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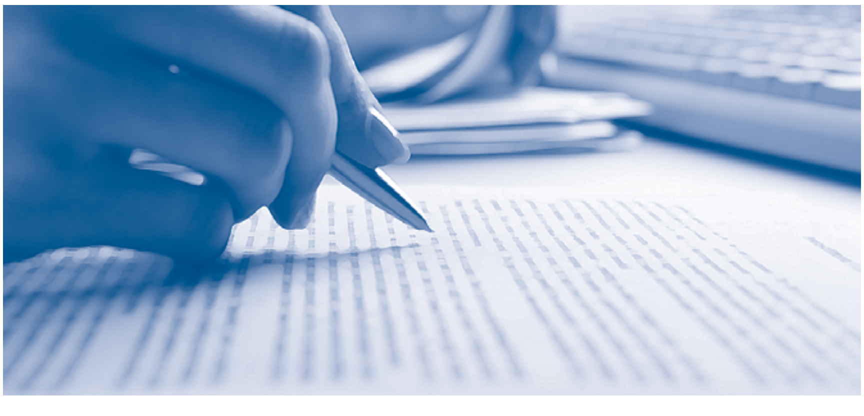

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Waldyr Dutra Areosa*

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Abstract

This Working Paper should not be reported as representing the views of the Banco Central do Brasil. The views expressed in the paper are those of the authors and do not necessarily reflect those of the Banco Central do Brasil.

The goal of this paper is to present how a Dynamic General Equilibrium Model (DSGE) can be used by policy makers in the qualitative and quantitative evaluation of the macroeconomics impacts of two monetary policy instruments: (i) short term interest rate and (ii) reserve requirements ratio. In our model, this last instrument affects the leverage of banks that have to deal with agency problems in order to raise funds from depositors. We estimated a modified version of Gertler and Karadi (2011), incorporating a reserve requirement ratio, in order to answer two questions: (i) what is the impact of a transitory increase of 1% *p.y.* of the short term interest rate on macroeconomic variables like GDP, inflation and investment? (ii) what is the macroeconomic impact of a transitory increase of 10% in the reserve requirement ratio? We found that these two shocks have the same qualitative effects on the most of the macroeconomic variables, but that the impact of interest rate is much stronger.

JEL Classification: E50, E58.

Keywords: Credit frictions, Monetary policy instruments, Interest rate rules, Reserves requirements.

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1 Introduction

After the sub-prime crisis of 2007-2008, it is now clear that the conventional practice of monetary policy was not enough to deal with the strong effects of financial crises on the real economy. The main macroeconomic models used by academics until the crisis did not take into account financial market imperfections' effects on macroeconomic variables. Despite recognizing the existence of such frictions, most of the models implicitly assumed that these frictions were not quantitatively important, which meant that financial markets did not have any role in generating or propagating macroeconomic fluctuations. In those models, the interest rate that borrowers pay on debt always would follow the interest rate controlled by the Central Bank, which implicitly assumed that the spread between those interest rates was constant.

Before the crisis, there was a widespread belief among policymakers that deposit insurance, capital requirements and supervision had been successful in detaining financial markets instability. However, as it is known now, the excess of leverage of financial institutions (mainly investment banks) was a crucial source and propagation mechanism of economic shocks during the crisis. Given that, some important economists argued that an excessive loose monetary policy was one of the causes of the excess of leverage in financial system[1]. Therefore, the implicit separation between monetary policy and financial stability would be misguided. These facts brought some challenges for the macroeconomics literature and policy makers alike, not only related to the construction of models with better descriptions of the monetary policy transmission mechanism, as to the inclusion of tensions between price and financial stability.

Therefore, new models to be developed should have two main features: (i) the presence of financial frictions causing endogenous changes of the spread between borrowing and lending rates; (ii) the analysis of possible new goals, as, for example, financial stability, and instruments for the Central Bank, and what would be the best Central Bank´s responses to the old and new economic shocks.

The aim of this paper is to show how a Dynamic Stochastic General Equilibrium (DSGE) model which incorporates a specific type of financial friction can be used by policy makers to evaluate, qualitatively and quantitatively, the macroeconomic effects of not only the Central Bank´s interest rate but also of the reserve requirements ratio. The reserve requirements that Central Bank can impose on banks could be an additional instrument for a Central Bank that is concerned with financial stability. For that purpose, some parameters of a slightly modified version of Gertler and Karadi (2011) model including

[1] Taylor (2007) argued that in the United States, the demand for housing is sensitive to moneymarket interest rates and that accommodative policy on the part of the Federal Reserve from 2001 was likely therefore to have contributed to the build-up in housing demand and asset prices. Similarly, White (2009) conjectured that when the stock market boom of the late 1990s collapsed and rates were sharply reduced in response "the seeds of the housing market boom and bust were sown."

reserve requirements are estimated using Brazilian data. With the estimated parameters, the same model is simulated and the main macroeconomic variables' responses to shocks in Central Bank´s interest rate and minimum reserve requirement ratio are compared. This comparison is a first step in understanding the main differences between these two instruments.

Related Literature. Bernanke, Gertler, and Gilchrist (1999) remains the benchmark DSGE model with financial frictions. As in Bernanke and Gertler (1989), Kiyotaki and Moore (1997) and others, they endogenize financial market frictions by introducing an agency problem between borrowers and lenders, creating a wedge between the cost of external finance and the opportunity cost of internal finance, which adds to the overall cost of credit that a borrower faces. The external finance premium decreases with the borrower's percentage stake in the outcome of an investment project.

The literature above focus on credit constraints faced by non-financial borrowers. The evidence suggests that disruption of financial intermediation is a key feature of both recent and historical crises[2]. Thus the current literature focus on financial intermediation. Examples of this literature are Curdia and Woodford (2010), Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). We focus on the work of Gertler and Karadi (2011). The authors develop a quantitative monetary DSGE model with financial intermediaries that face endogenously determined balance sheet constraints. We introduce reserve requirements in this framework and estimate the resultant model using Brazilian data.

Organization. This paper is organized as follows: in Section 2 the theoretical model is presented, while data and empirical strategy are presented in Section 3. The main results are presented in Section 4, where the estimated parameters are used to show the macroeconomic variables' responses to the monetary policy shocks (interest rate and reserve requirements). Finally, in Section 5 the conclusion and possible extensions are discussed.

2 Model

The model of Gertler and Karadi (2011) was used with a slight modification for including reserve requirements. In this model there are five types of agents besides the Central Bank: households, financial intermediaries, capital producers firms, intermediate goods producers firms and final goods producers firms.

This model is very similar to traditional New Keynesian DSGE models[3]. The main

[2]For a description of the disruption of financial intermediation during the current crises, see Brunnermeier (2008), Gorton (2008) and Bernanke (2009).

[3]See Woodford (2003) for a complet treatment of the basic New Keynesian DSGE literature.

difference is the inclusion of an agency problem in the financial intermediation process which restrains financial intermediaries' ability of raising funds from households. Besides, the authors include exogenous shocks in the quality of capital which is a potential source of economic fluctuation that is amplified by the presence of the financial frictions. As a result, if there is a decrease in the capital quality, there will be a worsening of agency problems and a decrease in credit supply and some amplification of the macroeconomic effects of the initial shock. As an extension, minimum reserve requirements are introduced in the model.

