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Keywords: Business Cycle Accounting; Brazilian recessions; DSGE

JEL Codes: E32

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1 Introduction

After troubled decades of high inflation, low economic growth and six monetary stabilization attempts, Brazil started the 2000s amid low economic growth rates. Since 2002, however, the country had experienced a positive economic cycle due to, among other factors, the favorable external environment and a commodity boom. In this context, the Brazilian economy experienced growth annual average of 3.91% between 2002 and 2010, above the 2.69% growth rate observed for the group of Latin American countries excluding Brazil.

Among the possible causes for this behavior, the adoption of countercyclical economic policies during the 2008 Great Recession stands out. Compared to developed countries, the Brazilian economy was little affected by adverse developments in the world economy, and presented average growth of 4.11% between 2008 and 2011, compared to 3.25% in the rest of the world. In that context, despite having its growth decelerating, from 5.09% in 2008 to -0.12% in 2009, the country grew again 7.52% in 2010.

From 2012 onward, however, Brazil experienced a deterioration in its fiscal accounts and, against the grain of the world, entered one of the worst recessions in its history. The average annual growth of -2.10% and the increase in unemployment of 6.50% in 2012 to 12.00% between 2014 and 2016 reflect the severity of the crisis the Brazilian economy went through. As a result, the average growth was 0.70% per year for the period of 2011 to 2019, compared to 2.03% of its Latin American peers.

Given this quick background, the present paper aims to quantitatively measure the economic distortions present in the Brazilian economy between 2002 and 2019. In addition, the objective is also to analyze the relative impacts on the product, hours worked and investment during the 2014 Crisis, and contrast them with the period of the 2008 Crisis. For this, this paper will use the analytical framework of Business Cycle Accounting (BCA), developed by Chari, Kehoe e McGrattan (2007).

BCA introduces four time-varying wedges in a DSGE (Dynamic Stochastic General Equilibrium), which represent frictions in productivity (efficiency wedge), in the labor market (labor wedge), in the capital market (investment wedge) and government spending or net exports (government wedge). Each wedge acts in a specific micro-founded decision of the model: production, intertemporal choice between work and leisure, an Euler equation and a budget constraint, respectively.

By construction, the wedges are able to jointly reproduce the variables observed from the model. Thus, a linear decomposition is performed after the estimation of wedges in order to determine which wedge, or which combination of wedges, is most relevant to explain observed economic fluctuations. For this, simulations of the variables of interest are performed by allowing only one wedge to be able to vary at a time, and keeping all the others constant and equal to their steady state values. From the comparison of these simulations, it is possible to determine the relative importance of each distortion [Brinca, Costa-Filho e Loria (2020)].

As highlighted by Chari, Kehoe e McGrattan (2007), the BCA, in addition to the of wedge accounting, described above, is also useful to guide researchers in the work of identifying relevant distortions to explain product fluctuations in neoclassical growth models. Once identified, it is possible to choose a model capable of capturing them to the detriment of less relevant ones.

This paper, therefore, intends to contribute to the literature in two ways: 1) provide a quantitative analysis for the economic distortions experienced by the Brazilian economy between 2002 and 2019, focusing on the recessions of 2008 and 2014; and 2) determine the main distortions capable of capturing product movements, hours worked and investment, in order to identify the most suitable class of models to explain the fluctuations of the analyzed period.

The text is arranged as follows. Section 2 reviews the literature on BCA and discusses the main results obtained from this framework so far. Section 3 details the analytical framework on which our paper is based, and is subdivided in order to present the model (Subsection 3.1), the data (Subsection 3.2) and the parameters used (Subsection 3.3). Later, in Section 4, Subsections 4.1 and 4.2 discuss the main results on the behavior of the modeled distortions and on the contrast between the episodes covered, respectively. Finally, Section 5 presents the final considerations.

2 Literature review

The first generation of Dynamic Stochastic General Equilibrium (DSGE) models, known as Real Business Cycles (RBC) models, was developed by Kydland e Prescott (1982). Based on a neoclassical model of growth, its standard method consists of explaining economic fluctuations driven by exogenous shocks of technology, and downplaying the relevance of nominal shocks.

However, Brinca, Costa-Filho e Loria (2020) argue that these models do not perform well when contrasted against the data. According to the authors, there are two possible reasons for this: the presence of measurement errors in the aggregate variables of the economy or the fact that these models are not able to capture the complexity of the real world, as the presence of price rigidities, frictions in the labor market and financial frictions.

Thus, Business Cycle Accounting (BCA) guides the development of more empirically relevant models. Developed by Chari, Kehoe e McGrattan (2007), the BCA captures short-term economic fluctuations and contrasts them with a "prototype model of economic growth", which contains wedges that vary over time and that have functions similar to the functions of productivity, the labor tax, the tax on investment and government spending, in affecting the optimal decisions of families and firms. These wedges will be denoted, from now on, by efficiency wedge, labor wedge, investment wedge and government wedge.

As the wedges, by construction, are able to reproduce all the fluctuations of the economy, it is possible to reinsert them individually and together in the model in order to determine which wedges (or combinations of wedges) are most relevant to explain business cycles. In addition to helping to understand short-term fluctuations, the BCA is also useful in establishing equivalences from the mapping of wedges in several more detailed model frictions. Table 1 presents an overview of the literature of wedges mapping in Real Business Cycles models, and serves to illustrate how diverse can be the market frictions and distortions captured by this class of models.

Table 1 – Literature on the mapping of wedges

Wedge	**Mapping**	**Reference**
Efficiency	Production units subject to idiosyncratic shocks	Lagos (2006)
Efficiency	Establishments with different productivities	Restuccia e Rogerson (2008)
Efficiency	Productivity from work practices	Schmitz (2005)
Efficiency	Credit limits and amplifying asset price shocks	Kiyotaki e Moore (1997)
Efficiency	Labor and investment frictions with technology shocks	Zanetti (2008)
Efficiency	More efficient financial intermediation increasing growth	Kim (2014)
Efficiency	Impacts of import price shocks on output and productivity	Lu (2013)
Efficiency	Working capital restriction	Christiano, Gust e Roldos (2004)
Efficiency	Advance-payment restriction	Chari, Kehoe e McGrattan (2005)
Efficiency	Financial frictions	Mendoza (2010)
Labor	Wage rigidity	Bordo, Erceg e Evans (2000)
Labor	Union and antitrust policy shocks	Cole e Ohanian (1999)
Labor	Price and wage markups	Gali, Gertler e Lopez-Salido (2007)
Labor	Search frictions	Hall (1997), Cheremukhin e Restrepo-Echavarria (2014) e Skibińska (2016)
Labor	Home production	Karabarbounis (2014)
Labor	Intangible capital	Gourio e Rudanko (2014)
Labor	Taxes and subsidies affecting the work-leisure relationship	Mulligan (2002)
Labor	Working capital on labor	Neumeyer e Perri (2005)
Labor	Cash-in-advance restriction on consumer goods	Neumeyer e Perri (2005)
Labor	Advance-payment restriction	Chari, Kehoe e McGrattan (2005)
Labor	Financial frictions	Mendoza (2010)
Investment	Credit market with agency costs	Carlstrom e Fuerst (1997)
Investment	Adjustment costs	Inaba e Nutahara (2009) e Kydland e Prescott (1982)
Investment	Financial accelerator: credit market, money and price rigidity	Bernanke, Gertler e Gilchrist (1999) e Gali, Gertler e Lopez-Salido (2007)
Investment	Shocks in capital accumulation	Cooper e Ejarque (2003)
Investment	Rational Inattention	Tutino (2011)
Investment	Financial frictions	Mendoza (2010)
Investment	Technological change in investment	Greenwood, Hercowitz e Krusell (1997)
Investment	Bank collateral restrictions	Kiyotaki e Moore (1997) e Gertler e Kiyotaki (2010)
Investment	Restrictions on foreign borrowing	Chari, Kehoe e McGrattan (2005)
Government	Foreign Credit Restrictions	Chari, Kehoe e McGrattan (2005)
Government	Incontingency	Mendoza (2006)
Asset market	Nominal equity tax	McGrattan (1999), Ireland (2004) e Smets e Wouters (2007)
Asset market	Limited participation in asset markets	Christiano e Eichenbaum (1992)
Monetary policy	Taylor rule deviations	McGrattan (1999), Ireland (2004) e Smets e Wouters (2007)
Monetary policy	Changes in inflation targets in regime changes	Gavin, Kydland e Pakko (2007)
Monetary policy	Financial frictions	Mendoza (2010)
Bond	Interest premium on international bonds	Mendoza (2010)
Bond	Collateral restriction	Mendoza (2006)
Bond	Financial frictions	Mendoza (2010)
International price	Limitations on international risk sharing	Baxter e Crucini (1995)
International price	Two countries and two goods economies	Backus, Kehoe e Kydland (1994)
International price	Tradables and nontradables	Stockman e Tesar (1990)
International price	Two countries economies with preference shocks	Stockman e Tesar (1990) e Wen (2007)

Source: Own tabulation from Brinca, Costa-Filho e Loria (2020), p. 35-36.

In this sense, Brinca, Costa-Filho e Loria (2020) highlight that the BCA approach extended in several dimensions, allowing this framework to capture such entire range of distortions that can be mapped to DSGE models. Beyond the BCA tradition, some methodological extensions were developed in order to contemplate wedges with other features, such as Monetary Business Cycle Accounting[1], Open- Economy Business Cycle Accounting,[2] and the International Business Cycle Accounting[3]. Such extensions, however, are beyond the scope of this paper, which considers the traditional BCA.

Chari, Kehoe e McGrattan (2007) applied the BCA to the United States with the objective of studying the causes of the economic fluctuations of two recessive episodes: the Great Depression of 1929 and the recession of 1982. For both episodes, the authors suggest that efficiency and labor wedges are able to reproduce most of the economic fluctuations from 1929 to 1939 and from 1979 to 1985. According to them, the investment wedge has, at best, a tertiary role, while government consumption wedge did not seem relevant to explain the analyzed fluctuations.

Cavalcanti (2007) applied the BCA to Portugal for the period from 1980 to 2000. According to the author, the procedure for accounting for fluctuations suggested that most part of the variations in output per worker can be explained by changes in the economic efficiency, which are reflected in the efficiency wedge. Cavalcanti (2007) uses as an example the episode of strong recovery of the Portuguese economy that followed the country's entry into European Union, in the early 1990s. Again, the labor wedge proved to be secondary and the investment wedge did not seem relevant to explain the studied fluctuations.

Kersting (2008) suggests that the labor wedge is also primarily responsible for explaining the economic fluctuations caused by the 1980s recession in the UK. The author analyzed the period from 1979 to 1989 based on the BCA methodology and concluded that, in addition to explaining much of the fluctuations in UK output, employment and investment, the improvement of the labor wedge contributed to the recovery of the product and the labor supply from 1984. According to Kersting (2008), there is evidence that this recovery occurred mainly as a result of labor reforms proposed by the government during this period.

Cho e Doblas-Madrid (2013) confirm the results presented so far in their study of a wide group of countries. The authors analyzed 23 episodes of financial crises from a sample of 13 countries, divided into two groups: Western (countries from Europe and Latin America) and Eastern (Asian countries). The study found evidence to suggest, like

[1] It introduces wedges that allow capturing the difference between nominal and real variables of the economy. For more details, see Brinca (2013) and Šustek (2011).

[2] It introduces external indebtedness via the introduction of a bond wedge. For more details, see He, Chong e Shi (2009), Hevia (2014), Lama (2011), Otsu (2010b) and Manfredini (2020).

