A – Micro Fundamentals Of The Small-Scale Dsge Model

A.1 Families

Following Gali, Lopez- Salido , and Valles (2007), the economy is inhabited by a continuum of infinitely long-lived residents, indexed by $j \in (0,1)$. A fraction $(1-\lambda)$of households have access to financial markets where they can trade a full set of contingent state bonds (government bonds), as well as buy and sell physical capital (which they accumulate and rent to firms). The terms savers, Ricardian consumers, or optimizing consumers (indexed by " o ") refer to a subset of these standard forward-looking individuals looking because it is possible for them to optimize their consumption in their infinite life prospects. In addition, Ricardian residents have a common initial capital endowment.

The remaining fraction λ of liquidity-constrained residents do not own any assets or liabilities, and their behavior is characterized by a simple “rule-of-thumb” behavior: they consume their disposable labor income in each period. They are known as spendthrifts, non-Ricardian consumers, or rule - of -thumb consumers (indexed by “ *r* ”) because they cannot optimize their consumption. They cannot access financial markets and do not have an initial capital endowment. Different interpretations of this behavior include shortsightedness, lack of access to financial markets, fear of saving, ignorance of intertemporal trading opportunities, active borrowing constraints, and so on.

The utility function with constant relative risk aversion (CRRA) of optimizing consumers in period *t* has the following separable form (GALI, 2008, chap. 3, p. 42):

$$U(C_t^o, N_t^o) = \frac{C_t^{o\,1-\sigma}}{1-\sigma} - \frac{N_t^{o\,1+\varphi}}{1+\varphi} \quad (A.1)$$

where $\varphi \geq 0$is the inverse of the Frisch elasticity of substitution in labor supply and represents the risk aversion of changes in leisure. The term $\sigma > 0$is the coefficient of relative risk aversion and, at the same time, the inverse of the intertemporal elasticity of substitution. Note that the utility function is positively affected by consumption and negatively affected by labor supply. Therefore, households obtain utility by consuming the final good and disutility by providing the labor supply.

Optimizing (Ricardian) consumers derive utility from the composite consumption of goods and labor. Let $C_t^o$and be $N_t^o$the consumption and hours worked of the optimizing consumers . The dynamic optimization problem of Ricardian residents consists of choosing the control variables $\{C_t^o, N_t^o, B_{t+1}^o, I_t^o, K_{t+1}^o\}_{t=0}^{\infty}$to maximize $E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^o, N_t^o)$subject to the budget constraints and the capital accumulation equation, taking as given the state variables $\{P_t, R_t, W_t, R_t^k, K_t^o, B_t^o, T_t^o, D_t^o\}$[4]. In other words, each Ricardian resident maximizes his lifetime utility by choosing: consumption (C_t^o); investment (I_t^o); his financial wealth in the next period in the form of government bonds (B_{t+1}^o), that is, the quantity of nominal risk-free bonds purchased in period *t* , and which pay one unit of money in period $t+1$; the stock of physical capital in the next period (K_{t+1}^o); and the hours worked (N_t^o). As for the state variables, we have: the price level in period *t* (P_t); the real wage (W_t); the real interest rate on the capital stock $\left(R_t^k\right)$, therefore, it is the rental rate that Ricardian residents charge for renting capital to firms; the capital stock ; (K_t^o)lump -sum taxes (or (T_t^o)lump -sum

[4] State variables are also called predetermined variables or backward-looking variables and describe the state of a given system at each instant in time. Control variables are also called non-predetermined variables or forward-looking variables .

transfers , if positive) paid by these consumers; the gross nominal return on the bonds purchased in period t (R_t); the dividends from ownership of firms (D_t^o); and the quantity of nominal risk-free securities of a period carried over from period $t-1$, and which pay one unit of cash in period t (B_t^o).

Specifically, the optimizing consumer seeks to maximize the following expected utility:

$$\max_{\{C_t^o,N_t^o,B_{t+1}^o,I_t^o,K_{t+1}^o\}_{t=0}^{\infty}} E_0\left\{\sum_{t=0}^{\infty}\beta^t U(C_t^o,N_t^o)\right\}$$

subject to the sequence of budget constraints (and implicitly to a condition of no Ponzi Games):

$$P_t[C_t^o+I_t^o]+R_t^{-1}B_{t+1}^o+R_{t-1}^F S_t B_{j,t}^F$$
$$=W_tP_tN_t^o+R_t^kP_tK_t^o+B_t^o-P_tT_t^o+D_t^o+S_tB_{j,t+1}^F-\frac{\chi_{BF}}{2}\left(B_{j,t+1}^F-B_{j,SS}^F\right)^2S_t \quad (A.2)$$