In the next sub-sections, the main features of the model will be presented, with special emphasis on the microeconomic foundations of each economic agent's decision[4]. In order to make future references easier, the summarized model can be found in Table 1, variables descriptions can be found in Table 2, while parameters can be found in Table 3.

2.1 Households

There is a continuum of households of measure one. They decide the optimal intertemporal and intratemporal allocation of consumption, savings and labor. For example, if ex-ante interest rate is high, households decrease current consumption and increase future consumption, i.e., increase savings. On the other hand, the higher is the real wage, more hours of labor will be supplied.

In short, decisions about consumption, labor and savings will be represented by a labor supply relation:

$$\varrho_t W_t = \chi Z_t^L L_t^{\varphi} \tag{1}$$

and an intertemporal consumption allocation relation:

$$E_t \beta \Lambda_{t,t+1} R_{t+1} = 1 \tag{2}$$

where W_t is real wage by hour, L_t is the number of hours worked, R_t is the gross interest rate and Z_t^L is a preferences exogenous shock that affects the marginal disutility of work. On the other hand, the stochastic discount factor is given by:

$$\Lambda_{t,t+1} = \frac{\varrho_{t+1}}{\varrho_t}, \tag{3}$$

where ϱ_t is the marginal utility of consumption and is given by:

$$\varrho_t = Z_t^C \left(C_t - hC_{t-1}\right)^{-\sigma} - \beta h E_t Z_{t+1}^C \left(C_{t+1} - hC_t\right)^{-\sigma}, \tag{4}$$

where C_t is the household consumption level and Z_t^C is a preferences exogenous shock that affects the marginal utility of consumption. The parameters $0 < \beta, h < 1$ e $\chi, \varphi, \sigma > 0$

[4]The complete derivation of the model is presented in Gertler and Karadi (2011).

are related to the households preferences[5].

2.2 Financial Intermediaries

Financial intermediaries lend money raised from households to the intermediate goods producers, which use these funds to acquire capital. Besides, financial intermediaries transform maturity, since they buy long term assets using short term debt (or deposits). As a result, a fall in asset prices shrinks intermediary balance sheets and may induce a fire sale of assets to meet balance sheet constraints. The overall contraction is magnified by the degree of leverage. In order to limit financial intermediaries ability to expand assets indefinitely, a moral hazard problem is introduced. Banks can choose to deviate a fraction λ of available funds. If banks choose to do it, depositors can force its bankruptcy and recover the remaining fraction $1 - \lambda$ of assets. Therefore, once funds are deviated, banks lose all future expected profit that it could earn. It can be shown that the greater the leverage, higher will be the benefit of deviation in comparison with the bankruptcy cost. In order to avoid banks from deviating funds, depositors will impose an endogenous limit on the leverage of the financial system. It is this mechanism that gives to the financial system a role in the amplification of shocks. If there is a shock that increases the perceived benefit of deviation, depositors will decrease the "allowed" leverage of the banks, which will generate a decrease in credit supply and investment.

The equations describing financial intermediaries' behavior are presented in the sequence. The private intermediaries demand for assets S_{pt} is:

$$Q_t S_{pt} = \phi_t N_t, \tag{5}$$

where Q_t is the market value of capital and N_t is the net worth of financial system. The variable ϕ_t is the leverage of financial system, and is given by:

$$\phi_t = \frac{\eta_t}{\lambda - \nu_t}, \tag{6}$$

where η_t is the marginal value of financial system's net worth and ν_t is the marginal value of financial system's assets, which are given by:

$$\begin{aligned} \eta_t &= E_t \left\{ \beta \Lambda_{t,t+1} \left[(1-\theta) R_{t+1} + \theta z_{t,t+1} \eta_{t+1} \right] \right\}, & (7) \\ \nu_t &= E_t \left\{ \beta \Lambda_{t,t+1} \left[(1-\theta) (R_{kt+1} - R_{t+1}) + \theta x_{t,t+1} \nu_{t+1} \right] \right\}, & (8) \end{aligned}$$

where R_{kt+1} is the gross return on capital and the parameter $0 < \theta < 1$ measures the survival probability of a bank[6]. Intuitively, the leverage level "allowed" to banks depends

[5] For parameters descrption, see Table 3.

[6] The gross return on capital is equal to the gross return on asset.

positively on the continuity value of banks operations, which depends positively on η_t and ν_t and negatively on the benefits that banks can have if they deviate funds, given by λ.

The growth rate of net worth, $z_{t,t+1}$, and of assets, $x_{t,t+1}$, are given by:

$$z_{t,t+1} = (R_{kt+1} - R_{t+1})\phi_t + R_{t+1}, \tag{9}$$

$$x_{t,t+1} = \left(\frac{\phi_{t+1}}{\phi_t}\right) z_{t,t+1}. \tag{10}$$

Finally, the evolution of net worth can be represented by:

$$N_t = \theta z_{t-1,t} N_{t-1} e^{e_{Net}} + \omega Q_t S_{pt-1}, \tag{11}$$

where $e_{N_{et}}$ is an exogenous shock and the parameter $0 < \omega < 1$ measures transfers from households to the new bankers that initiate operations in each period.

2.3 Monetary, Credit and Reserve Requirements' Policies

The monetary policy is represented by a Taylor rule, where the Central Bank uses the net nominal interest rate, i_t, as its instrument:

$$i_t = (1-\rho)\left[\bar{\imath} + \kappa_\pi \pi_t + \kappa_y \left(\ln Y_t - \ln Y_t^*\right)\right] + \rho i_{t-1} + \varepsilon_t, \tag{12}$$

where π_t is the final goods inflation, Y_t is the final goods production, Y_t^* is the natural level of production and ε_t is a exogenous monetary policy shock.

One policy option in this model would be Central Bank easing financial intermediation, what Gertler and Karadi (2011) call credit policy. In the model, this would mean that a fraction ψ_t of assets would be intermediated by the Central Bank. Therefore, total assets in the whole financial system (including Central Bank), S_t , would be:

$$\begin{aligned} Q_t S_t &= Q_t S_{pt} + \psi_t Q_t S_t \\ &= \phi_t N_t + \psi_t Q_t S_t \\ &= \phi_{ct} N_t, \end{aligned} \tag{13}$$

where the Equation (5) was used to reach the last equality and:

$$\phi_{ct} = \frac{\phi_t}{1-\psi_t} \tag{14}$$

represents the leverage level of the whole financial system (including the Central Bank). The proportion ψ_t of assets funded by the Central Bank could be, for example, a function of the *spread* between interest rates:

$$\psi_t = \kappa E_t \left[(\ln R_{kt+1} - \ln R_{t+1}) - (\ln R_k - \ln R) \right], \tag{15}$$

where $\kappa > 0$ and $\ln R_k - \ln R$ represents the steady state *spread*.