[3] It introduces relationships between two countries via international price wedge. For more details, see Hirata e Otsu (2016), Otsu (2010a) and Ohanian, Restrepo-Echavarria e Wright (2013).

all the other cases noted above, that efficiency wedges showed greater power in most cases. However, the authors emphasize that the secondary wedges vary from episode to episode. More specifically, investment wedges proved to be more relevant than labor wedges in Asian countries, while the opposite was observed in European and Latin American countries.

Similar conclusions were obtained by Simonovska e Söderling (2015), who applied the BCA for Chile for the period 1998 to 2007. The authors also found evidence that suggested a better performance of efficiency and labor wedges in explaining the fluctuations of the observed series. Again, the investment wedge was tertiary in the study and the government wedge didn't seem relevant. Results like this suggest, according to the authors, the need for economic policies that prioritize the reduction of rigidities in the labor market and incentives for private credit.

More recently, Brinca *et al.* (2016) applied the same methodology to analyze the Great Recession of 2008 and the recession of 1980 in OECD countries. The authors concluded that, with the exception of the United States, Spain, Ireland and Iceland, the efficiency wedge was able to better explain the fluctuations of the Great Recession. In addition, the authors concluded that the efficiency wedge was more relevant to explain the fluctuations observed in the Great Recession than those observed in the 1980s recession. The opposite was verified for the investment wedge.

In the only study we found that includes Brazil, Graminho (2006) analyzed the economic fluctuations experienced by this country between 1980 and 2000 under the traditional BCA framework, and concluded that productivity shocks were able to better explain the fluctuations in output, investment and consumption in the 1980 decade. Among the factors that may have contributed to this, according to the author, are the creation of state-owned companies and the shutdown of the economy in response to the oil shock of 1974, whose consequences were the creation of barriers to entry imposed on foreign competition and less efficient capital production. As for the period from 1990 to 2000, Graminho (2006) suggests that the labor wedge was able to better explain the fluctuations of the variables under study. According to the author, this occurs because there is evidence of recovery of technology as a result of trade liberalization, as well as an increase in distortions in the labor market after the introduction of the 1988 Brazilian Constitution.

In view of all the studies presented, Table 2 summarizes the main references present in the literature on BCA and its ramifications.[4]

[4] To avoid excessive repetition, some of the references presented in the table were omitted from the text.

Table 2 – Summary of the BCA literature and ramifications

Reference	**Countries**	**Periods***	**Ranking of wedges****
Ahearne, Kydland e Wynne (2006)	Ireland	1973-2002	Efficiency > labor
Bridji (2013)	France	1896-1939	Efficiency > labor = investment
Brinca (2014)	OECD	1970-2011	Efficiency > labor
Brinca *et al.* (2016)	OECD	2008-2015	Efficiency > labor = investment
Cavalcanti (2007)	Portugal	1979-2000	Efficiency > labor
Cavalcanti *et al.* (2008)	Argentina	1992-2006	Efficiency > government
Chadha e Warren (2013)	UK	1974-2010	Efficiency > investment
Chakraborty (2009)	Japan	1980-2000	Efficiency = investment > labor
Chakraborty e Otsu (2013)	BRICs	1990-2009	Efficiency = investment > labor
Chari, Kehoe e McGrattan (2007)	USA	1929-2004	Efficiency > labor > investment
Cho e Doblas-Madrid (2013)	13 countries	23 episódios	Efficiency > labor > investment
Cunha (2006)	Japan	23 episódios	Efficiency > investment
Elgin e Çiçek (2011)	Turkey	1968-2009	Efficiency > labor
Gerth e Otsu (2017)	European countries	2008-2014	Efficiency > labor = investment
Graminho (2006)	Brazil	1980-2000	Efficiency = labor
Iskrev (2013)	Portugal	1998-2012	Efficiency > labor
Kersting (2008)	UK	1979-1989	Efficiency = labor > investment
Kobayashi e Inaba (2006)	Japan	1981-2003	Labor > efficiency = investment
Kolasa (2013)	European Countries	1995-2011	Efficiency > labor > investment
Ljungwall e Gao (2009)	China and India	1978-2006	Efficiency > labor = investment
López e García (2016)	Spain	1976-2012	Efficiency
Meza (2008)	Mexico	1994-2000	Efficiency > labor
Orsi e Turino (2014)	Italy	1982-2008	Labor > efficiency
Saijo (2008)	Japan	1921-1936	Efficiency > labor = investment
Sarabia (2007)	South Korea	1982-2005	Investment > labor > efficiency
Sarabia (2008)	Mexico	1987-2006	Efficiency > labor > investment
Simonovska e Söderling (2015)	Chile	1998-2007	Efficiency > labor = investment
Vasilev (2017)	Bulgaria	1999-2014	Efficiency > labor

Source: Own tabulation from Brinca, Costa-Filho e Loria (2020), p. 53-54.
Note: When more than one period was studied, the most comprehensive of them was considered.

3 Methodology

This paper will make use of the methodological framework developed by Chari, Kehoe e McGrattan (2007)[5], which consists of an analytical framework capable of associating the short-term fluctuations observed in an economy to certain distortions, represented by the wedges. In a canonical neoclassical model of growth, wedges are introduced associated with productivity, labour, investment and government spending in the economy. Then, they are inserted individually as well as jointly in the model in order to analyze their marginal and joint contribution to explain a given shock. The model is described in the sequence.

[5]The choice of the traditional version of BCA over the version for *small-open economies*, as developed, for example, by Lama (2011), was due to the unavailability of good data for adjustment costs, which are necessary to induce stationarity in the open economy model.

3.1 Model

Our framework closely follows Chari, Kehoe e McGrattan (2007). The representative family is an expected utility maximizer, which depends positively on per capita consumption, c_t, and negatively on per capita labor, l_t, and is discounted over time by a factor $0 < \beta < 1$. N_t denotes the working-age population of the economy, which grows at the rate g_n. The family solves the following intertemporal problem:

$$\max_{\{c_t,x_t,l_t\}} E\sum_{t=0}^{\infty}\beta^t U(c_t, 1-l_t)N_t \tag{1}$$

subject to the constraints

$$(1+\tau_{c_t})c_t + (1+\tau_{xt})x_t = (1-\tau_{kt})r_t k_t + (1-\tau_{lt})w_t l_t + \tau_{kt}\delta k_t + T_t \tag{2}$$

$$N_{t+1}k_{t+1} = [(1-\delta)k_t + x_t]N_t \tag{3}$$

$$c_t, x_t \geq 0 \ \ \forall t \tag{4}$$

where x_t, k_t, r_t, w_t e T_t denote, respectively, per capita investment, per capita capital level, capital rental rate, wage, and lump-sum tax in a given period t of the economy. Furthermore, τ_{ct}, τ_{xt}, τ_{kt} e τ_{lt} denote taxes on consumption, investment, capital and labor, respectively. The capital stock depreciation parameter of this economy is denoted by $0 < \delta < 1$.

The representative price-taking firm must choose the optimal quantities of aggregate capital, K_t, and aggregate labor, L_t, that it will acquire in order to maximize its profit, and for that solves the following static problem:

$$\max_{\{K_t,L_t\}} F(K_t, Z_t L_t) - r_t K_t - w_t L_t \tag{5}$$

where Z_t denotes an exogenous labor-increasing productivity variable, which grows at the rate g_z. In addition, the government must satisfy the following budget constraint:

$$G_t + N_t T_t = \tau_{kt}(r_t - \delta)N_t k_t + \tau_{lt} w_t l_t N_t + \tau_{ct} N_t c_t + \tau_{xt} N_t x_t \tag{6}$$

where G_t denotes government spending. In equilibrium, the following must hold:

$$N_t(c_t + x_t) + G_t = F(K_t, Z_t L_t) \tag{7}$$

$$N_t k_t = K_t \tag{8}$$

$$N_t l_t = L_t \tag{9}$$

The first order conditions for the consumer problem are:

$$\frac{U_2(\hat{c}_t, 1-l_t)}{U_1(\hat{c}_t, 1-l_t)} = \frac{1-\tau_{lt}}{1+\tau_{ct}}\hat{w}_t \tag{10}$$

$$\frac{1+\tau_{xt}}{1+\tau_{ct}}U_1(\hat{c}_t, 1-l_t) = \hat{\beta}E_t\left[\frac{U_1(\hat{c}_{t+1}, 1-l_{t+1})}{1+\tau_{ct+1}}\{(1-\tau_{kt+1}r_{t+1})r_{t+1}+\delta\tau_{kt+1}+(1-\delta)(1+\tau_{xt+1})\}\right], \tag{11}$$

where $\hat{\beta} = \beta\frac{h(1+g_z)}{(1+g_z)}$, and $h(.)$ is a function of $1+g_z$, which will depend on the choice of the functional form for utility. Furthermore, for any variable x, one defines $\hat{x}_t \equiv \frac{X_t}{N_t z_0(1+g_z)^t}$.

On the firm's side, the first-order conditions are:

$$r_t = F_1(\hat{k}_t, z_t l_t) \tag{12}$$

$$\hat{w}_t = F_2(\hat{k}_t, z_t l_t)z_t \tag{13}$$

The resource constraint of the economy in per capita terms can be written as:

$$\hat{c}_t + \hat{g}_t + \hat{x}_t = F(\hat{k}_t, z_t l_t) \tag{14}$$

Following the literature, the following functional forms are assumed for the production function of production and for utility, respectively:

$$F(K, ZL) = K^\theta (ZL)^{1-\theta} \tag{15}$$

$$U(c, 1-l) = \ln(c) + \psi\ln(1-l) \tag{16}$$

where $0 < \theta < 1$ denotes the share of capital in the economy's income, and$\psi > 1$ denotes a parameter of preference for leisure over labor. With this, it is possible to derive the following first order conditions[6]:

$$\hat{c}_t + \hat{g}_t + (1+g_z)(1+g_n)\hat{k}_{t+1} - (1-\delta)\hat{k}_t = \hat{y}_t \tag{17}$$

[6]For details of the derivations, see Kehoe, Chari e McGrattan (2006).

$$\hat{y}_t = \hat{k}_t^{\theta}(z_t l_t)^{1-\theta} \tag{18}$$

$$\frac{\psi \hat{c}_t}{1-l_t} = (1-\tau_{lt})(1-\theta)\frac{\hat{y}_t}{l_t} \tag{19}$$

$$\frac{(1+\tau_{xt})}{\hat{c}_t} = \hat{\beta} E_t \frac{1}{\hat{c}_{t+1}}\left[\theta\frac{\hat{y}_{t+1}}{\hat{k}_{t+1}} + (1-\delta)(1+\tau_{xt+1})\right]. \tag{20}$$

3.1.1 Computing the equilibrium

As highlighted by Kehoe, Chari e McGrattan (2006), there are two methods from which it is possible to compute the equilibrium of the model: non-linear and log-linear. For this paper, the equilibrium computation will be done using the log-linear method[7].