where $dU/dC_t^o>0$and $dU/dN_t^o<0$. The term $\beta\in(0,1)$is a discount factor. The term $E_t$is an operator that represents the expectations of all states of the economy conditional on the information in the period. At the beginning of each period the consumer receives labor income $W_tP_tN_t^o$after taxes on labor income. The consumer also receives income from renting out his capital stock $K_t^o$to firms at the real rental cost R_t^k, in other words, $R_t^kP_tK_t^o$it is the after-tax capital income obtained from renting out the capital stock at the real rate R_t^k.

In relation to the rest of the world, $B^F$is the one-year foreign debt security, $R^F$is the international interest rate, $S_t$is the nominal exchange rate, and $\chi$is the parameter governing the sensitivity adjustment cost. The term $(\chi_{BF}/2)\left(B_{j,t+1}^F-B_{j,SS}^F\right)^2S_t$represents the stationarity induction technique (Schmitt-Grohé and Uribe, 2003).

One of the contributions of this study lies in the fact that it adds to the budget constraint of optimizing consumers and rule - of -thumb distortionary taxation rules that respond to their lagged term in a period, as well as to the output gap and the public debt stock, together, as will be specified later, aiming to investigate how the presence of distortionary taxation affects the trajectory of household consumption in this economy.

The second restriction refers to the capital accumulation equation, which is given by:

$$K_{t+1}^o=(1-\delta)K_t^o+\phi\left(\frac{I_t^o}{K_t^o}\right)K_t^o \quad (A.3)$$

where capital adjustment costs are introduced through the function $\phi\,(I_t^o/K_t^o)/K_t^o$, which determines the change in the capital stock induced by investment spending I_t^o. The capital stock K_t^odepreciates at a rate δ. It is assumed that $\phi' > 0$, $\phi'' \leq 0$, $\phi'(\delta) = 1$and $\phi(\delta) = \delta$.

Lagrangian Function associated with the budget constraint (A.2) and the capital accumulation equation (A.3) is expressed as follows:

$$\mathcal{L}\text{: } E_0\left\{\sum_{t=0}^{\infty}\beta^t\left(\frac{C_t^{o\,1-\sigma}}{1-\sigma}-\frac{N_t^{o\,1+\varphi}}{1+\varphi}\right)\right.$$
$$+\sum_{t=0}^{\infty}\lambda_t^o\,[W_tP_tN_t^o + R_t^KP_tK_t^o + B_t^o - P_tT_t^o + D_t^o - P_tC_t^0 - P_tI_t^o$$
$$\left. - R_t^{-1}B_{t+1}^o] + \sum_{t=0}^{\infty}\nu_t^o\left[(1-\delta)K_t^o + \phi\left(\frac{I_t^o}{K_t^o}\right)K_t^o - K_{t+1}^o\right]\right\}$$

In analogy to Gali, Lopez- Salido and Valles (2007), the first-order conditions for the optimizing consumer problem can be written as follows:

$$\frac{\partial\mathcal{L}}{\partial C_t^o}\text{:}\quad \beta^t C_t^{o\,-\sigma} - \lambda_t^o P_t = 0 \;(A.4)$$

We $(A.4)$have:

$$\lambda_t^o = \frac{\beta^t}{C_t^{o\,\sigma}P_t}\;;\quad (A.4.1)\qquad \lambda_{t+1}^o = \frac{\beta^{t+1}}{C_{t+1}^{o\;\;\sigma}P_{t+1}}\;;\;(A.4.2)$$

$$\frac{\partial\mathcal{L}}{\partial N_t^o}\text{:}\quad -\beta^t N_t^{o\,\varphi} + \lambda_t^o W_t P_t = 0 \Rightarrow \lambda_t^o = \frac{\beta^t N_t^{o\,\varphi}}{W_tP_t}\;(A.5)$$

$$\frac{\partial\mathcal{L}}{\partial B_{t+1}^o}\text{:}\quad -\lambda_t^o R_t^{-1} + \lambda_{t+1}^o = 0 \Rightarrow \lambda_{t+1}^o = \lambda_t^o R_t^{-1}\;(A.6)$$