The Central Bank can also change the minimum reserve requirements rules. It is assumed that each financial institution has to retain:

$$RR_{jt} = \tau_t B_{jt} \tag{16}$$

of minimum reserve requirements, where τ_t is the reserve requirements ratio. It is assumed that the remuneration of reserve requirements is $R_{t+1}^{RR} \leq R_{t+1}$. Therefore, the relevant cost of funds for financial intermediaries is not R_{t+1}anymore, but R_{t+1}^{τ} defined as:

$$R_{t+1}^{\tau} = \frac{R_{t+1} - \tau_t R_{t+1}^{RR}}{1 - \tau_t} \geq R_{t+1}. \tag{17}$$

So, in order to incorporate reserve requirements in the model, it is only necessary to replace R_{t+1} by R_{t+1}^{τ} in equations (6)-(11) from financial intermediaries.

As the goal of this work is to compare reserve requirements and interest rate effects, it is assumed that the government does not use credit policy, i.e., ψ_t will be always equal to zero. Note, however, that the leverage of financial system still can be affected by the Central Bank, since the Central Bank´s interest rate, the reserve requirements ratio and the reserve requirements remuneration all affect R_{t+1}^{τ}, and so affects η_t and ν_t , which impact the leverage level of the private financial system.

2.4 Intermediate Goods Producers

Intermediate goods producers are subject to a competitive market, where they finance their capital acquisition for the next period, K_{t+1} , through borrowing the amount S_t

$$Q_t K_{t+1} = Q_t S_t. \tag{18}$$

In each period t, each firm produces the amount Y_{mt}

$$Y_{mt} = A_t \left(U_t \xi_t K_t \right)^{\alpha} L_t^{1-\alpha}, \tag{19}$$

using capital, K_t, and labor, L_t, and changing the capital utilization rate, U_t. The exogenous shock A_t refers to total factor productivity, while the exogenous shock ξ_t refers to capital quality. The parameter $\alpha > 0$ represents the effective participation of capital in production.

Assuming that capital replacement costs are fixed and equal to one and calling the intermediate goods price by P_m, the optimal choices of capital utilization and labor demand by these firms are:

$$P_{mt}\alpha\frac{Y_{mt}}{U_t} = \delta'(U_t)\xi_t K_t, \tag{20}$$

$$P_{mt}(1-\alpha)\frac{Y_{mt}}{L_t} = W_t, \tag{21}$$

where the depreciation rate of capital as a function of the utilization rate is given by:

$$\delta(U_t) = \delta_c + \frac{b}{1+\zeta}U_t^{1+\zeta}. \tag{22}$$

Finally, firms pay to the financial intermediaries the *ex post* return on capital

$$R_{kt+1} = \frac{\left[P_{mt+1}\alpha\frac{Y_{mt+1}}{\xi_{t+1}K_{t+1}} + Q_{t+1} - \delta(U_{t+1})\right]\xi_{t+1}}{Q_t} \tag{23}$$

since all firms have zero profit in each state of nature.

2.5 Capital Producers

In the end of each period, capital producers buy capital from the intermediate goods producers in a competitive market, refurbish it and produce new capital, in order to sell the refurbished and new capital to the intermediate producers. Each unity of new capital is sold by Q_t, while the refurbished capital is sold by one. It is assumed that there are adjustment costs in the net investment, I_{nt},

$$I_{nt} = I_t - \delta(U_t)\xi_t K_t \tag{24}$$

but not in the gross investment, I_t. Therefore, the optimal investment decision is:

$$Q_t = 1 + f_t + \frac{I_{nt}+\bar{I}}{I_{nt-1}+\bar{I}}f_t' - E_t\beta\Lambda_{t,t+1}\left(\frac{I_{nt+1}+\bar{I}}{I_{nt}+\bar{I}}\right)^2 f_{t+1}', \tag{25}$$

where:

$$f_t \equiv f\left(\frac{I_{nt}+\bar{I}}{I_{nt-1}+\bar{I}}\right) = \frac{\eta_i}{2}\left(\frac{I_{nt}+\bar{I}}{I_{nt-1}+\bar{I}} - 1\right)^2 \tag{26}$$

are the adjustment costs, $\bar{I}$ is the steady state level of investment and $\eta_i > 0$ is the inverse of net investment's elasticity in relation to capital price in the steady state.[7]

The capital evolution is given by:

$$K_{t+1} = \xi_t K_t + I_{nt}. \tag{27}$$

[7] It is supposed that there is no adjustment cost to replace the depreciated capital.

2.6 Final Goods Producers

There is a continuum of retail firms in a monopolist competition setup, where the elasticity of substitution between goods is $\epsilon > 1$. These firms just buy the goods produced by the intermediate goods producers and combine them in order to produce the final good. However, they are subject to nominal price rigidity, i.e., in each period, a firm has a probability of $1-\gamma$ of being allowed to adjust its price optimally. Between adjustment periods, firms index their prices to a fraction $0 < \gamma_p < 1$ of the past inflation. Therefore, the aggregate production Y_t is given by:

$$Y_t = Y_{mt} D_t, \tag{28}$$

where D_t is a index of price dispersion arising from nominal price rigidity

$$D_t = \gamma D_{t-1} \Pi_{t-1}^{-\gamma_p \varepsilon} \Pi_t^{\varepsilon} + (1-\gamma) \left(\frac{1 - \gamma \Pi_{t-1}^{\gamma_p(1-\gamma)} \Pi_t^{\gamma - 1}}{1-\gamma} \right)^{-\frac{\varepsilon}{1-\gamma}}, \tag{29}$$

where $\Pi_t \equiv P_t / P_{t-1}$.

The optimal price, P_t^* , chosen by firms able to set prices in period t can be represented recursively by:

$$\Pi_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{F_t}{Z_t} \Pi_t, \tag{30}$$

where $\Pi_t^* \equiv P_t^* / P_{t-1}$ and

$$F_t = Y_t P_{mt} + E_t \left[\beta \gamma \Lambda_{t,t+1} \frac{\Pi_t^{-\gamma_p \varepsilon}}{\Pi_{t+1}^{-\varepsilon}} F_{t+1} \right], \tag{31}$$

$$Z_t = Y_t + E_t \left[\beta \gamma \Lambda_{t,t+1} \frac{\Pi_t^{\gamma_p(1-\varepsilon)}}{\Pi_{t+1}^{(1-\varepsilon)}} Z_{t+1} \right]. \tag{32}$$

This equation shows that the optimal pricing decision depends not only on the current demand and cost conditions, but also on the expected future demand and cost conditions. This occurs because firms do not know for sure when they will set their prices optimally again in the future. It is important to note that the further ahead is the period of time, the smaller will be its weight and that this weight depends negatively on the probability of resetting prices optimally $1-\gamma$. Finally, the inflation dynamics is given by:

$$\Pi_t^{1-\varepsilon} = \gamma \Pi_{t-1}^{\gamma_p(1-\varepsilon)} + (1-\gamma) \left(\Pi_t^* \right)^{1-\varepsilon}. \tag{33}$$

2.7 Closing the Model

The resource constrain of the economy is given by:

$$Y_t = C_t + I_t + f\left(\frac{I_{nt} + \bar{I}}{I_{nt-1} + \bar{I}}\right)\left(I_{nt} + \bar{I}\right) + G_t + \Omega\psi_t Q_t K_{t+1}, \tag{34}$$

and government expenditures G_t are financed by lump-sum taxes T_t and revenues from government intermediation

$$G_t + \Omega\psi_t Q_t K_{t+1} = T_t + \left(R_{kt} - R_t\right)\psi_{t-1} Q_t S_{t-1}. \tag{35}$$

The parameter Ω in this equation is the unity cost of the public sector financial intermediation.