Applying the log-linearization procedure to the steady-state of equations (17)-(19), and adopting the notation in which, for any variable x, $\hat{x}_t \equiv \dfrac{X_t}{N_t z_0 (1+g_z)^t}$, we have:

$$\ln l_t = \phi_{kt}\ln\hat{k}_t + \phi_{lz}\ln z_t + \phi_{ll}\tau_{lt} + \phi_{lg}\ln\hat{g}_t + \phi_{lk'}\ln\hat{k}_{t+1} \tag{21}$$

$$\ln\hat{y}_t = \phi_{yk}\ln\hat{k}_t + \phi_{yz}\ln z_t + \phi_{yl}\tau_{lt} + \phi_{yg}\ln\hat{g}_t + \phi_{yk'}\ln\hat{k}_{t+1} \tag{22}$$

$$\ln\hat{x}_t = \phi_{xk'}\ln\hat{k}_{t+1} + \phi_{xk}\ln\hat{k}_t \tag{23}$$

$$\ln\hat{c}_t = \phi_{ck}\ln\hat{k}_t + \phi_{cz}\ln z_t + \phi_{cl}\tau_{lt} + \phi_{cg}\ln\hat{g}_t + \phi_{ck'}\ln\hat{k}_{t+1} \tag{24}$$

where each ϕ is a function of the already known parameters of the economy[8]. For the capital stock, the first order dynamic condition (20) is used, (20), whose log-linearization procedure around the steady state results in a solution of the form:

$$\ln\hat{k}_{t+1} = \gamma_0 + \gamma_k\ln\hat{k}_t + \gamma_z\ln z_t + \gamma_l\tau_{lt} + \gamma_x\tau_{xt} + \gamma_g\ln\hat{g}_t \tag{25}$$

where the γ's are fitted to satisfy the log-linearization of (20)[9].

3.1.2 Maximum likelihood estimation

We can derive the wedges from the data and the model's analytical solution. The government wedge, $\hat{g}_t$, is calculated directly from the data, adding up government

[7] The non-linear method is beyond the scope of this paper. For more details, see Kehoe, Chari e McGrattan (2006), p. 5.

[8] For details of the log-linearized model, see Kehoe, Chari e McGrattan (2006), p. 14-17.

[9] For details, see Kehoe, Chari e McGrattan (2006), p. 14-17.

expenditures and net exports[10], as in Chari, Kehoe e McGrattan (2007). Efficiency and labor wedges,zt and (1 lt), respectively, are calculated from the production function and the consumption-leisure relationship, respectively. On the other hand, the investment wedge, $\frac{1}{1+\tau_{xt}}$, must be estimated, as it depends on future expectations.

The estimation procedure follows Chari, Kehoe e McGrattan (2007) and we assume that the stochastic process that governs the state follows an autoregressive vector VAR(1) for the event $s_t = (A_t, \tau_{lt}, \tau_{xt}, g_t)$ of the form:

$$s_{t+1} = P_0 + P s_t + \varepsilon_{t+1}, \tag{26}$$

where the ε_t shock is a white noise with covariance matrix $V = QQ'$. So, from the maximum likelihood method, we estimate the parameters of equations (21)-(25) to obtain the trajectories of the four wedges. More specifically, we want to estimate the following system in state space form:

$$\begin{aligned} X_{t+1} &= A\, X_t + B\, \varepsilon_{t+1} \\ Y_t &= C\, X_t + \omega_t \\ \omega_t &= D\, \omega_{t-1} + \eta_t, \end{aligned} \tag{27}$$

where

$$X_t = \left[\ln\hat{k}_{t+1}, \ln z_t, \tau_{lt}, \tau_{xt}, \ln\hat{g}_t, 1\right]', \tag{28}$$

$$Y_t = \left[\ln\hat{y}_t, \ln\hat{x}_t, \ln l_t, \ln\hat{g}_t\right] \tag{29}$$

$$A = \begin{bmatrix} \gamma_k & \gamma_z & \gamma_l & \gamma_x & \gamma_g & \gamma_0 \\ 0_{4\times1} & & P & & & P_0 \\ 0 & & 0_{1\times4} & & & 1 \end{bmatrix}, \tag{30}$$

$$B = \begin{bmatrix} 0_{1\times4} \\ Q \\ 0 \end{bmatrix}, \tag{31}$$

[10] The rationale for this choice is given by Chari, Kehoe e McGrattan (2005), where the authors show that there is equivalence between open and closed economy models that consider the government wedge.

$$C = \begin{bmatrix} \phi_{yk} & \phi_{yz} & \phi_{yl} & 0 & \phi_{yg} & \phi_{y0} \\ \phi_{xk} & 0 & 0 & 0 & 0 & \phi_{x0} \\ \phi_{lk} & \phi_{lz} & \phi_{ll} & 0 & \phi_{lg} & \phi_{l0} \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} + \begin{bmatrix} \phi_{yk'} \\ \phi_{xk'} \\ \phi_{lk'} \\ 0 \end{bmatrix} \begin{bmatrix} \gamma_k & \gamma_z & \gamma_l & \gamma_x & \gamma_g & 0 \end{bmatrix}'. \quad (32)$$

Note that the expression for ω_t describes the serial autocorrelation process, so that D is formed by the parameters of this process, $E\Big[\eta_t\eta_t'\Big] = R$ e $E\Big[\varepsilon_t\eta_s'\Big] = 0$, $\forall t, s$. We can rewrite the system as follows:

$$X_{t+1} = A\,X_t + B\,\varepsilon_{t+1} \quad (33)$$

$$\bar{Y}_t = \bar{C}X_t + CB\varepsilon_{t+1} + \eta_{t+1}, \quad (34)$$

where $\bar{Y}_t \equiv Y_{t+1} - DY_t$.

The log-likelihood function to be maximized is given by expression (355), where Θ is a vector that contains the parameters to be estimated, u_t is an innovation vector and Ω_t its covariance matrix[11].

$$L(\Theta) = \sum_{t=0}^{T-1} \Big\{ \ln\mid\Omega_t\mid + \mathrm{tr}\Big(\Omega_t^{-1}u_tu_t'\Big) - \ln\mid\frac{\partial f(Z_t,\Theta)}{\partial Z_t}\mid \Big\} \quad (35)$$

3.2 Data

In order to be able to implement the described methodology, data from the main observable aggregates of the economy is colletcted. The observables will represent income, investment, hours worked, government spending, private consumption and the population of the economy.

In the construction of these series, data from the Gross Domestic Product (GDP), Consumption, Government Spending, Gross Fixed Capital Formation, Exports and Imports of Goods and Services, Taxes on Goods and Services, Employed Population, Adult Population, and Average Hours Worked by Worker were collected. While the Average Hours Worked series was taken from the Penn World Table 10.0, all the other series were taken from the Brazilian Institute of Economics and Statistics (IBGE). Appendix A details the sources used and the treatments performed.

3.3 Calibrated and estimated parameters

Population and technology growth rates, g_n e g_z, respectively, were calculated according to the observed variables used in the model. The parameters related to capital

[11]Para detailed derivations, see Kehoe, Chari e McGrattan (2006).

stock depreciation (δ), intertemporal discount factor (β), labor weight in the utility funcion (ψ), and share of capital in total income (θ) were calibrated according to Graminho (2006). Appendix B details the mentioned calculations and the values used.

Given the calibrated parameters, the parameters P_0, P e V of the autoregressive vector VAR(1) of the process that governs the movement of wedges are estimated using the maximum likelihood procedure. For this, the decision rules of the log-linear model are used as well as data on output, consumption, income, investment, government spending and net exports.

4 Results

Having quarterly data from Brazil for the period from 2002 Q1 to 2019 Q4, the calibrated model was used to decompose the economic fluctuations observed in the period. The main results are discussed in the following two subsections: in the first one, the fluctuations observed in the modeled distortions (wedges) are analyzed and related to the Brazilian economy; in the second, the results of the one-wedge economies and the most promising ways to model fluctuations from the 2008 and 2014 recessions in Brazil are presented.

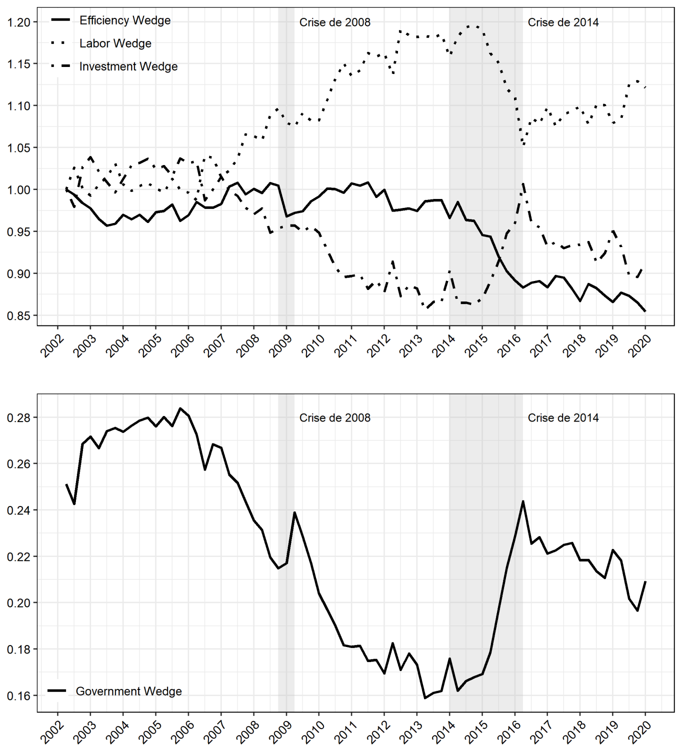
4.1 Wedges

Figure 1 shows the evolution of efficiency, labor, investment and government wedges. In the case of the latter, its share in the detrended per capita income, $\hat{y}_t$, is shown. In that sense, we show A_t, $(1 - \tau_{lt})$, $1/(1 + \tau_{xt})$ and $\hat{g}_t/\hat{y}_t$, respectively, for each wedge. Due to the difference of scales and higher volatility, the government wedge is presented in a separate panel. All variables were normalized in relation to their first observation, so that 2002 Q1 = 1.

In Figure 1, it is possible to observe a worsening of the efficiency wedge in the two periods that coincide with the two most recent economic recessions that hit the Brazilian economy: the 2008 Great Recession and the 2014 recession. Between 2007 Q2 and 2008 Q4, the efficiency wedge declined by 3.96% and, between 2014 Q1 and 2016 Q1, it declined by 10.33%.

It is important to highlight that, in addition to the difference in the intensity of the worsening of the efficiency wedge in the two episodes, it is also possible to notice a relevant difference in their behavior after each one of the periods. After the 2008 recession, the efficiency wedge experienced improvements and returned to the 2007 Q2 level in 2010 Q4. The same, however, did not happen in the 2014 crisis. After 2016 Q1, the efficiency wedge kept getting worse until it accumulated a decrease of 13.25% in 2019 Q4 compared to 2014 Q1.

Figure 1 – *Efficiency*, *Labor* e *Investment Wedges*



Source: Own elaboration

The worsening of the efficiency wedge from 2011 onwards may be correlated with the persistence of counter-cyclical economic policies introduced as a result of the 2008 recession, policies which became permanent from the beginning of the 2010s. According to Spilimbergo, Srinivasan e Walutowy (2018), the maintenance of these policies promoted a combination of adversities, such as market distrust, fall in private investment, deterioration of fiscal accounts, high inflation and interest rates, which put Brazil in one of the most severe and lasting recessions in its recent history.

Among these policies, the expansion of public financing through the National Bank for Economic and Social Development (BNDES) stands out. According to Almeida, Oliveira e Schneider (2014), the development bank was the protagonist of state policies adopted from 2003 with a view to promoting economic growth and, in 2011, it already had more than US$ 312 billion in assets. By way of contrast, this number is close to the US$ 338 billion from the World Bank, which operates worldwide.

The authors also point out that the BNDES' incentive structure works in order to prioritize loans to large companies, which are already well established in the market and who have broad access to private capital markets: "the officials from BNDES are partially compensated for the total disbursement of the bank and not for promoting diversification and innovation. Therefore, the bank's incentive structure reinforces the risk minimization bias when lending to large companies in traditional sectors". [p.18]almeidabndes.