$$\frac{\partial\mathcal{L}}{\partial I_t^o}\text{:}\quad -\lambda_t^o P_t + \phi'\left(\frac{I_t^o}{K_t^o}\right)\nu_t^o = 0 \Rightarrow \lambda_t^o = \frac{1}{P_t}\phi'\left(\frac{I_t^o}{K_t^o}\right)\nu_t^o\;(A.7)$$

$$\frac{\partial \mathcal{L}}{\partial K_{t+1}^{o}}: \lambda_{t+1}^{o} R_{t+1}^{K} P_{t+1} + \nu_{t+1}^{o}(1-\delta) - \nu_{t+1}^{o}\left(\frac{I_{t+1}^{o}}{K_{t+1}^{o}}\right)\phi_{t+1}' + \nu_{t+1}^{o}\phi_{t+1} - \nu_{t}^{o} = 0 \ (A.8)$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_{t}^{o}}: \ W_t P_t N_t^o + R_t^K P_t K_t^o + B_t^o - P_t T_t^o + D_t^o = P_t C_t^o + P_t I_t^o + R_t^{-1} B_{t+1}^o \ (A.9)$$

$$\frac{\partial \mathcal{L}}{\partial \nu_{t}^{o}}: \ K_{t+1}^o = K_t^o + \phi\left(\frac{I_t^o}{K_t^o}\right) K_t^o \ (A.10)$$

From $(A.4.1)$, $(A.4.2)$and $(A.6)$, we obtain the Euler equation for consumption presented in equation $(A.11)$, which describes the attitude of smoothing consumption over time since the opportunity cost implicit in the interest rate must be taken into account, and whose expression is given by:

$$1 = \ R_t E_t\left\{\Lambda_{t,t+1}\left(\frac{P_t}{P_{t+1}}\right)\right\} \ (A.11)$$

where $\Lambda_{t,t+1}$is the stochastic discount factor for *k* -periods-ahead real *payoffs given by:*

$$\Lambda_{t,t+1} \equiv \beta^k \left(\frac{C_{t+1}^{o\ \sigma}}{C_t^{o\,\sigma}}\right)^{-1} \ (A.12)$$

where $\beta^k = \beta^{t+k}/\beta^t$. Note that the consumption tax enters the Euler equation affecting intertemporal decisions.

A competitive labor market is assumed, with each resident choosing the number of hours offered given the market wage. From $(A.4.1)$ and $(A.5)$, we obtain equation $(A.13)$, which states that taxation distorts labor-consumption trade-offs. Therefore, equation $(A.13)$ below states that any change in tax revenues on consumption and labor income has a direct effect on hours worked and consumption and, therefore, on the marginal rate of substitution between consumption and labor, which in turn equals the real wage:

$$W_t = C_t^{o\,\sigma} N_t^{o\,\varphi} \ (A.13)$$

Lagrangian multipliers are obtained :

$$\nu_t^o = \frac{\beta^t}{C_t^{o\,\sigma} \phi'\left(\frac{I_t^o}{K_t^o}\right)} \quad (A.14.1)$$

$$\nu_{t+1}^o = \frac{\beta^{t+1}}{C_{t+1}^{o\ \sigma} \phi'\left(\frac{I_{t+1}^o}{K_{t+1}^o}\right)} \quad (A.14.2)$$

From $(A.4.2)$, $(A.8)$and $(A.14.2)$, we obtain the following intermediate expression for the value of the installed capital:

$$Q_t = R_{t+1}^k \Lambda_{t,t+1} + \Lambda_{t,t+1} Q_{t+1} \left[(1-\delta) + \ \phi_{t+1} - \left(\frac{I_{t+1}^o}{K_{t+1}^o}\right) \phi_{t+1}' \right] \quad (A.15)$$

Where:

$$Q_t = \frac{1}{\phi_t'\left(\frac{I_t^o}{K_t^o}\right)} \quad e \quad Q_{t+1} = \frac{1}{\phi_{t+1}'\left(\frac{I_{t+1}^o}{K_{t+1}^o}\right)} \quad (A.16)$$

Equation (A.16) defines Tobin's Q , which measures the shadow price of a unit of investment in physical capital. In other words, equation (A.16) equalizes the benefit of increasing investment in a unit, which is expressed by the marginal increase in capital multiplied by the real value over Q_t, that is, $\phi_t'(I_t^o/K_t^o)Q_t = 1$.