Finally, the link between nominal and real interest rates is given by the Fisher equation:

$$1 + i_t = R_{t+1}\frac{E_t P_{t+1}}{P_t}, \tag{36}$$

whereas the link between nominal and real remuneration of reserve requirements is given by

$$1 + i_t^{RR} = R_{t+1}^{RR}\frac{E_t P_{t+1}}{P_t}. \tag{37}$$

The summarized model (and simplified by the substitution of S_{pt} and S_t by $\left(1 - \psi_t\right) K_{t+1}$ and K_{t+1} and by removal of W_t using the labor market equilibrium condition) can be found in Table 1.

3 Estimation

After the construction of the theoretical model, summarized in Table 1, the parameters in Table 3 will be estimated, using Brazilian quarterly data. Before, it is necessary to define: (i) the observable variables that will be used in the estimation and (ii) the calibration and the priors distributions of the parameters. These two topics will be treated in the next sub-sections.

3.1 Data

We use quarterly data from 1999Q3 to 2010Q2. Nine observable variables were used: GDP (Y_t), Consumption (C_t), government expenditures (G_t), investment (I_t), hours of labor (L_t), real wages (W_t), inflation (π_t), Central Bank interest rate - Selic (i_t) and the stock of credit to firms ($Q_t S_t$). Regarding GDP, consumption, government expenditures and investment, seasonally adjusted series from IBGE were used (average of 1995=100)[8].

[8] See www.ibge.gov.br.

Regarding hours of labor and real wages, the same procedure of Castro, Gouvea, Minella, Santos, and Souza-Sobrinho (2011) was used. As there was a methodological change in 2002, there is a discontinuity in those series. In order to avoid this problem, the old and new series were seasonally adjusted[9], then the growth rate of the old series was used in order to estimate the values of the new series in the past[10]. The stock of credit to firms was seasonally adjusted using the same procedure of the other series[11]. Following Castro, Gouvea, Minella, Santos, and Souza-Sobrinho (2011), for the non stationary series (Y_t, C_t, G_t, I_t, L_t, W_t, e Q_tS_t), the first difference of the natural logarithm less its average will be used.

The inflation rate was calculated as the cumulated quarterly variation of the consumer price index (IPCA) with seasonal adjustment[12], then the average inflation from 2005 on was subtracted. This procedure is very similar to the one employed by Castro, Gouvea, Minella, Santos, and Souza-Sobrinho (2011). The only difference is that these authors subtracted from each observation the inflation target from 2005 on, which was 4,5%, while the actual average annual inflation from 2005 on was of 4,78%, which means that our procedures are very similar. For the Selic rate, the procedure was very similar, the only difference is that the series was not seasonally adjusted.

As nine shocks were included in the model, there are degrees of freedom to use up to nine observable variables. The chosen observable variables were described above. The shocks affect the value of the following variables: productivity (A_t), government expenditures (G_t), Central Bank interest rate - Selic (i_t), capital quality (ξ_t), reserve requirements ratio (τ_t), nominal remuneration of the reserve requirements $\left(i_t^{RR}\right)$, consumption (C_t), labor supply (L_t) and bank net worth's evolution (N_t). It was assumed that the shocks affecting A_t, τ_t, C_t and L_t follow a autoregressive process of order 1. So, assuming this shock structure, their persistences and standard deviations were estimated. It was assumed that the shock affecting i_t follows a white noise process. Since there is a smoothing parameter in the Taylor rule, we are assuming that the monetary policy shock has the same persistence of the interest rate (calibrated in 0.8). Finally, the shocks G_t, ξ_t , i_t^{RR} and N_t were considered purely transitory. So, for these shocks and for the monetary policy shock only the standard deviations were estimated. A brief summary of the data used can be found in Table 4.

[9] In order to seasonally adjust the series the X12 ARIMA was used.

[10] The series used were withdrawn from IPEA data site. The series from the old methodology are: occupied population- metropolitan areas- number of people, IBGE, PME and Average income from the main job- Metropolitan areas, Index (July of 1994=100), IBGE, PME. The series from the new methodology are: occupied population, employed, metropolitan areas, number of people, IBGE, PME and Average usual real income - occupied population, measured in R$ of March of 2005 , IBGE, PME.

[11] The series 3959 of the Central Bank of Brazil's webpage was used : Credit operations with non earmarked funds - Consolidate balance (end of period) - Legal entities total. See www.bcb;gov.br.

[12] The seasonal adjustment procedure used was the same as before, the X12 ARIMA. The series used was IPCA - general - index (December of 1993 = 100) - IBGE, withdrawn from IPEA data.

3.2 Calibration and Priors

Bayesians techniques were used in order to estimate the model of Gertler and Karadi (2011) adapted for the Brazilian case. The Bayesian methodology consists of using available information about the economy in the form of priors related to the parameters' distributions and use observable data to update these distributions, so the posteriors of the parameters' distributions can be calculated[13].

The model has 41 parameters, of which 23 were calibrated and 18 were estimated. Regarding calibration, the results of Castro, Gouvea, Minella, Santos, and Souza-Sobrinho (2011) was used as a base[14]. The calibrated parameters and their values can be found in Table 5. Because of the modeling choice, some parameters have different interpretations here. For example, the parameter γ_p , which measures the indexation's level of the economy, has a different interpretation in the present model, but the parameter estimated in the SAMBA will be used anyway, since the interpretations are very similar. Whenever the parameter in the present model has a sufficiently distinct interpretation, it will be estimated. These are the cases of ζ and η_i, which are the elasticity of the marginal depreciation of capital in relation to the capacity utilization and the inverse of the elasticity of net investment in relation to the capital price, respectively.

The category of parameters that are specific to the model of Gertler and Karadi (2011): θ , ω e λ, which are the survival probability of a bank, the proportional transfers from households to the new bankers that initiate operations in each period and the proportional benefit that banks can have if they deviate funds, respectively. The last parameter measures the severity of the information asymmetry's problems in the financial intermediation. θ and λ will be estimated and ω will be calibrated as in Gertler and Karadi (2011). In Table 6, the estimated parameters, and their priors and posteriors, can be found.

4 Analyses

Using the parameters estimated, as described in Section 3, two analyses were made:

1. What are the responses of the main macroeconomic variables to a one per cent shock in the Central Bank interest rate?

2. What are the responses of the main macroeconomic variables to a ten per cent shock in the reserve requirements ratio?

The response to the Central Bank interest rate shock was used as a benchmark, to which the reserve requirements' responses will be compared.

[13] For a review of the recent literature, see Schorfheide (2011).

[14] These authors estimated the parameters of a model with specific features of the Brazilian economy, which was called SAMBA (Stochastic Analytical Model with a Bayesian Approach).