Regarding the labor wedge, it is possible to observe a relatively constant increase starting in 2006 Q1. Up to its peak in 2014 Q3, the cumulative increase was 21.16%. Unlike the efficiency wedge, the labor wedge improved in the 2008 recession, increasing 5% between 2007 Q2 and 2008 Q2. In the 2014 crisis, however, there was a drop of 11.14% between 2014 Q1 and 2016 Q1, a period that coincides with the abrupt increase in unemployment, from 6.5% to 12.0%.

Despite the 2008 recession, the labor wedge continued to improve until it reached its highest in 2014 Q3, accumulating an improvement of 15.41% compared to that observed in 2007 Q2. This behavior differs from that observed in the efficiency wedge. Nonetheless, during the 2014 crisis, both showed significant declines. Still, while the efficiency wedge showed no improvement after 2016 Q1, the labor wedge accumulated a positive variation of 6.72% between 2016 Q1 and 2019 Q4.

The improvement in the labor wedge from 2006 is possibly related to the reduction of unemployment in Brazil. From 9.1% in 2002, the unemployment rate dropped to 6.1% in 2012, a reduction of 32%. In addition, Barbosa Filho, Pessôa e Veloso (2010) argue that this movement was accompanied by a reduction in the degree of informality in the Brazilian economy, which went from 43.6% in 2002 to 32.5% in 2012.

As shown in both panels in Figure 1, the investment and government wedges decreased during the 2008 recession and increased during the 2014 crisis. While the first accumulated variations of -1.87% between 2017 Q2 and 2008 Q2 and 16.41% between 2014 Q1 and 2016 Q1, the latter showed variations -9.33% and 50.48% during the same periods, respectively.

It is important to note, however, that unlike the two other wedges, the investment and government wedges have already shown negative oscillations since 2006 Q1, which persisted until the mid-2000s. While the investment wedge deteriorated 13.86% between 2006 Q1 and 2015 Q1, the government wedge reduced 40.29% between 2006 Q1 and 2014 Q1.

4.2 2008 and 2014 Recessions

In this subsection, one-wedge economies are introduced, which consist of the reproduction of a given variable with only one of the wedges active, keeping all the others constant and equal to their steady state values. With this, the objective is to determine the most relevant wedges to explain the fluctuations experienced by the Brazilian economy, in particular those of the 2008 and 2014 crises.

4.2.1 2008 Great Recession

Table 3 illustrates the peak-trough variations of the variables observed in the 2008 recession, as well as its components. That is, the percentage variation between the largest value of a given variable (peak) and its trough are shown. For this exercise, specifically, the third quarter of 2008 was assumed as the peak for all variables, and the quarter immediately preceding the first positive change observed in the series after the peak is taken as the trough, specified in the second column of Table 3. In addition, the columns ΔX, ΔX_A, ΔX_L, ΔX_X and ΔX_G report the observed X, the counterfactual X in an efficiency wedge economy, the counterfactual X in a labor wedge economy, the counterfactual X in an investment wedge economy and the counterfactual X in a government wedge economy.

Table 3 – Peak-through Variations and components during the 2008 recession

Variable (X)	Trough	ΔX	ΔX_A	ΔX_L	ΔX_X	ΔX_G
Output	2008 T4	-4.56	-3.10	-1.69	0.57	-0.34
Hours Worked	2009 T1	-3.87	-3.81	-3.00	0.98	2.04
Investment	2009 T1	-19.35	-20.63	-6.07	5.01	2.93

Source: Own elaboration.

It is possible to notice that the efficiency wedge maps the most relevant distortions to explain the fluctuations in output, hours worked and investment observed in the 2008 recession. For the analyzed period, the economy with only the efficiency wedge was able to reproduce approximately 68% of the drop in product, in addition to producing practically the same fluctuations in hours worked and in investment.

In the secondary level, the economy with only the labor wedge also performed well in reproducing fluctuations in output and worked hours, but was unable to replicate the fall in investment. Economies with only investment and government wedges did not show satisfactory results, and produced fluctuations in the opposite direction to those present in the observed variables.

In addition to the peak-through variation, the ϕ statistics was also computed, which is commonly reported in BCA studies to capture the correlation between a variable and its components computed from the one-wedge exercises. Equation (36) describes the correlation ϕ between a variable Y and one of its components, i, with $i = \{A, \tau_l, \tau_x, g\}$.

$$\phi_i^Y = \frac{1/\sum_t (y_t - y_{it})^2}{\sum_j (1/\sum_t (y_t - y_{jt})^2)} \tag{36}$$

As argued by Brinca *et al.* (2016), the use of the ϕ statistics for BCA is desirable because: 1) its domain belongs to the $[0, 1]$ interval, making interpretation simple; 2) when a wedge perfectly explains the fluctuations of a variable (ie, $y_t - y_{it} = 0\,\forall t$), then $\phi_i^Y = 1$;

and 3) because it is the inverse of the sum of squares of the residuals for each of the normalized wedges, with the sum of all the wedges being such that $\sum_i \phi_i^Y = 1$.

Table 4 shows the ϕ statistics for the components of output, hours worked and investment for the period 2008 Q2 to 2009 Q3[12]. It is noteworthy that the results confirm the peak-trough analysis for product and investment fluctuations, the efficiency wedge being the most decisive component to explain them, followed by the labor wedge. On the other hand, the ϕ statistics of the components of hours worked suggest that the labor wedge is best suited to explain the observed fluctuations, followed by the efficiency wedge.

Table 4 – ϕ statistics for the components of the observed variables: 2008 recession

ϕ_A^Y	$\phi_{\tau L}^Y$	$\phi_{\tau_x}^Y$	ϕ_g^Y	ϕ_A^L	$\phi_{\tau_L}^L$	$\phi_{\tau x}^L$	ϕ_g^L	ϕ_A^x	$\phi_{\tau_L}^x$	$\phi_{\tau_x}^x$	ϕ_g^x
0.67	0.20	0.07	0.06	0.17	0.74	0.04	0.05	0.67	0.19	0.07	0.07

Source: Own elaboration.

Figures 8, 9 and 10 in Annex A contrast, respectively, output, hours worked and investment with their components. The values were normalized so that 2008 Q2 = 1 and confirm the points discussed so far. As mentioned in the peak-trough analysis, the efficiency wedge is, in fact, a more determining factor in reproducing the fluctuations experienced by the observed variables, being able to predict almost perfectly all the falls caused by the 2008 recession.

In addition, Figure 9 justifies the low ϕ statistic for the efficiency component wedge of hours worked. It is possible to notice that, although the efficiency wedge economy reproduces the decline observed between 2008 Q2 and 2009 Q1, it overestimates the recovery of this variable from 2009 Q2, which does not happen in the labor wedge economy.

Finally, Figures 14, 15 and 16 in Annex B illustrate the exercise of contrasting the variables observed with a prototype economy that contains all but one wedges. For example, the no efficiency wedge economy reproduces the observed variables "turning off" the efficiency wedge. The results also confirm that investment and government wedges are the least relevant distortions in the reproduction of observed fluctuations.

Therefore, the exercises performed seem to suggest that models that incorporate distortions related to the efficiency and employment level of the economy are the most promising to explain the fluctuations experienced by output, hours worked and investment during the 2008 recession in Brazil.

4.2.2 2014 Crisis

Similar to what was done in the previous subsection, Table 5 summarizes the results of the peak-trough analysis for the period of the 2014 crisis. Again, the highest product

[12]Different from the peak-trough analysis, the ϕ statistic was computed including the post-crisis recovery period, following Brinca *et al.* (2016).

observed immediately before the start of the crisis (2014 Q1), was chosen as the peak and the quarter representing the observation immediately preceding the first positive variation of the series was the trough. For each of the observed variables, the trough column details the chosen period.

Table 5 – Peak-through variations and components: 2014 crisis

Variable (X)	Trough	ΔX	ΔX_A	ΔX_L	ΔX_X	ΔX_G
Product	2016 T1	-16.48	-19.84	-12.14	10.00	6.30
Hours Worked	2017 T1	-8.17	-7.53	-13.38	3.10	6.48
Investment	2017 T2	-40.69	-50.01	-17.10	2.30	17.07

Source: Own elaboration

The first point to draw attention is the longer duration of the decline period in all observed variables. While the resumption of output growth took a quarter to happen in the 2008 recession, in the 2014 episode the beginning of the recovery started only two years later, as can be seen in the 'trough' column of Table 5. For hours worked and investment, two quarters were needed for recovery in the 2008 recession, compared to three years and a quarter in the 2014 crisis, respectively.

In addition to the longer duration, Table 5 also shows the greater severity of the episode, with the drop observed for the product being more than three times greater than that observed in the economy in 2008. Moreover, changes in hours worked and investment represent more than twice those seen in the previous episode for the same variables.

From the aforementioned fluctuations, we can see that the efficiency wedge was again able to reproduce them with greater accuracy, producing variations of -19.84%, -8.17% and -50.01% for product, hours worked and investment, in view of observed variations of -16.48%, -8.17% and -40.69%, respectively.

Similar to the 2008 episode, the labor wedge was the second component that best explained the fluctuations of the 2014 crisis, reproducing about 73% of the fall in the product and 42% of the fall in investment. In addition, similar to what was observed in the exercise for the 2008 period, the investment wedge and government wedge economies produced fluctuations in the opposite direction of those experienced by the observed variables.

Additionally, Table 6 repeats the ϕ statistics calculation exercise for 2014. More specifically, we choose to contemplate the period between 2014 Q1 and 2016 Q1. In relation to the fluctuations in the product, the results confirm the peak-trough analysis, and point out that the efficiency wedge component was responsible for 79% of the fluctuations experienced by the observed variable, and the labor wedge, accounts for 16%. Once again, the investment and government wedges were not relevant.

In addition, the efficiency wedge component was also able to reproduce 49%

Table 6 – ϕ statistics for components of the observed variables: 1014 crisis

ϕ_A^Y	$\phi_{\tau L}^Y$	$\phi_{\tau_x}^Y$	ϕ_g^Y	ϕ_A^L	$\phi_{\tau_L}^L$	$\phi_{\tau x}^L$	ϕ_g^L	ϕ_A^x	$\phi_{\tau_L}^x$	$\phi_{\tau_x}^x$	ϕ_g^x
0.79	0.16	0.02	0.03	0.49	0.26	0.11	0.14	0.37	0.49	0.03	0.11

Source: Own elaboration.

of fluctuations observed in hours worked, followed by the labor wedge, with 26%. For investment, however, the labor wedge was the most important component, being responsible for 49% of the movements observed in the period, followed by the efficiency wedge, with 37%.

The greater relevance of the efficiency wedge to explain the 2014 fluctuations is also reflected in the one wedge off economies. Figures (17)-(19) in Annex B show that the no efficiency wedge is unable to keep up with the trend of the product, hours worked and investment. On the other hand, the withdrawal of the government wedge does not seem to significantly impact the reproduction of the observed variables, corroborating with the conclusions obtained from the peak-trough and ϕ analyses.

It is important to highlight the greater relevance of the efficiency wedge and the opposite movement by the labor wedge. The loss of relevance of the labor wedge to explain the economic fluctuations experienced by the product during the 2014 crisis stands in opposition to what was found by Manfredini (2020), and may be related to the use of historical series or different treatments for the hours worked data.

It is necessary to emphasize, additionally, the inversion between the components of the efficiency and labor wedges as the main factor capable of reproducing hours worked and investment for both episodes. While in the first episode the labor wedge proved to be the most relevant to explain fluctuations in hours worked, in the second episode the efficiency wedge became more important. The opposite can be seen for investment.