From $(A.12)$, $(A.15)$and $(A.16)$, we obtain the following equation (A.17), which states that the marginal cost of an additional unit of investment must be equal to the present value of the marginal increase in equity that is generated. In other words, equation (A.17) defines the real shadow value of capital, Q_t, which is equal to the discounted present value of the future income streams generated by increasing one unit of capital:

$$Q_t = E_t \left\{ \Lambda_{t,t+1} \left[R_{t+1}^k + Q_{t+1} \left((1-\delta) + \ \phi_{t+1} - \left(\frac{I_{t+1}^o}{K_{t+1}^o}\right) \phi_{t+1}' \right) \right] \right\} \quad (A.17)$$

Note that under the assumption in ϕ, the elasticity of the investment-capital ratio with respect to Q is given by $\eta \equiv -1/\phi''(\delta)\delta$.

According to Gali, Lopez- Salido and Valles (2007), non-Ricardian residents or “rule - of -thumb ” consumers neither borrow nor save, but consume all their disposable labor income in each period t. They do not smooth their consumption path in the face of fluctuations in labor income, nor do they substitute intertemporally in response to changes in the interest rate. Specifically, the utility of *rule - of -thumb* consumers in each period is given by:

$$U(C_t^r, N_t^r) = \frac{C_t^{r\,1-\sigma}}{1-\sigma} - \frac{N_t^{r\,1+\varphi}}{1+\varphi} \quad (A.18)$$

Since these consumers do not have access to the capital market, their budget constraint becomes static and is given by:

$$C_t^r = W_t N_t^r - T_t^r \quad (A.19)$$

Therefore, the consumption and labor of non-Ricardian residents are subject to the same tax revenues on consumption and labor income equivalent to those of Ricardian residents. However, non-Ricardian residents have substantially lower incomes compared to Ricardian residents due to the absence of income on the capital stock in the budget constraint described in equation (A.19).

The static optimization problem of non-Ricardian residents consists of choosing $\{C_t^r, N_t^r\}_{t=0}^{\infty}$to maximize $U(C_t^r, N_t^r)$ subject to (A.19), taking as given the state variables $\{W_t, T_t^r\}$. In equation (A.19), consumption is equal to the disposable wage income after taxation. Here, the term C_t^rrepresents the consumption of rule - of -thumb residents and N_t^rtheir hours worked. The taxes paid by rule - of -thumb consumers (T_t^r) can be distinguished from those paid by optimizing residents (T_t^o). Only consumers belonging to this class are assumed to receive (pay) lump -sum transfers (taxes) from the government. Since non-Ricardian agents cannot save for the future, they simply maximize period utility subject to (A.19). Hence, these non-Ricardian residents consume all their labor income in each period.

Lagrangian function associated with the budget constraint (A.19) and the first-order conditions of the non-Ricardian consumer maximization problem are given by:

$$\mathcal{L}: \left(\frac{C_t^{r\,1-\sigma}}{1-\sigma} - \frac{N_t^{r\,1+\varphi}}{1+\varphi}\right) + \lambda_t^r [W_t N_t^r - T_t^r - C_t^r]$$

$$\frac{\partial \mathcal{L}}{\partial C_t^r}: \quad C_t^{r\,-\sigma} - \lambda_r^r = 0 \Rightarrow \lambda_r^r = C_t^{r\,-\sigma} \quad (A.20)$$

$$\frac{\partial \mathcal{L}}{\partial N_t^r}: \quad -N_t^{r\varphi} + \lambda_t^r W_t = 0 \Rightarrow \lambda_t^r = \frac{N_t^{r\varphi}}{W_t} \; (A.21)$$

From (A.20) and (A.21), under the assumption of a competitive labor market, we obtain equation (A.22), in which the optimal labor supply of rule - of -thumb residents take the same analytical form as that obtained for optimizing consumers , satisfying:

$$W_t = C_t^{r\sigma} N_t^{r\varphi} \; (A.22)$$

Thus, equation (A.22) indicates that taxation on consumption and labor income also distorts the consumption-labor choice of non-Ricardian residents.

In particular, in this economy the consumption tax could be equated to a value added tax (VAT), which is commonly transferred by firms to the final consumer. Therefore, this tax distorts the consumption decisions of both types of consumers, Ricardian and non-Ricardian. In the case of Ricardian residents, this tax enters the Euler equation affecting intertemporal decisions. Furthermore, both types of taxes affect the supply of labor, distorting production.