The responses of the following variables were analyzed: (i) credit (Q_tK_{t+1}), (ii) investment (I_t), (iii) investment price (Q_t), (iv) GDP (Y_t), (v) consumption (C_t), (vi) ex-ante credit interest rate (E_tR_{kt+1}), (vii) Central Bank interest rate - Selic (i_t), (viii) inflation (π_t) and (ix) reserve requirements ratio.

For each instrument, three cases will be presented, which capture different levels of persistence: (i) low ($\rho = \rho_\tau = 0$), (ii) medium ($\rho = \rho_\tau = 0.5$) e (i) high ($\rho = \rho_\tau = 0.8$).

4.1 Responses to a Monetary Policy Shock

Figure 1 presents the responses of some macroeconomic variables to a unexpected decrease of 1% $p.y.$ in the Central Bank interest rate - Selic.

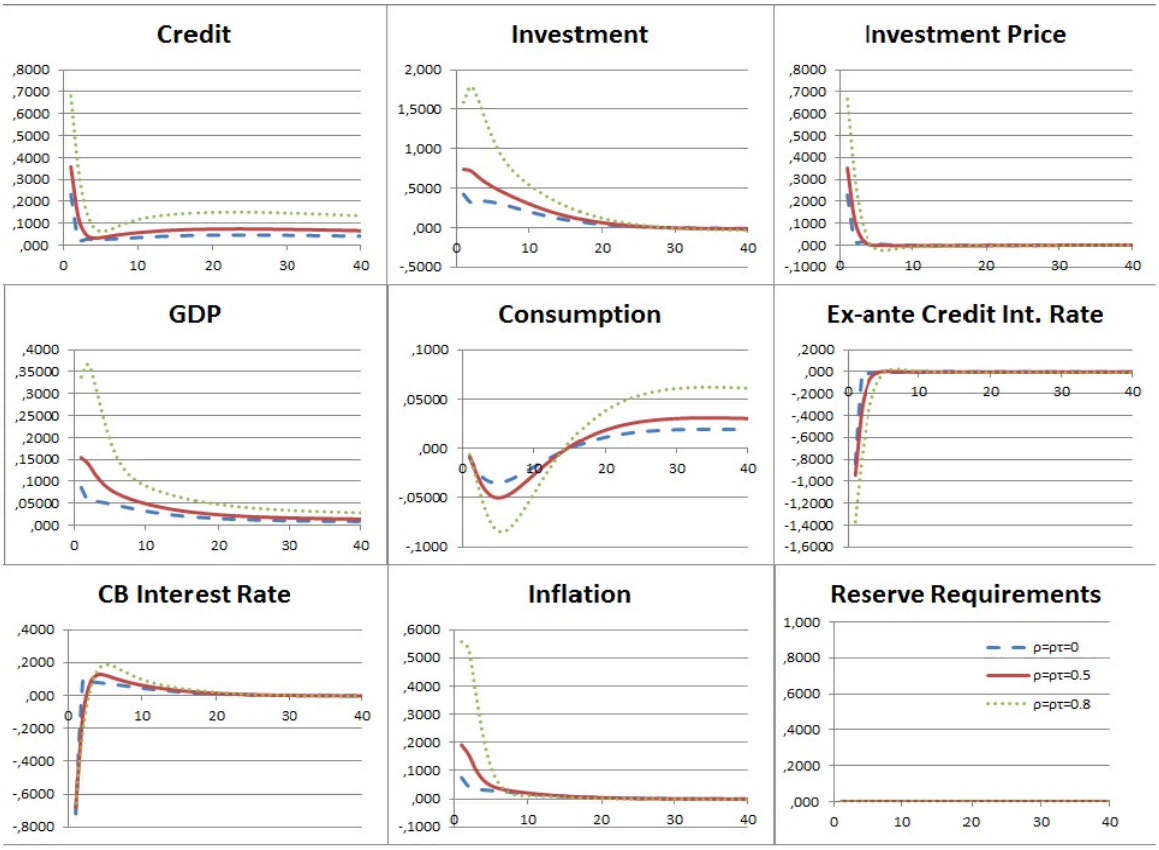

Figure 1: Percentage Change from the Steady State in response to a 1% p.y. decrease of the Central Bank ´s interest rate.

A decrease in the interest rate has its traditional effect: it decreases the cost and increases the volume of credit, increasing investment. Consumption also increases, with a delay, which can be explained by habit formation (parameter h). In the absence of habit formation ($h = 0$), the increase on consumption would be immediate. As a result, inflation, output and output gap increase. All these effects are larger if the shock persistence is larger. It is important to note that the reserve requirements ratio does not respond to any endogenous variable, which explain why this variable is constant during the experiment.

4.2 Responses to a Reserve Requirements Ratio Shock

Figure 2 presents the responses of the same macroeconomic variables to an unexpected decrease of 10% in the reserve requirements ratio.