In the BCA framework, therefore, the evidence presented suggests that the recession episodes that the Brazilian economy went through as of 2014 can be characterized as a recession related to productivity fluctuations. In that regard, models that map distortions related to efficiency and the labor market should be more promising than those related to investment-related distortions and to government spending.

5 Final considerations

After a decade of economic performance above its peers, Brazil experienced adverse conditions from 2014 onwards, which led to a significant deterioration in the macroeconomic environment and culminated in one of the worst recessions in its history. In order to study these economic fluctuations, the present paper used quarterly data from 2002 to 2019 to model the distortions present in the Brazilian economy during this period in light of the methodology developed by Chari, Kehoe e McGrattan (2007).

As shown in Subsection 4.1, the efficiency wedge improved between 2003 Q2 and 2008 Q2, before falling 3.96% due to the 2008 recession. In the 2014 crisis, on the other hand, it deteriorated in a more relevant way until accumulating a drop of 13.25% in 2019 Q4, compared to 2014 Q1. The labor wedge improved practically continuously until the beginning of 2015, until experiencing a negative variation of 11.14% between 2014 Q1 and 2016 Q1, which coincides with the increase in unemployment due to the 2014 crisis. Investments and labor wedges, on the other hand, proved to be countercyclical.

When the recessive episodes of 2008 and 2014 are contrasted, we found that the 2014 crisis was relatively more severe and longer lasting than the 2008 recession. The peak-trough variation shows that output, hours worked and the investment changed negatively by 4.56%, 3.87% and 19.35% between the second quarter of 2008 and the quarter referring to the trough point of the series for the 2008 recession, respectively. For the 2014 crisis, the variations were -16.48%, -8.17% and -40.69% for an average period of 11 quarters, respectively.

In addition, simulations were performed for the variables observed through the individual and joint introduction of wedges in the model, which gave rise to one-wedge and one-wedge off economies. From this, the ϕ statistic was calculated in order to determine the contribution of each of the components of the observed variables. The results of this exercise suggest that, for both recession episodes, the efficiency wedge best explained the fluctuations analyzed, followed by the labor wedge. In that regard, models that map distortions related to productivity and the labor market should perform better when contrasted with the data.

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APPENDIX A – Data

In order to use the proposed methodology, data from the following macroeconomic aggregates are required: Gross Domestic Product, Consumption, Government Spending, Investment, Exports and Imports. All of them were obtained from the Brazilian Institute of Geography and Statistics (IBGE). The series at 1995 prices were used with seasonally adjusted, quarterly frequency, between 2002 Q1 and 2019 Q4. Furthermore, the ratio between taxes on goods and GDP at market prices was used to deduct the tax component from income and private consumption. Table 7 summarizes the sources mentioned, as well as the treatments given to each variable.

Table 7 – Macroeconomic Aggregates

Notation	**Description**	**Unit**	**Frequency**	**Source**	**Period**
$\tilde{Y}_t$	Gross Domestic Product	10^6 R$ of 1995 SA	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
$\tilde{C}_t$	Consumption	10^6 R$ of 1995 SA	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
$\tilde{G}_t$	Government Spending	10^6 R$ of 1995 SA	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
I_t	Fixed Capital Gross Formation	10^6 R$ of 1995 SA	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
X_t	Exports	10^6 R$ of 1995 SA	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
M_t	Imports	10^6 R$ of 1995 SA	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
T_t	Taxes	10^6 R$	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
$Y_{pm,t}$	Gross Domestic Product	10^6 R$	Quarterly	IBGE - CNT	2002 T1 - 2019 T4
t_t	$T_t/Y_{pm,t}$	-	Quarterly	-	2002 T1 - 2019 T4
G_t	$\tilde{G}_t + X_t - M_t$	-	Quarterly	-	2002 T1 - 2019 T4
Y_t	$\tilde{Y}_t(1 - t_t)$	-	Quarterly	-	2002 T1 - 2019 T4
C_t	$\tilde{C}_t(1 - t_t)$	-	Quarterly	-	2002 T1 - 2019 T4

Source: Own elaboration.

Due to the unavailability of good data on hours worked in Brazil, we decided to construct a series based on data from the Average Annual Hours Worked by Persons Engaged (AVH) from *Penn World Table 10.0* and Occupied Population data. To change the frequency of the AVH series to the quarterly frequency, we linearly interpolated and divided the result by four.

In addition, the PME database was interrupted in March 2016, with the release of data referring to the month of February 2016. PNAD-C database replaced the old PME, broadening the coverage to the entire country, in contrast to the PME, which only covered the Metropolitan Regions of Recife, Salvador, Belo Horizonte, Rio de Janeiro, São Paulo and Porto Alegre, which makes the two methodologies not comparable to each other.

Thus, we chose to retropolate the PNAD-C data using the rates of change for PME. This procedure was used for the Occupied Population series, used in the creation of the series of hours worked, and in the series of Labor Force (PIA), used in the construction of the per capita variables. Table 8 summarizes the procedure.

Table 8 – Hours Worked Series

Notation	**Description**	**Unit**	**Frequency**	**Source**	**Period**
AVWH_a	Average annual hours worked by persons engaged	Hours	Annual	*Penn World Table 10.0*	2002 - 2019
$\text{PO}_{\text{PME},t}$	Occupied Population (PME)	Thousands	Quarterly	IBGE - PME	2002 T1 - 2015 T4
$\text{PO}_{\text{PNAD-C},t}$	Occupied Population (PNAD-C)	Thousands	Quarterly	IBGE - PNAD-C	2012 T1 - 2020 T4
AVWH_t	Linear Interpolation$(AVWH_a)$ /4	-	Quarterly	-	2002 T1 - 2020 T4
$\widehat{\text{PO}}_t$	$\text{PO}_{\text{PNAD-C},t+1} * (\text{PO}_{\text{PME},t}/\text{PO}_{\text{PME},t+1})$, se $t \leq 2011$ T4	-	Quarterly	-	2002 T1 - 2011 T4
$\widetilde{\text{PO}}_t$	$\text{PO}_{\text{PNAD-C},t}$, se $t \geq 2012$ T1	-	Quarterly	-	2012 T1 - 2020 T4
PO_t	$\widehat{\text{PO}}_t \cup \widetilde{\text{PO}}_t$	-	Quarterly	-	2002 T1 - 2020 T4
H_t	$\text{AVWH}_t * \text{PO}_t$	-	Quarterly	-	2002 T1 - 2020 T4

Source: Own elaboration

In addition, the construction of the per capita series was carried out by dividing the macroeconomic aggregates by the number of workers in the economy, as measured by the PIA. Furthermore, the series of hours worked was divided by the constant value 1250, which represents the labor endowment. This procedure is standard in the literature and we chose to follow the procedure used by Simonovska e Söderling (2015).

Table 9 – Per Capita Series

Notation	Description	Unit	Frequency	Source	Period
$\text{PIA}_{\text{PME},t}$	Labor Force (PME)	Thousands	Quarterly	IBGE - PME	2002 T1 - 2015 T4
$\text{PIA}_{\text{PNAD-C},t}$	Labor Force (PNAD-C)	Thousands	Quarterly	IBGE - PNAD-C	2012 T1 - 2020 T4
$\widehat{\text{PIA}}_t$	$\text{PIA}_{\text{PNAD-C},t+1} * (\text{PIA}_{\text{PME},t}/\text{PIA}_{\text{PME},t+1})$, se $t \leq$ 2011 T4	-	Quarterly	-	2002 T1 - 2011 T4
$\widetilde{\text{PIA}}_t$	$\text{PIA}_{\text{PNAD-C},t}$, se $t \geq$ 2012 T1	-	Quarterly	-	2012 T1 - 2020 T4
PIA_t	$\widehat{\text{PIA}}_t \cup \widetilde{\text{PIA}}_t$	-	Quarterly	-	2002 T1 - 2020 T4
ypc_t	Y_t/PIA_t	-	Quarterly	-	2002 T1 - 2019 T4
cpc_t	C_t/PIA_t	-	Quarterly	-	2002 T1 - 2019 T4
ipc_t	Y_t/PIA_t	-	Quarterly	-	2002 T1 - 2019 T4
gpc_t	G_t/PIA_t	-	Quarterly	-	2002 T1 - 2019 T4
hpc_t	$H_t/\text{PIA}_t/1250$	-	Quarterly	-	2002 T1 - 2019 T4

Source: Own elaboration

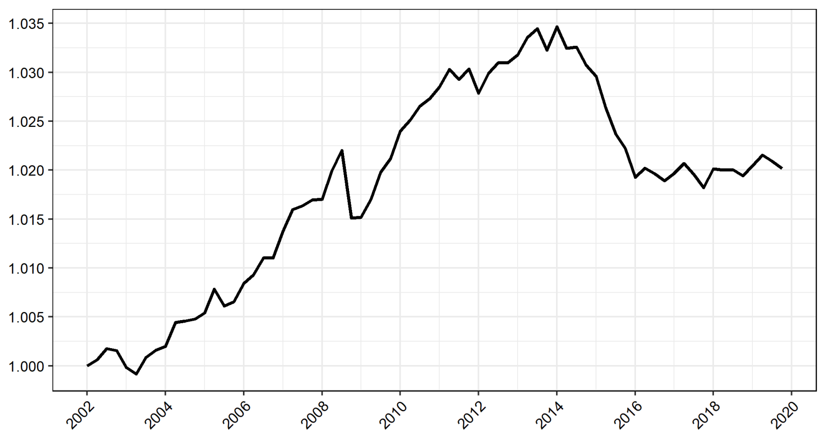
Finally, Table 10 depicts the series used in the modeling and Figures (2)-(7) present them graphically.

Table 10 – Series in Ln

Notation	Description	Unit	Frequency	Source	Period
y_t	$\ln \text{ypc}_t$	-	Quarterly	-	2002 T1 - 2019 T4
c_t	$\ln \text{cpc}_t$	-	Quarterly	-	2002 T1 - 2019 T4
i_t	$\ln \text{ipc}_t$	-	Quarterly	-	2002 T1 - 2019 T4
g_t	$\ln \text{gpc}_t$	-	Quarterly	-	2002 T1 - 2019 T4
h_t	$\ln \text{hpc}_t$	-	Quarterly	-	2002 T1 - 2019 T4