A.2 Aggregation

According to Gali, Lopez- Salido and Valles (2007), aggregate consumption and labor supply are given by a weighted average of corresponding variables for each type of consumer. Formally:

$$C_t \equiv \lambda C_t^r + (1-\lambda) C_t^o \; (A.23)$$

$$N_t \equiv \lambda N_t^r + (1-\lambda) N_t^o \; (A.24)$$

Since only Ricardian residents invest and accumulate capital, aggregate investment and aggregate capital stock are given by:

$$I_t \equiv (1-\lambda) I_t^o \; (A.25)$$

$$K_t \equiv (1-\lambda) K_t^o \; (A.26)$$

lump -sum aggregate tax corresponds to a weighted average of the lump -sum tax for each of the consumers:

$$T_t \equiv \lambda T_t^r + (1-\lambda) T_t^o \ (A.27)$$

In steady-state equilibrium, each type of consumer is assumed to work the same number of hours, such that $N_t = N_t^r = N_t^o$, and are affected by the same lump -sum tax revenue, that is, $T_t = T_t^r = T_t^o$.

A.3 Firms

Gali, Lopez- Salido and Valles (2007) argue that the aggregate supply of the economy is represented by two sectors. The existence of a continuum of monopolistically competitive producers of differentiated intermediate goods (indexed by " i ") is considered. These goods are then used as inputs by a perfectly competitive firm to produce a single final good.

A.3.1 Final Goods Signature

The final good, which will be used for internal absorption (private consumption C_t , investment I_t and government spending G_t), is produced by a perfectly competitive representative firm, whose production function consists of a Dixit and Stiglitz (1977) technology with constant returns to scale, which aggregates the intermediate goods:

$$Y_t = \left(\int_0^1 X_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}} \ (A.28)$$

where $X_t(i)$is the quantity of an intermediate good used as an input in the production of $Y_t$by firm i , $i \in (0,1)$. The coefficient εrepresents the constant elasticity of substitution between individual goods (or price elasticity of demand), and is a measure of the market power of each firm $(\varepsilon > 1)$. As $\varepsilon \to \infty$, intermediate goods become perfect substitutes in production, as the firm faces a horizontal demand curve, $\varepsilon/(\varepsilon-1) \to 1$, price equals marginal cost, and we return to the case of perfect competition. On the other hand, as $\varepsilon < \infty$ intermediate goods are imperfect substitutes in consumption, and it is this that gives firms market power.

The variable Y_t is a CES production function, which exhibits diminishing marginal product, a property that will lead firms to diversify and produce all available intermediate goods. Aggregating consumer and government demand, the firm is faced with the following negatively sloped demand function or curve for its intermediate good i , with constant and homogeneous price elasticity of degree one in the final product :

$$X_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} Y_t \; (A.29)$$

where profit maximization takes as given the price P_t of the final good, as well as the prices $P_t(i)$for intermediate goods $i \in (0,1)$. Substituting the demand curve for intermediate good *i* for the firm in the production function (A.28), we obtain the aggregate price index, which also represents the zero-profit condition:

$$P_t = \left(\int_0^1 \left(P_t(i)\right)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}} \; (A.30)$$

A.3.2 Intermediate Goods Firm

The production function with constant returns to scale for the intermediate goods firm is given by a Cobb-Douglas technology in terms of homogeneous capital and labor inputs:

$$Y_t(i) = A_t K_t(i)^{\alpha} N_t(i)^{(1-\alpha)} \; (A.31)$$

where $\alpha \in (0,1)$. The terms $K_t(i)$and $N_t(i)$represent the capital and labor services contracted by firm *i* . The exogenous and stationary technological shock, which captures the trend of total factor productivity (TFP) in this sector, is considered to follow the stochastic process:A_t

$$A_t = {A_{t-1}}^{\rho_a} exp(\varepsilon_t^a) \; (A.32)$$

where $\varepsilon_t^a$is white noise, an innovation considered to be independent, identically and normally distributed with zero mean and constant variance, that is, $\varepsilon_t^a \sim N(0, \sigma_a^2)$and $0 < \rho_a < 1$. The technological shock is common to all producers of intermediate goods.

A.3.3 Cost Minimization

According to Gali, Lopez- Salido and Valles (2007), producers of intermediate goods solve a two-stage problem. First, given the real wage $(W_t)$and the rental rate on physical capital $\left(R_t^k\right)$, they rent $N_t(i)$e $K_t(i)$in perfectly competitive factor markets in order to minimize real cost. The optimal combination of capital $K_t(i)$and labor $N_t(i)$is obtained from the firm's cost minimization problem:

$$\underbrace{min}_{\{K_t(i)N_t(i)\}} \left(R_t^k K_t(i) + W_t N_t(i)\right)$$

Subject to equation (A.31) which describes the production function with constant returns to scale for the intermediate goods firm.