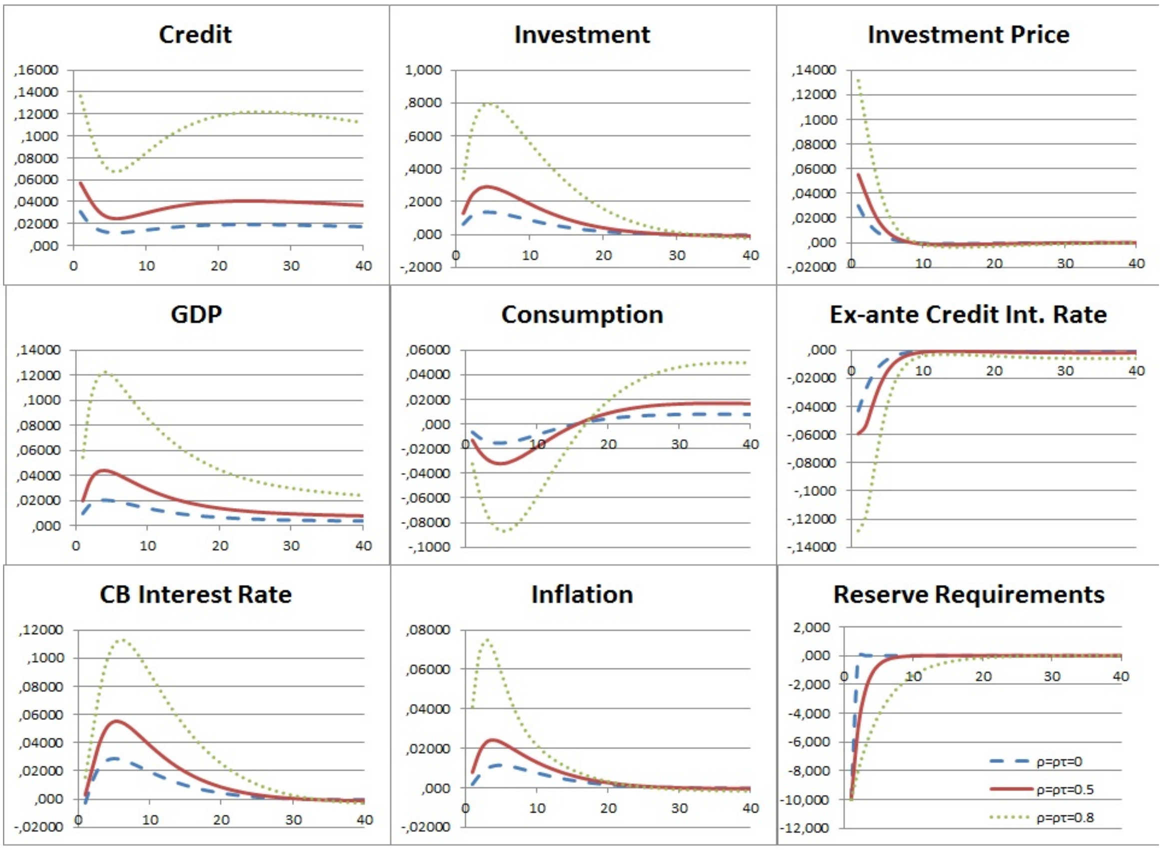

Figure 2: Percentage Change from the Steady State in response to a 10% decrease of reserve requirements ratio (with monetary policy).

The impact of the reserve requirements reduction, although similar to an interest rate reduction, is quantitatively smaller in all variables, except consumption. As in the case of the monetary policy shock, there is a decrease in the credit's cost, but in a smaller order of magnitude. However, the impact on credit volume presents an interesting aspect: despite the initial impact of the Central Bank interest rate being larger than reserve requirements', the persistence as well as the magnitude of the impact in posterior periods are very similar.

An important question to be considered when doing the above analysis is that in this model the reserve requirements ratio is purely exogenous, since it does not respond to any endogenous variables. Therefore, in the case of the monetary policy experiment, the reserve requirements are constant all the time, while in the reserve requirements experiment the Central Bank interest rate is changing, since there is a Taylor rule (12) in which this interest rate responds to changes on the inflation and output gap. So, Figure 2 captures not only the responses to the reserve requirements change, but also the effects caused by the induced change in the Central Bank interest rate.

In order to isolate the reserve requirements effects, the original Taylor rule was changed by one in which the Central Bank interest rate responds with a delay to the same variables appearing in the equation (12)

$$i_t = (1-\rho)\left[\bar{\imath} + \kappa_\pi \pi_{t-k} + \kappa_y \left(\ln Y_{t-k} - \ln Y^*_{t-k}\right)\right] + \rho i_{t-1} + \varepsilon_t. \tag{38}$$

This means that the monetary policy will begin to respond to the inflation and output gap after k periods. With this change, it is expected an amplification of the economy's response to the reserve requirements shock when compared to Figure 2, since previously the increase of the Central Bank interest rate, in response to the consequences of the reserve requirements decrease, neutralized partially the reserve requirements effects. The choice of k, the delaying parameter of monetary policy, depends on the values of the other parameters of the model. Considering the benchmark calibration presented in Tables 5 and 6, the highest possible value of k is 6. Alternatively, we could also consider the case where ρ is very close to one in equation (12).

Figure 3 presents the responses of the same macroeconomic variables to a decrease of 10% in the reserve requirements ratio when the Taylor rule with a delaying is used. It is important to note that only the periods in which the Central Bank interest rate remained constant will be presented ($k = 6$).

As expected, the economy's response to the reserve requirements increased when compared to Figure 2, without any qualitative change.

5 Conclusion

In this paper, we tried to identify the systematic impact of reserve requirements on macroeconomic variables, as well as the main differences between this instrument and the Central Bank interest rate. In order to do that, a Dynamic Stochastic General Equilibrium Model (DSGE), incorporating financial frictions and reserve requirements, was used.

In short, a decrease in the reserve requirements ratio has the same qualitative effects of a decrease in the Central Bank interest rate, although its quantitative impact is smaller. For example, while a persistent ($\rho = 0,8$) reduction of $1\%p.y$ of the Central Bank interest rate increases contemporaneously the GDP in 0.34%, a persistent ($\rho_\tau = 0.8$) reduction of 10% of the reserve requirements ratio increases GDP contemporaneously only in at most

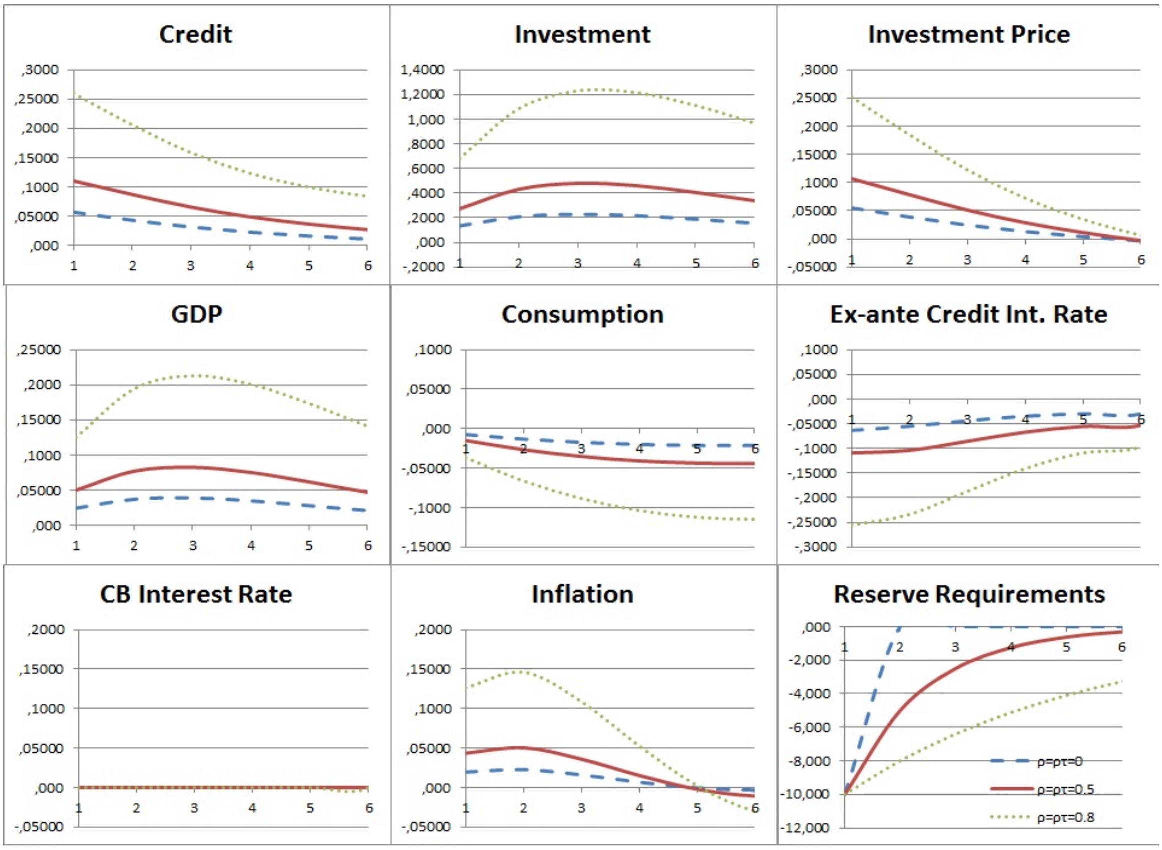

Figure 3: Percentage Change from the Steady State in response to a 10% decrease of reserve requirements ratio (without monetary policy).