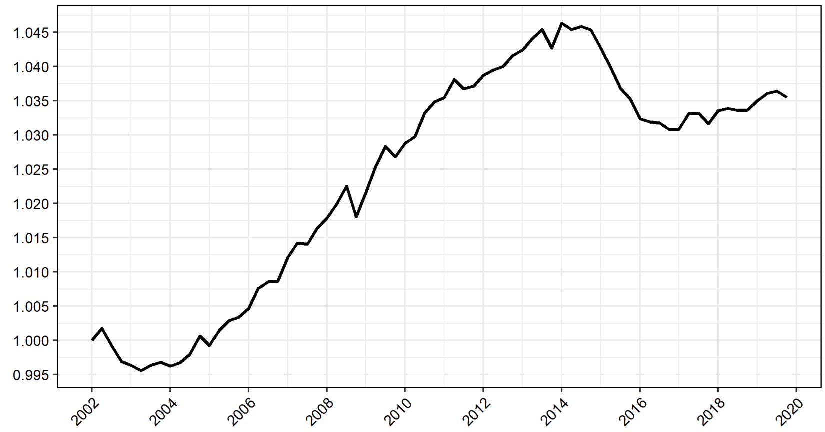
Source: Own elaboration

Figure 2 – Natural Logarithm of Income Per Capita, 2002 Q1 = 1



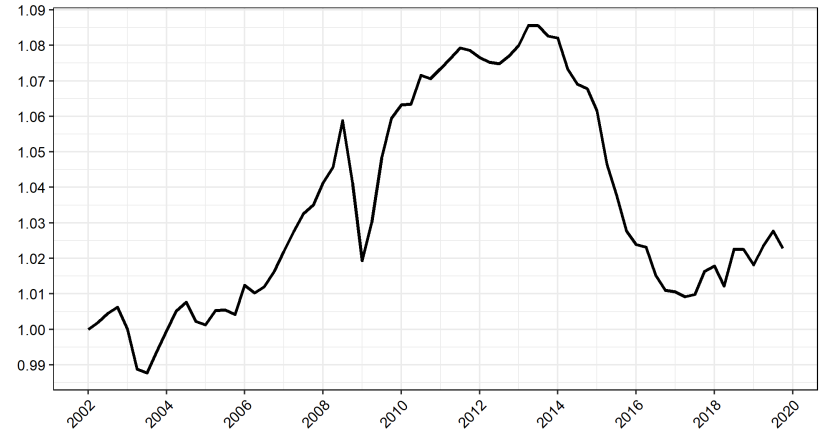
Source: Own elaboration

Figure 3 – Natural Logarithm of Consumption Per Capita, 2002 Q1 = 1



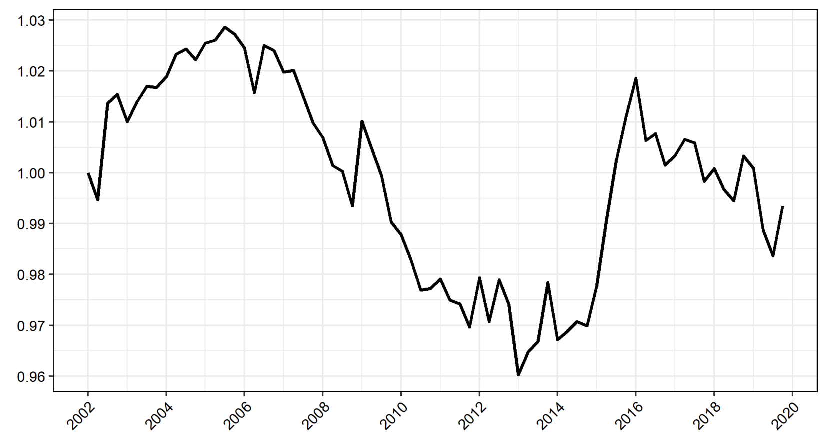
Source: Own elaboration

Figure 4 – Natural Logarithm of Investiment Per Capita, 2002 Q1 = 1



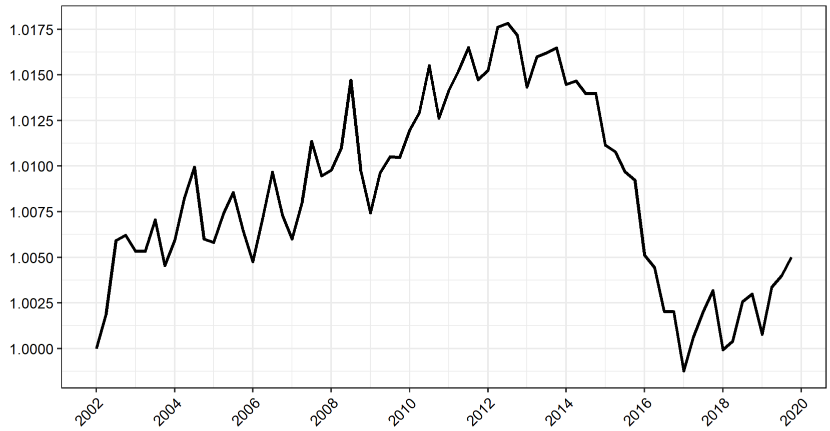
Source: Own elaboration

Figure 5 – Natural Logarithm of $G + (X - M)$ Per Capita, 2002 Q1 = 1



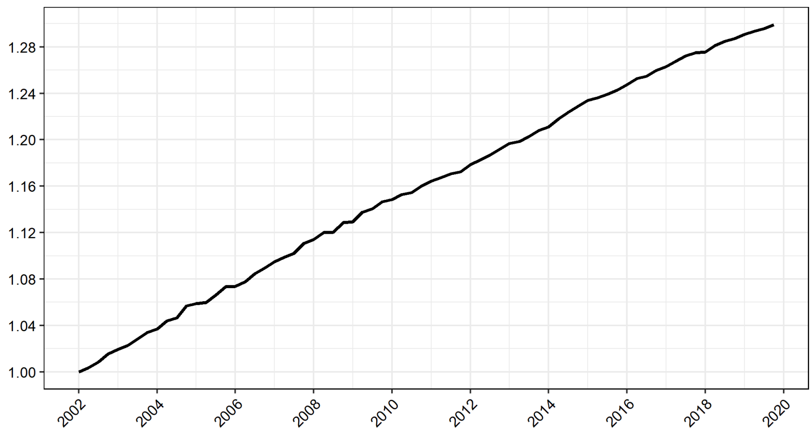
Source: Own elaboration

Figure 6 – Natural Logarithm of Hours Worked Per Capita, 2002 Q1 = 1



Source: Own elaboration

Figure 7 – Natural Logarithm of Labor Force, 2002 Q1 = 1



Source: Own elaboration

APPENDIX B – Parameters

Based on the Labor Force, the population growth was calculated:

$$g_n = \left(\frac{\text{PIA}_{2019\text{T}4}}{\text{PIA}_{2002\text{T}1}}\right)^{1/71} - 1 \tag{37}$$

To calculate the growth of the technology, we found g_z that solves the following system of equations:

$$\begin{aligned}
0 &= \ln \text{ypc}_{2002\text{T}1}(1+g_z) - \ln \text{ypc}_{2002\text{T}1} - \ln{(1+g_z)}^0 \\
0 &= \ln \text{ypc}_{2002\text{T}2}(1+g_z) - \ln \text{ypc}_{2002\text{T}2} - \ln{(1+g_z)}^1 \\
0 &= \ln \text{ypc}_{2002\text{T}3}(1+g_z) - \ln \text{ypc}_{2002\text{T}3} - \ln{(1+g_z)}^2 \\
&\vdots \\
0 &= \ln \text{ypc}_{2019\text{T}4}(1+g_z) - \ln \text{ypc}_{2019\text{T}4} - \ln{(1+g_z)}^{71}
\end{aligned} \tag{38}$$

The remaining parameters were calibrated according to what is usual in the literature, and are summarized in Table 11.

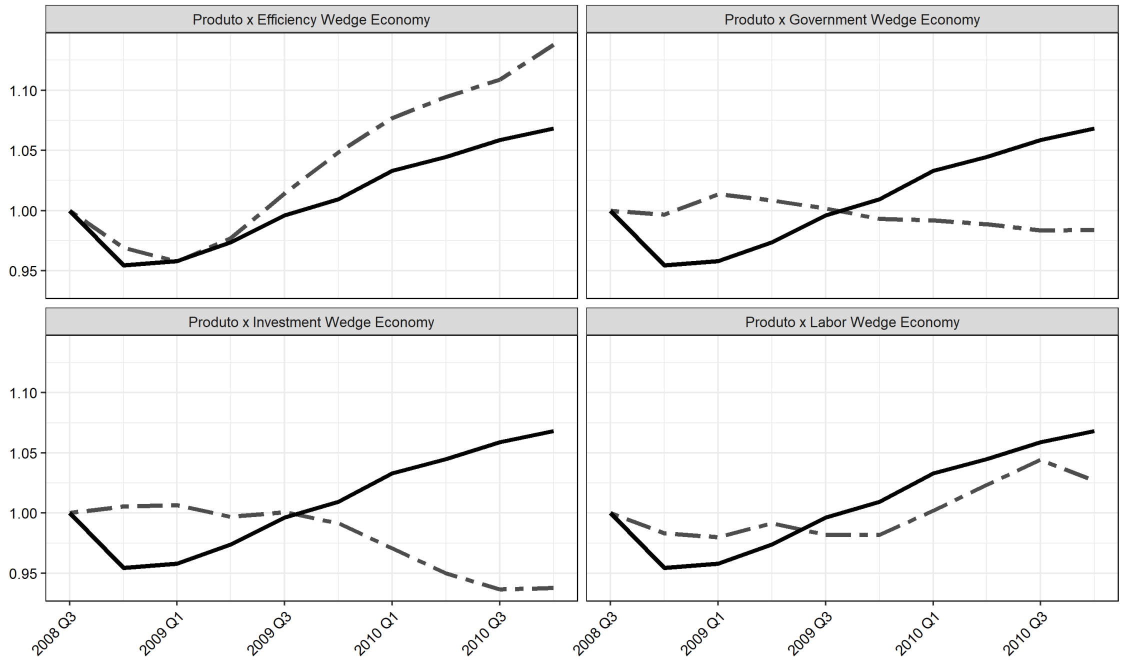
Table 11 – Calibrated Parameters

Variable	**Description**	**Reference**	**Annual**	**Quartely**
g_n	Population Growth	Calculated	1.49%	0.37%
g_z	Technology Growth	Calculated	1.52%	0.38%
δ	Capital Depreciation	Graminho (2006)	4.06%	1.03%
β	Intertemporal Discount	Graminho (2006)	97.42%	99.35%
ψ	Labor parameter	Graminho (2006)	2.18	2.18
θ	Capital share on income	Graminho (2006)	0.33%	0.33%