Cost minimization, taking the wage and rental cost of capital as given, implies the following rate of substitution between capital and labor:

$$\frac{K_t(i)}{N_t(i)} = \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{W_t}{R_t^k}\right) \ (A.33)$$

The real marginal cost (or Lagrange multiplier with respect to the constraint) is common to all firms and is given by:

$$MC_{t+k} = \psi \frac{\left(R_{t+k}^k\right)^{\alpha} (W_{t+k})^{1-\alpha}}{A_{t+k}} \ (A.34)$$

where $\psi \equiv \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$. Equation ($A$.34) implies that real marginal cost is a function of wages, technology, and the real interest rate on the capital stock. Intuitively, technological improvements contribute to reducing firms' marginal cost of production. However, the real interest rate on the capital stock and the real wage paid to workers are factors that contribute to raising firms' marginal cost.

A.3.4 Price Determination

As in Gali, Lopez- Salido and Valles (2007), it is assumed that intermediate firms set nominal prices in a staggered manner, according to the stochastic time-dependent rule proposed by Calvo (1983). Define θas being the probability of keeping prices constant and $(1-\theta)$ the probability of changing prices. Each firm resets its prices with probability $(1-\theta)$ in each period, regardless of the time elapsed since the last adjustment, in order to maximize the present value of future profits. Therefore, in each period, a proportion $(1-\theta)$ of producers reset their prices, while a fraction θ keep their prices unchanged, according to the following expression:

$$P_t(i) = P_{t-1}(i) \ (A.35)$$

Following Calvo (1983), equation (A.36) below shows that when a firm i receives a signal to optimally set a new price, that firm chooses the price that maximizes the discounted value of its profits, conditional on the chosen price being effective. Therefore, with probability $(1-\theta)$, a firm i that resets its price in period t will seek to solve the following maximization problem:

$$\max_{P_t^*} E_t \sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k}(i) \left[\left(\frac{P_t^*}{P_{t+k}} \right) - MC_{t+k} \right] \right\} \quad (A.36)$$

Subject to the sequence of demand constraints (or demand curve):

$$Y_{t+k}(i) = \left(\frac{P_t^*}{P_{t+k}} \right)^{-\varepsilon} Y_{t+k} \quad (37)$$

where the stochastic discount factor $\Lambda_{t,t+k}$is obtained from equation (A.12), since the firms belong to Ricardian individuals. The firm takes as given the trajectories of MC_{t+k}, $P_{t+k}$and Y_{t+k}. For any period $k \geq 0$, in which the producer of intermediate goods that has a chance ($1 - \theta$) of redefining prices in period t will maintain that price. The term P_t^*represents the price chosen by the firms that redefine their prices in period t . Inserting restriction (A.37) into the objective function (A.36), we obtain:

$$\max_{P_t^*} E_t \sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,t+k} \left(\frac{P_t^*}{P_{t+k}} \right)^{-\varepsilon} Y_{t+k} \left[\left(\frac{P_t^*}{P_{t+k}} \right) - MC_{t+k} \right] \right\} \quad (A.38)$$

where $MC_{t+k}$is the marginal real cost, while the parameter θrepresents the probability that the price P^*chosen at t will still apply in later periods. Equation (38) represents the "expected discounted sum" of all profits that the price setter will make conditional on his choice of t $P_t^*$and weighted by how likely P_t^*it will be to remain in place in future periods.

Since all firms that adjust price at t face the same decision problem, that is, there are no firm-specific state variables, each firm chooses the same optimal price P_t^*. The first-order condition of this problem is given by:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k}(i) \left[\frac{P_t^*}{P_{t+k}} - \mu^p MC_{t+k} \right] \right\} = 0 \quad (A.39)$$

Equation (A.39) shows that the price set by firm *i* at time *t* is a function of expected future marginal costs. The price will be a markup on these weighted marginal costs.