0.12% (in the case where Central Bank interest rate is kept constant).

It is important to note that the tool used here is flexible, in the sense that the model can be adapted to answer other questions (for example, it is possible to include an endogenous reserve requirements ratio reacting to the spread of the economy). At the same time it has its limitations, since our model abstracts from features that can be important depending on the question one is asking (for example, there are no interbank market imperfections in the model, which was an important factor in amplifying the effects of the subprime crisis) and ignores important characteristics of a small open-economy like Brazil. Overall, our model is just a first step in quantifying the macroeconomic effects of reserves requirements in a framework suited for monetary policy analysis.

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Table 1: Summary of the Model

Agent/Description	Equation
Households	
Marginal utility of consumption	$\varrho_t = Z_t^C \left(C_t - hC_{t-1}\right)^{-\sigma} - \beta h E_t Z_{t+1}^C \left(C_{t+1} - hC_t\right)^{-\sigma}$
Euler equation	$E_t \beta \Lambda_{t,t+1} R_{t+1} = 1$
Stochastic discount factor	$\Lambda_{t,t+1} \equiv \varrho_{t+1}/\varrho_t$
Labor supply	$W_t \varrho_t = \chi Z_t^L L_t^\varphi$
Financial intermediaries	
Value of banks' assets	$\nu_t = E_t\{\beta\Lambda_{t,t+1}[(1-\theta)(R_{kt+1} - R_{t+1}^\tau) + \theta x_{t,t+1}\nu_{t+1}]\}$
Value of banks' net worth	$\eta_t = E_t\{\beta\Lambda_{t,t+1}\left[(1-\theta)R_{t+1}^\tau + \theta z_{t,t+1}\eta_{t+1}\right]\}$
Total leverage	$\phi_{ct} \equiv \frac{\phi_t}{1-\psi_t}$
Private leverage	$\phi_t \equiv \frac{\eta_t}{\lambda - \nu_t}$
Growth rate of banks assets	$z_{t,t+1} = (R_{kt+1} - R_{t+1}^\tau)\phi_t + R_{t+1}^\tau$
Growth rate of banks net worth	$x_{t,t+1} = (\phi_{t+1}/\phi_t) z_{t,t+1}$
Agregate Capital	$Q_t K_{t+1} = \phi_{ct} N_t$
Net worth evolution	$N_t = \theta z_{t-1,t} N_{t-1} e^{e_{Net}} + \omega Q_t (1-\psi_{t-1})\xi_t K_t$
Intermediate goods producers	
Production function	$Y_{mt} = A_t (U_t \xi_t K_t)^\alpha L_t^{1-\alpha}$
Labor demand	$P_{mt}(1-\alpha)\frac{Y_{mt}}{L_t} = W_t$
Capacity utilization	$P_{mt}\alpha\frac{Y_{mt}}{U_t} = \delta'(U_t)\xi_t K_t$
Depreciation rate	$\delta(U_t) = \delta_c + \frac{b}{1+\zeta} U_t^{1+\zeta}$
Return on capital	$R_{kt+1} = Q_t^{-1}[P_{mt+1}\alpha\frac{Y_{mt+1}}{\xi_{t+1}K_{t+1}} + Q_{t+1} - \delta(U_{t+1})]\xi_{t+1}$
Capital producers	
Net investment	$I_{nt} = I_t - \delta\left(U_t\right)\xi_t K_t$
Optimal investiment decision (net)	$Q_t = 1 + f_t + \frac{I_{nt}+\bar{I}}{I_{nt-1}+\bar{I}} f_t' - E_t \beta \Lambda_{t,t+1}\left(\frac{I_{nt+1}+\bar{I}}{I_{nt}+\bar{I}}\right)^2 f_{t+1}'$
Adjustment cost	$f_t \equiv \frac{\eta_i}{2}\left(\frac{I_{nt}+\bar{I}}{I_{nt-1}+\bar{I}} - 1\right)^2$
Capital accumulation	$K_{t+1} = \xi_t K_t + I_{nt}$
Final goods producers	
Production	$Y_t = Y_{mt} D_t$
Price dispersion	$D_t = \gamma D_{t-1}\Pi_{t-1}^{-\gamma_p\varepsilon}\Pi_t^\varepsilon + (1-\gamma)\left(\frac{1-\gamma\Pi_{t-1}^{\gamma_p(1-\gamma)}\Pi_t^{\gamma-1}}{1-\gamma}\right)^{-\frac{\varepsilon}{1-\gamma}}$
Recursive equation of optimum price	$\begin{cases} \Pi_t^* = \frac{\varepsilon}{\varepsilon-1}\frac{F_t}{Z_t}\Pi_t \\ F_t = Y_t P_{mt} + E_t[\beta\gamma\Lambda_{t,t+1}\frac{\Pi_t^{-\gamma_p\varepsilon}}{\Pi_{t+1}^{-\varepsilon}} F_{t+1}] \\ Z_t = Y_t + E_t[\beta\gamma\Lambda_{t,t+1}\frac{\Pi_t^{\gamma_p(1-\varepsilon)}}{\Pi_{t+1}^{(1-\varepsilon)}} Z_{t+1}] \end{cases}$
Inflation dynamics	$\Pi_t^{1-\varepsilon} = \gamma\Pi_{t-1}^{\gamma_p(1-\varepsilon)} + (1-\gamma)(\Pi_t^*)^{1-\varepsilon}$
Central Bank	
Taylor rule	$i_t = (1-\rho)[\bar{\imath} + \kappa_\pi \pi_t + \kappa_y(\ln Y_t - \ln Y_t^*)] + \rho i_{t-1} + \varepsilon_t$
Credit policy	$\psi_t = \kappa E_t[(\ln R_{kt+1} - \ln R_{t+1}) - (\ln R_k - \ln R)]$
Cost of funds	$R_{t+1}^\tau \equiv \frac{R_{t+1} - \tau_t R_{t+1}^{RR}}{1-\tau_t}$
Other relations	
Economy constraint	$Y_t = C_t + I_t + f_t(I_{nt} + \bar{I}) + G_t + \Omega\psi_t Q_t K_{t+1}$
Government constraint	$G_t + \Omega\psi_t Q_t K_{t+1} = T_t + (R_{kt} - R_t)\psi_{t-1} Q_t K_t$
Fisher Equation	$\begin{cases} 1 + i_t = R_{t+1}\frac{E_t P_{t+1}}{P_t} \\ 1 + i_t^{RR} = R_{t+1}^{RR}\frac{E_t P_{t+1}}{P_t} \end{cases}$