Source: Own elaboration

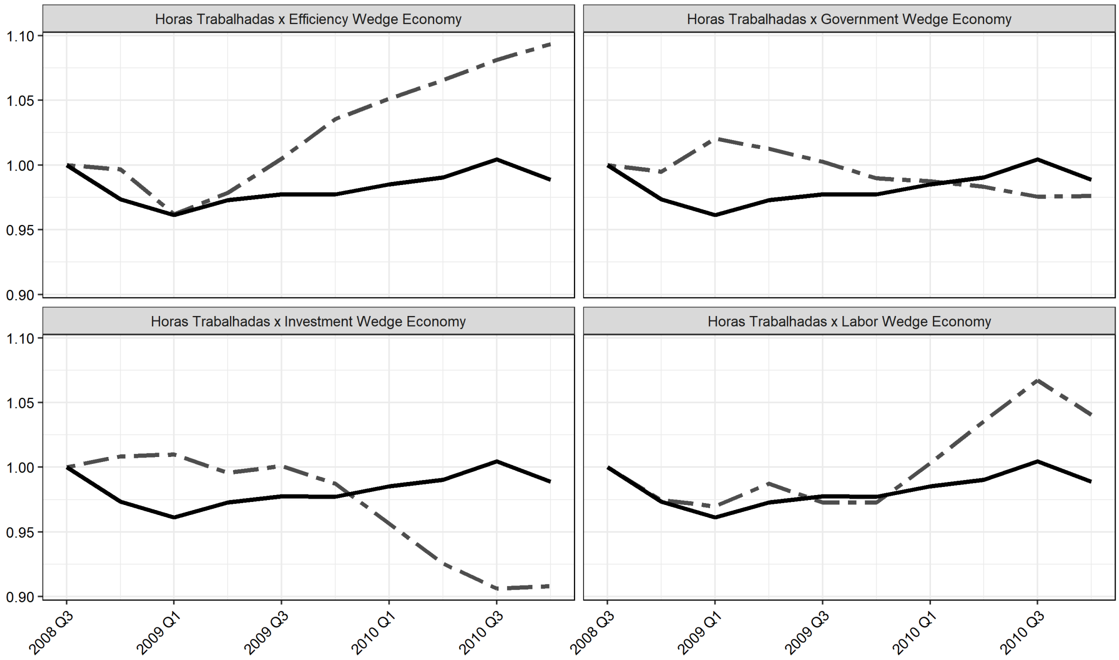
ANNEX A – One Wedge Economies

Figure 8 – 2008 Recession: Output and One Wedge Economies



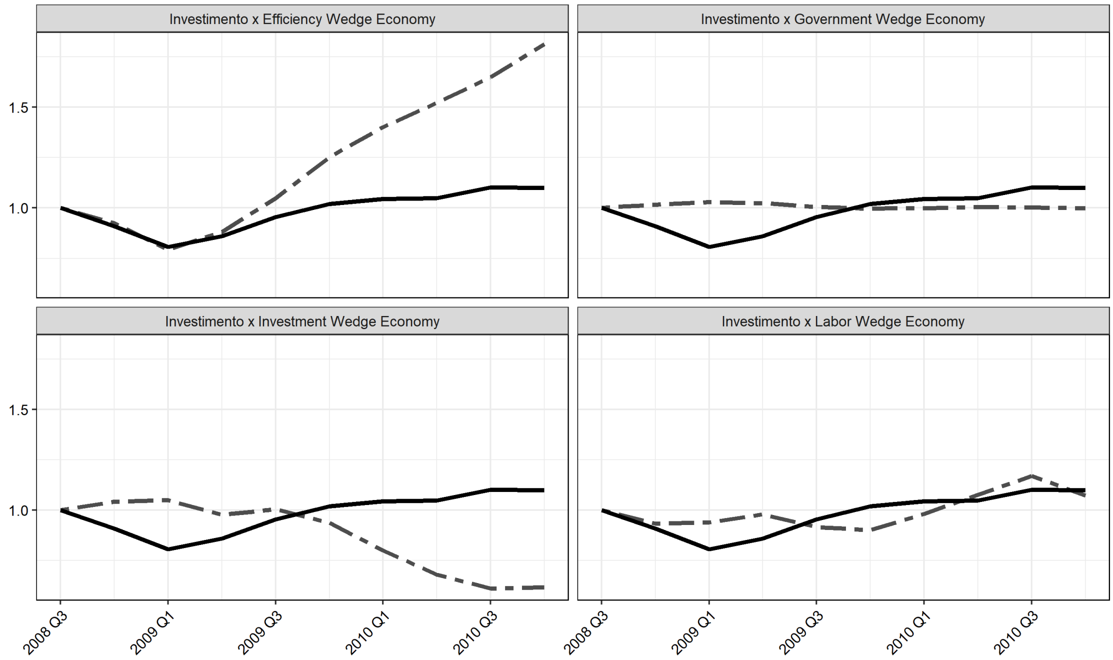
Source: Own elaboration

Figure 9 – 2008 Recession: Hours Worked and One Wedge Economies



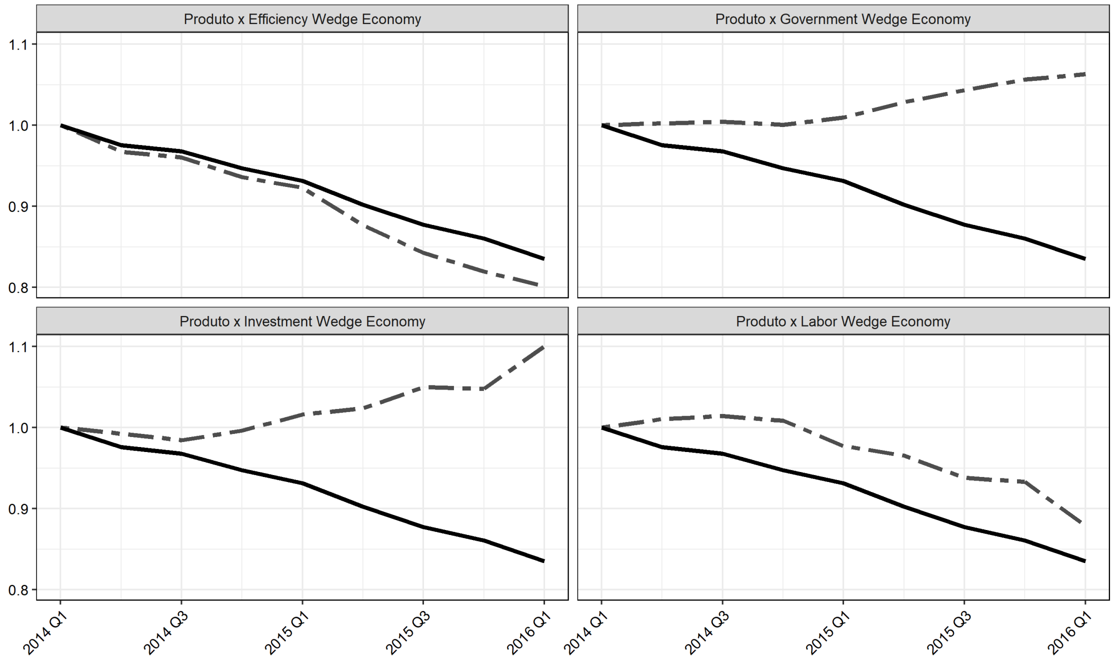
Source: Own elaboration

Figure 10 – 2008 Recession: Investment and One Wedge Economies



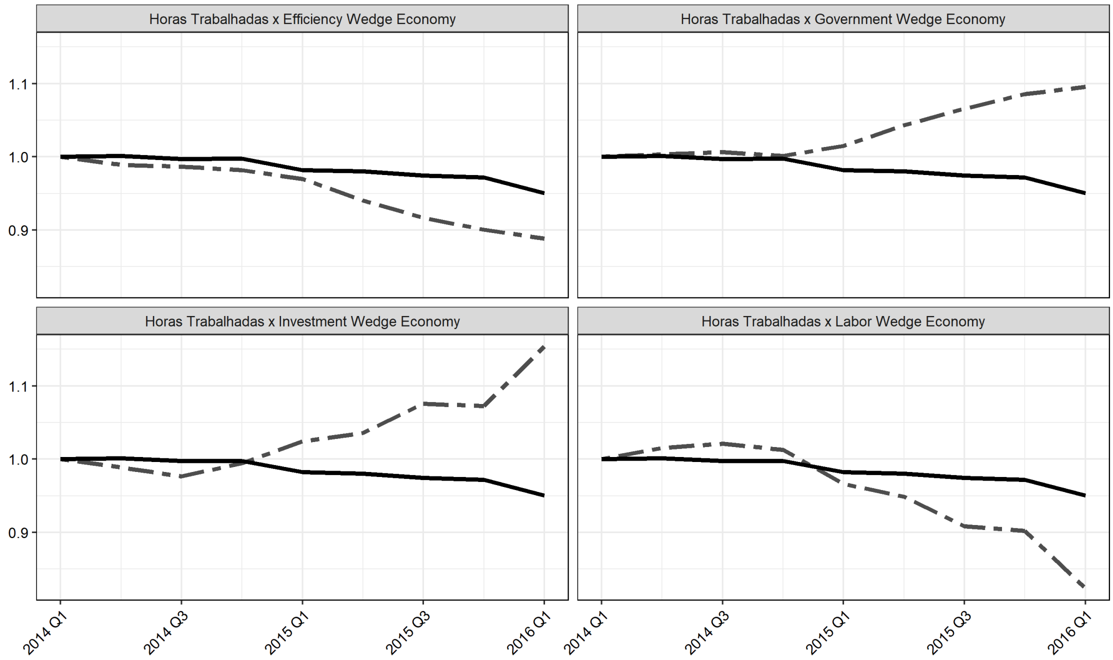
Source: Own elaboration

Figure 11 – 2014 Crisis: Output and One Wedge Economies



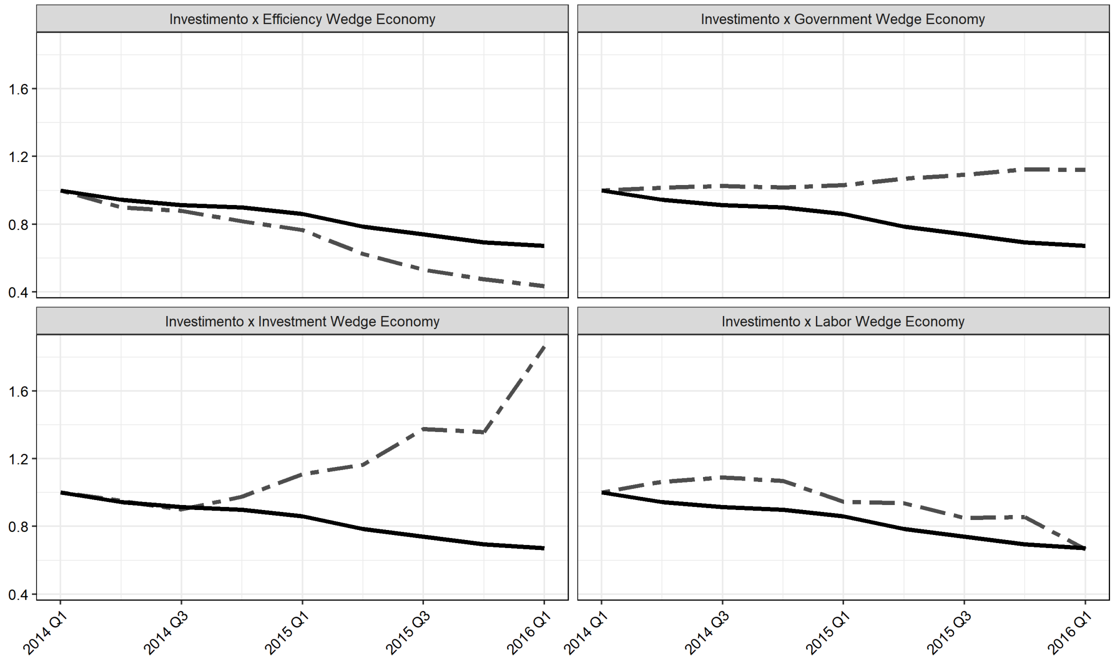
Source: Own elaboration

Figure 12 – 2014 Crisis: Hours Worked and One Wedge Economies



Source: Own elaboration

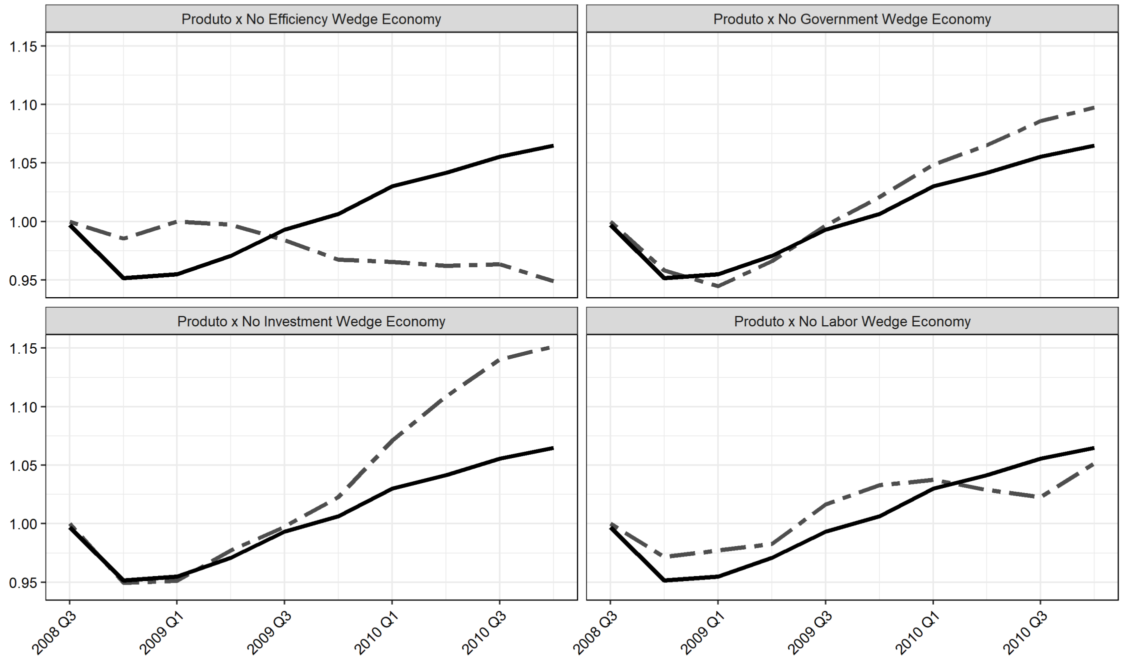
Figure 13 – 2014 Crisis: Investment and One Wedge Economies