According to Gali, Lopez- Salido and Valles (2007), the parameter μ^p described in equation (A.40) below is the frictionless gross price markup, obtained from the firm's maximization problem, being the only one that prevails in the steady state of zero inflation, so that:

$$\mu^p \equiv \varepsilon/(\varepsilon-1) \quad (A.40)$$

Finally, through the law of large numbers, the equation that describes the dynamics of the aggregate price level is given by:

$$P_t = [\theta P_{t-1}^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}} \quad (A.41)$$

where P_t^* is the optimal price symmetrically chosen by those firms that are authorized to set prices in period *t*. Dividing both sides of equation (A.41) by P_{t-1}, we have:

$$\Pi_t^{1-\varepsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\varepsilon} \quad (A.42)$$

where $\Pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate between $t-1$ and t, and P_t^* is the price set in period *t* by firms that re-optimize their prices in that period. Equation (42) shows that all firms will choose the same price since they face an identical problem. Note that in the steady state with zero inflation, $P_t^* = P_{t-1} = P_t$, for all t . Log-linearizing equation (42) around $\Pi_t = 1$ and $P_t^*/P_{t-1} = 1$, we have the following expression for inflation:

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}) \quad (A.43)$$

According to Gali (2008, chap. 3, p. 44), equation (43) shows that inflation results from the fact that firms reoptimize in a given chosen period a price that differs from the average price of the economy in the previous period. Therefore, in order to understand the evolution of inflation over time, one must analyze the factors underlying price setting by firms.

A.4 Natural Product Level

According to Gali (2008, chap. 3, p. 48), the natural level of output, represented by y_t^n, is defined as the equilibrium level of output under flexible prices and wages, as well as imperfect competition, and is expressed by:

$$y_t^n = \psi_{y,t}^n \tilde{a}_t + \chi_y^n \tilde{k}_t + \upsilon_{y,t}^n + \varpi_{y,t}^n \quad (A.44)$$

Where :

$$\psi_{y,t}^n \equiv \gamma_c\left(\varphi + \tilde{k}_t^\alpha\right)/[\sigma(1-\alpha) + \gamma_c(\varphi + \alpha)]$$

$$\upsilon_{y,t}^n \equiv -\gamma_c(1-\alpha)\mu^p/[\sigma(1-\alpha) + \gamma_c(\varphi + \alpha)]$$

$$\chi_y^n \equiv \gamma_c\varphi\alpha/[\sigma(1-\alpha) + \gamma_c(\varphi + \alpha)]$$

$$\varpi_{y,t}^n \equiv \sigma(1-\alpha)(\gamma_i\tilde{\imath}_t + g_t)/[\sigma(1-\alpha) + \gamma_c(\varphi + \alpha)]$$

Following the macroeconomic literature, the output gap is defined as the deviation between output and the natural level of output that would prevail with full price and wage flexibility in the steady state, and is represented by $\hat{y}_t = \tilde{y}_t - y_t^n$.

Expression $(A.44)$ arises from the problem of minimizing the costs of the firm producing intermediate goods under imperfect competition and from the problem of maximizing household consumption [5]. Note that, when $\mu^p = 0$(perfect competition), the natural level of output corresponds to the equilibrium level of full employment output in classical economics. The equilibrium dynamics of output are determined independently of monetary policy; in other words, monetary policy is neutral with respect to full employment output, which fluctuates in response to changes in technology and the capital stock.

The presence of market power on the part of firms has the effect of reducing the level of output uniformly over time, without affecting its sensitivity to changes in technology.

[5] Its derivation is described in detail in Appendix D of this study.

A.5 Balanced Budget Rule

The government follows a balanced budget rule given by the following budget constraint:

$$R_t^{-1}B_{t+1} = B_t - P_t[T_t - G_{t-1}] \quad (A.45)$$

Where $P_t[T_t - G_{t-1}]$is the primary budget surplus in relation to past expenditure. Note that total tax revenue is one of the fiscal policy instruments that reacts to the output gap, either through lump -sum taxation or through distortionary taxation.

The term $G_{t-1}$is lagged government spending, which is justified by capturing inertia, i.e., budgetary rigidity in Brazilian fiscal policy. Several studies have shown that the increase in mandatory expenditures, constitutional and legal transfers, the obligation to apply minimum resources in areas such as health and education (Constitutional Amendment No. 29/2000 and Article No. 212 of the Federal Constitution) and the creation of a series of revenues linked to certain expenditures contribute to an increase in budgetary rigidity, resulting in a strong stagnation of fiscal policy. In addition, the phenomenon of budgetary rigidity may be associated with problems of lag in the implementation of macroeconomic stabilization policies, due to there being an internal gap, i.e., a time lag between the recognition of the economic shock and the implementation of fiscal measures in response to this shock. For example, in Brazil, decisions on spending and taxation must involve the participation of the Federal Legislative Branch (National Congress) and the Federal Executive Branch through their competent bodies, which makes the legislative process more time-consuming.