Table 2: Variables of the Model

Variable	Description
Y_{mt}, P_{mt}	{Production, Price} of intermediate goods
Y_t	Final goods production
D_t	Price dispersion
K_t	Capital
L_t	Labor
I_t	Gross Investment
I_{nt}	Net Investment
C_t	Consumption
Q_t	Market value of one unity of capital
δ_t	Depreciation rate of capital
U_t	Capital utilization
ϱ_t	Marginal utility of consumption
$\Lambda_{t,t+1}$	Stochastic discount factor
N_t	Net worth
R_{kt}	Gross return on capital
R_t, R_t^{τ}, R_t^{RR}	Gross interest rate {without reserve requirements, with reserve requirements, of reserve requirements' remuneration}
ν_t, η_t	Value of {asset, Net worth} of banks
ϕ_t	Private leverage
$z_{t,t+1}$, $x_{t,t+1}$	Growth rate of {asset, Net worth} of banks
$\Pi_t^* \equiv P_t^*/P_{t-1}$	Optimal price normalized by previous period prices
F_t, Z_t	{Numerator, Denominator} of the optimal price normalized choice
$\Pi_t \equiv P_t/P_{t-1}$	Gross inflation
i_t	Net interest rate
Z_t^C, Z_t^L, A_t, G_t, ξ_t, i_t^{RR}, τ_t, $e_{N_{et}}$, ε_t	Exogenous shock {on consumption utility, on labor desutility, on technology, on government expenditures, on capital quality, on reserve requirements remuneration, on reserve requirements ratio, on banks' net worth, of monetary policy}
ψ_t	Proportion of assets financed by the Central Bank
W_t	Real wage

Table 3: Parameters of the Model

Parameter	Description	Value
β	Households discount rate	$[0,1]$
σ	Intertemporal elasticity of substitution	>0
h	Habit formation parameter	$[0,1]$
χ	Relative weight of labor in the households utility function	>0
φ	Inverse of labor supply elasticity	>0
λ	Fraction of capital that can be deviated by banks	$[0,1]$
ω	Proportional transfers to new banks	$[0,1]$
θ	Survival probability of banks	$[0,1]$
α	Capital share in the production	$[0,1]$
δ	Depreciation rate	$[0,1]$
η_i	Inverse of net investment elasticity in relation to the capital price	>0
ζ	Elasticity of marginal depreciation in relation to the utilization rate	>0
$\bar{G}$	Government expenditures in the steady state	$[0,1]$
ϵ	Elasticity of substitution among final goods	>1
γ	Probability of a final producer not adjust price optimally	$[0,1]$
γ_p	Parameter of price indexation of final goods	$[0,1]$
κ_π, κ_y	Taylor rule's coefficient associated to the { inflation; output gap }	>0
κ_s	Coefficient of credit policy in relation to the *spread*	>0
$\bar{\psi}$	Government participation in the credit market in the *steady state*	$[0,1]$
$\bar{R}^{RR}$	Real remuneration of reserve requirements in the *steady state*	>0
$\bar{\tau}$	Reserve requirements ratio in the *steady state*	$[0,1]$
ρ_C, ρ_L, ρ_A, ρ_G, ρ_ξ, $\rho_{i^{RR}}$, ρ_τ, ρ_N, ρ	Persistence of the shock { on consumption utility; on labor desutility; on technology; on government expenditures; on capital quality; on reserve requirements remuneration; on reserve requirements ratio; on banks' net worth; of monetary policy }	$[0,1]$
σ_C, σ_L, σ_A, σ_G, σ_ξ, $\sigma_{i^{RR}}$, σ_τ, σ_N, σ_i	Standard deviation of the shock { on consumption utility; on labor desutility; on technology; on government expenditures; on capital quality; on reserve requirements remuneration; on reserve requirements ratio; on banks' net worth; of monetary policy }	>0
Ω	Unit cost of government intermediation	>0

Table 4: Observable Variables

Variable	Description	Source	Treatment
Y_t	Production of final goods	IBGE/SCNT[1]	fdl[3]
C_t	Household consumption	IBGE/SCNT[1]	fdl
G_t	Government expenditures	IBGE/SCNT[1]	fdl
L_t	Labor	IBGE/PME[1]	fdl
I_t	Gross investment	IBGE/SCNT[1]	fdl
W_t	Real wage	IBGE/PME[1]	fdl
i_t	Net interest rate	BCB/SNIPC[2]	asl[4]
π_t	Net inflation (IPCA)	IBGE[1]	asl
$Q_t K_{t+1}$	Market value of capital	BCB[2]	fdl

1. IBGE: www.ibge.gov.br

2. BCB: www.bcb.gov.br

3. fdl: first difference of natural logarithm

4. asl: adjusted smoothed level, is the value discounted by the average from 2005 on

Table 5: Calibrated Parameters

Parameter	Value	Source
β	0.990	Castro, Gouvea, Minella, Santos, and Souza-Sobrinho (2011)
σ	1.300	
h	0.740	
χ	1.000	
φ	1.000	
α	0.448	
δ	0.015	
$\bar{G}$	0.200	
ϵ	11.000	
γ	0.740	
γ_p	0.330	
ρ	0.790	
κ_π	2.430	
κ_y	0.160	
ρ_G	0.000	
ω	0.002	Gertler and Karadi (2011)
κ_s	0.000	Absence of endogenous response to the spread.
$\bar{\psi}$	0.000	
$\bar{R}^{RR}$	1.000	Steady state without reserve requirements remuneration
$\rho_{i^{RR}}$	0.000	Absence of persistence of reserve requirements remuneration
ρ_ξ	0.000	Absence of persistence of capital quality shock
ρ_N	0.000	Absence of persistence of net worth value shock
Ω	0.001	Low unity cost of government intermediation

Table 6: Priors and Posteriors

Parameter	Prior			Posterior		
	Distribution	Mean	Standard Deviation	Mean	Conficende Int.	
θ	Beta	0.952	0.050	0.988	0.984	0.994
λ	Beta	0.250	0.050	0.220	0.143	0.292
ζ	Gamma	1.000	0.250	1.608	0.9830	2.146
η_i	Gamma	4.000	2.000	1.043	0.749	1.344
$\bar{\tau}$	Beta	0.300	0.050	0.403	0.295	0.539
ρ_A	Beta	0.500	0.250	0.090	0.000	0.203
ρ_t	Beta	0.500	0.250	0.996	0.9921	0.9998
ρ_C	Beta	0.130	0.250	0.137	0.054	0.221
ρ_L	Beta	0.250	0.250	0.189	0.116	0.257
σ_A	Gamma Inv.	1.130	Inf	0.146	0.133	0.161
σ_G	Gamma Inv.	0.010	Inf	0.016	0.013	0.019
σ_i	Gamma Inv.	0.320	Inf	0.041	0.038	0.046
σ_ξ	Gamma Inv.	0.100	Inf	0.102	0.080	0.122
σ_t	Gamma Inv.	0.070	Inf	2.356	1.312	3.421
$\sigma_{i^{RR}}$	Gamma Inv.	0.010	Inf	0.861	0.018	1.206
σ_C	Gamma Inv.	8.800	Inf	1.702	1.035	4.101
σ_L	Gamma Inv.	0.170	Inf	0.08	0.064	0.095
σ_N	Gamma Inv.	0.010	Inf	0.110	0.001	0.490

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