Source: Own elaboration

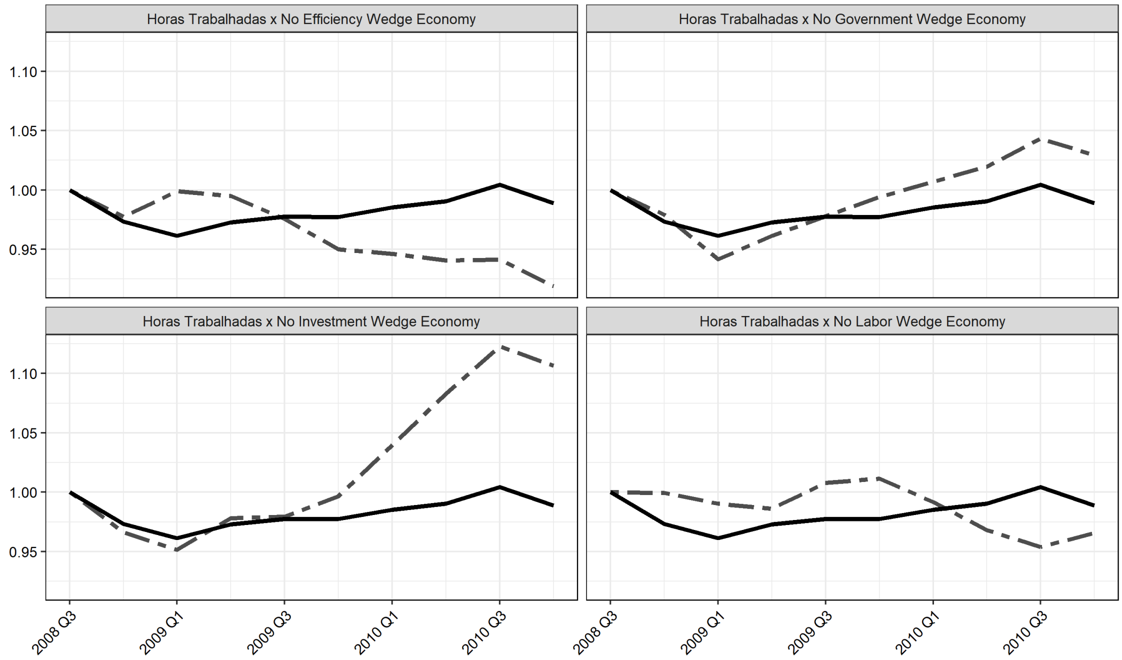
ANNEX B – One Wedge Off Economies

Figure 14 – 2008 Recession: Output and One Wedge Off Economies



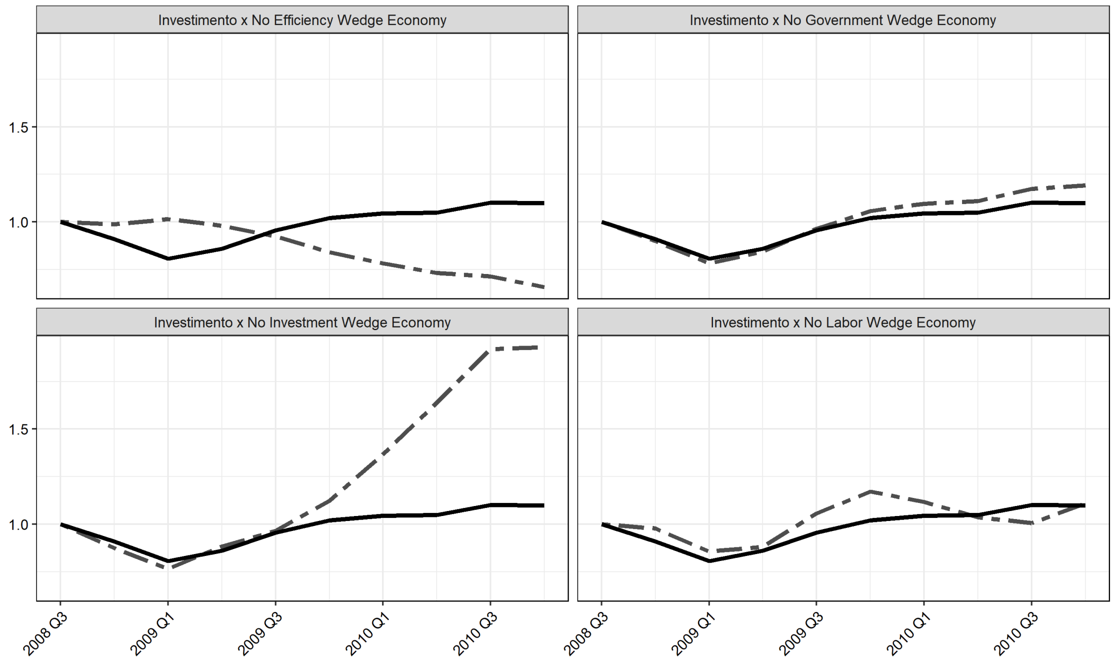
Source: Own elaboration

Figure 15 – 2008 Recession: Hours Worked and One Wedge Off Economies



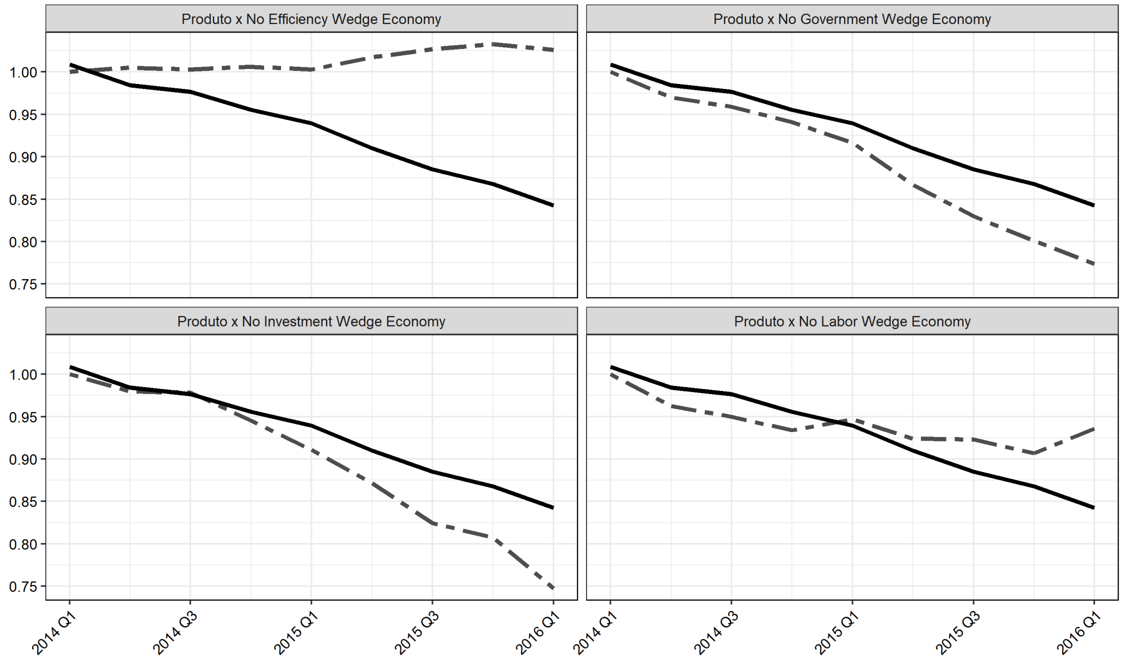
Source: Own elaboration

Figure 16 – 2008 Recession: Investment and One Wedge Off Economies



Source: Own elaboration

Figure 17 – 2014 Crisis: Output and One Wedge Off Economies

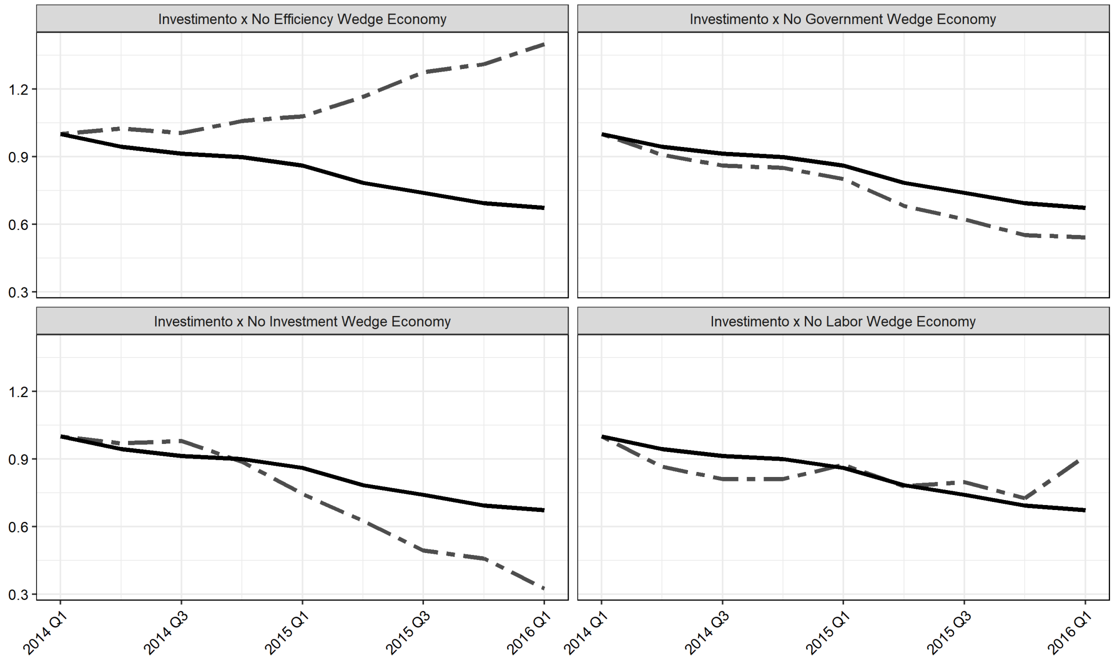


Source: Own elaboration

Figure 18 – 2014 Crisis: Hours Worked and One Wedge Off Economies

Source: Own elaboration

Figure 19 – 2014 Crisis: Investment and One Wedge Off Economies



Source: Own elaboration