A.6 Market Equilibrium

In market equilibrium, consumption is a Dixit-Stiglitz type CES aggregator of composite consumption defined over the output of firms:

$$C_t^h = \left(\int_0^1 C_t^h(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right)^{\frac{\varepsilon}{\varepsilon-1}}, \qquad h = o, r \quad (A.46)$$

Regarding equilibrium in the factor market, the labor market requires that each resident provide a quantity of labor $N_t$that is equal to the sum of the labor supplied by each firm j:

$$N_t = \int_0^1 N_t(j)dj \quad (A.47)$$

On the other hand, complete utilization of capital is observed:

$$K_t = \int_0^1 K_t(j)dj \quad (A.48)$$

The stationary competitive equilibrium for this autarchic economy is defined as being a set of allocations $\{C_t^o, C_t^r, I_t^o, N_t^o, N_t^r, K_t^o, T_t^o, T_t^r, D_t^o, B_t, B_{t+1}, G_t\}_{t=0}^{\infty}$and price vectors for $\{P_t, P_t^*, W_t, R_t^k, MC_t\}_{t=0}^{\infty}$, with an economic policy based on government spending rules, $\{g_t^o, g_t^r\}_{t=0}^{\infty}$, which respond to their lagged terms, the stock of public debt and fluctuations in the level of economic activity, as well as a monetary policy that follows a Taylor rule, such that it jointly satisfies:

(i) Optimizing consumers maximize their expected utility subject to the sequence of budget constraints: equations (A.12) and (A.13) are satisfied;

(ii) Rule - of - thumb consumers consume all their disposable income: equation (A.22) is satisfied;

(iii) Markets Clear: equations (A.23), (A.24), (A.25), (A.26) and (A.27) are satisfied;

(iv) Firms producing intermediate goods minimize costs: equation (A.33) is satisfied;

(v) The natural level of output is defined as the equilibrium level of output under flexible prices and wages: equation (A.44) is satisfied;

(vi) The government budget constraint is balanced in each period: equation (A.52) is satisfied;

(vii) Equations (A.53), (A.54), (A.55) and (A.56) are satisfied;

Appendix B – Observable Variable Links

Variable Description		Link
Interest rate – Selic target		https://www3.bcb.gov.br/sgspub/consultarvalores/consultarValoresSeries.do?method=consultarValores
Inflation Expectations		https://www3.bcb.gov.br/expectativas2/#/consultaSeriesEstatisticas
Economic Uncertainty Index		https://extra-ibre.fgv.br/IBRE/sitefgvdados/consulta.aspx
National Treasury Result		https://www.gov.br/tesouronacional/pt-br/estatisticas-fiscais-e-planejamento/resultado-do-tesouro-nacional-rtn
Structural Primary Result		https://www12.senado.leg.br/ifi/dados/arquivos/resultado-fiscal-estrutural/view
Future Interest Rate		https://www2.bmf.com.br/pages/portal/bmfbovespa/boletim1/SistemaPregao1.asp?pagetype=pop&caminho=Resumo%20Estat%EDstico%20-%20Sistema%20Preg%E3o&Data=30/03/2023&Mercadoria=DI1
Quarterly inflation of free prices		https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries
Quarterly inflation measured by IPCA		https://sidra.ibge.gov.br/Table/7061
CRB – Commodity Research Bureau		https://www.bloomberg.com/quote/CRY:IND?embedded-checkout=true
Exchange rate variation in the quarter		https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries

Child 1+2 (0-10S, 90W-80W)		https://psl.noaa.gov/data/correlation/nina1.data
Inflation target announced by the National Monetary Council (CMN)		https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries
Brent Oil in US		https://br.financas.yahoo.com/quote/BZ%3DF/history?period1=1200960000&period2=1705881600&interval=1d&filter=history&frequency=1d&includeAdjustedClose=true
Quarterly inflation of administered prices		https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries
Inflation target announced by CMN and softened		https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries
Credit Default Swaps for 5-year Brazilian debt securities		https://www.bloomberg.com
Growth rate Qoq		https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9300-contas-nacionais-trimestrais.html?=&t=series-historicas&utm_source=landing&utm_medium=explica&utm_campaign=pib#evolucao-taxa
US Treasury Federal Funds Effective Rate		https://fred.stlouisfed.org/series/FEDFUNDS

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