REAL AND NOMINAL RIGIDITIES IN THE BRAZILIAN ECONOMY: AN ANALYSIS USING A DSGE MODEL

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Abstract

In the recent literature, there is growing interest in the development of economic models that deal with the role of nominal price rigidity, based on the optimizing behavior of rational agents in a dynamic stochastic general equilibrium (DSGE) framework. However, contrary to evidence, monetary policy shocks generate weak persistence of real and nominal variables. In this paper, the DSGE model developed by Dib (2003) was estimated for Brazil using Bayesian methods, which combine nominal rigidity and real rigidity to check whether the inclusion of the latter may increase the former and, consequently, the persistence of monetary policy shocks. Results showed that the inclusion of real rigidity contributes to the increase of nominal rigidity, particularly when included as employment adjustment costs. Simulation exercises showed that, when the model includes real rigidity, money supply, money demand and technology shocks have more persistent effects on some macroeconomic variables.

Keywords: DSGE models. Bayesian estimation. Real rigidity. Nominal rigidity.

1 Introduction

According to Dib (2003), there has been growing interest in the development of economic models that deal with the role of nominal price rigidity, based on the optimizing behavior of rational agents in a dynamic stochastic general equilibrium (DSGE) framework. These models explicitly account for the relationships between the behavior of aggregate quantities and prices, and the decisions for household utility maximization and firms' profit maximization. However, as pointed out by Dib (2003), monetary policy shocks generate only weak persistent effects on real and nominal variables, contradicting the bulk of evidence, which indicates that the effects of these shocks last several quarters. The problem of persistence has led to a rapid growth in the number of studies whose purpose is to identify alternative transmission channels.

In this sense, as demonstrated by Goodfriend and King (1997), one of the most frequently discussed topics in the macroeconomic field is the difference between flexible price models in the new classical macroeconomics and the analysis of real business cycles (RBC) and sticky price models in the New Keynesian economics. The main difference between them is that, in the first two types, monetary policy is not important for real activity, whereas in sticky price models monetary policy is central to the evolution of real activity.

According to Goodfriend and King (1997), new trends have been established for economic thinking, including some of the points addressed in the models mentioned above. The New

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Neoclassical Synthesis involves the systematic application of intertemporal optimization and rational expectations, according to Lucas critique (1976), and is applicable to price and output decisions, as in Keynesian models, and to decisions about consumption, investment and supply factors, as in real business cycles. Therefore, the New Neoclassical Synthesis model provides the tools for the analysis of the role of alternative monetary policies in an environment with rational expectations. However, as highlighted by Chari, Kehoe and McGrattan (2000), despite its advantages, persistent output movements as a response to monetary shocks are hard to obtain.

An important study by Chari, Kehoe and McGrattan (2000) which investigated the persistence of output movement after monetary shocks demonstrated that the generation of persistence requires that prices not change excessively over a long period after a shock. To generate such rigidity, the authors used a model in which small frictions lead to long periods of endogenous price stickiness, and prices are therefore set in a staggered fashion.[5] However, they found that this measure alone does not generate business cycles that respond satisfactorily to monetary shocks, and is not, therefore, a solution to long-term issues.

In a later study, Kiley (2002) compared two types of models with different forms of rigidity and analyzed their implications for relative price variability in an environment with stationary inflation. The author's purpose was to check how the differences between the models may affect the loss of welfare and whether the different forms of rigidity result in similar output movements in response to monetary shocks. Therefore, in a dynamic general equilibrium environment, the Taylor models (1980), in which the prices are fixed in a staggered fashion, and the Calvo models (1983), with partial price adjustments, were used. The results, however, contradicted the current literature, revealing that the economy responds to shocks in absolutely different ways, and the social cost of rigidity is considerably higher in the Calvo model (1983). Still, Kiley (2002) concluded that this model implies a greater distortion of relative prices and greater persistence in response to shocks because there is a number of firms that cannot adjust their prices for many periods.

In a paper published in the same year, Huang and Liu (2002) showed that there are two types of staggered contracts, one for prices and one for wages, and that the assumption that they have similar impacts on persistence, that is, both can generate it or neither of them can, may lead to errors. To confirm these findings, the authors worked with a dynamic stochastic general equilibrium model. Their results showed that the mechanism of staggered wage setting has greater persistence, whereas staggered price setting does not produce the same effect.

To analyze the inadequacy of the mechanism of staggered price setting in generating persistence, Huang and Liu (2002) built a model that included real rigidity, and inserted this factor in the segmentation of the labor market. Their exercise helped to elucidate possible interactions between nominal and real rigidities that may increase persistence in response to shocks. The authors found that this type of real rigidity does not change the result of the mechanism of staggered wage setting in the aggregate dynamics, but improves the capacity of the mechanism of staggered price setting in generating real persistence as an effect of monetary shocks.

Corroborating this view, Ball and Romer (1990) demonstrated that, in a static structure, the level of nominal rigidity arising from a given *menu cost* increases according to the level of real rigidity, which produces greater real effects in response to monetary shocks. Nonetheless, real rigidity does not imply nominal rigidity, that is, in the absence of nominal rigidity, prices adjust completely in response to monetary supply shocks, regardless of the extent of real rigidity.

In another study in the same vein, Dib and Phaneuf (2001) incorporated real rigidity into the model as a way to increase the persistence in response to shocks. Based on the papers published by

[5] In the present paper, we use the term "staggered price setting" originally coined by Taylor (1980).

Ireland (1997) and Rotemberg and Woodford (1997), the authors used a model with monopolistic competition between firms, nominal rigidity in price adjustment costs and real rigidity given by the convex cost of labor input adjustment. First, Dib and Phaneuf (2001) estimated a model without real rigidity for the US postwar economy, and found a low price adjustment cost. In addition, they found that the money supply shocks yield a weak, non-persistent response of output, real wages and hours worked. In this context, the authors found that increasing the magnitude of price adjustment costs does not promote the endogenous creation of persistence, confirming the results reported by Chari, Kehoe and McGrattan (2000).

The same authors then estimated a model that has real and nominal rigidity. They found that, for a given price adjustment cost parameter, labor adjustment cost mitigates the initial response of real wages and hours worked to demand shocks and to aggregate supply due to the smaller initial change in labor input. Nevertheless, firms continue to adjust labor in subsequent periods. The time necessary to do that depends on the magnitude of labor adjustment costs. Thus, monetary shocks may have more persistent effects on real wages and hours worked. Also, the authors demonstrated that, in this context, prices and marginal costs of production adjust more slowly to monetary shocks, generating greater persistence. They concluded that the combination of real and nominal rigidities increases nominal price rigidity and thus generates an output response that is more persistent after a monetary shock.

In a later paper, Dib (2003) included another form of real rigidity in the model, which, in addition to being found in the labor market, it may also appear in goods/capital. Therefore, he developed a model that combines these two forms of real rigidity with nominal rigidity, and estimated it for the Canadian economy. In his model, nominal rigidity is given in the form of price adjustment costs, and real rigidity is modeled as the convex costs of adjusting capital and/or employment. Dib (2003) demonstrated that rigidity in capital and labor markets in a model with price adjustment cost might induce a gradual response of real variables to shocks, and the marginal costs of production of fixed-price firms may also adjust more slowly. The results found for the Canadian economy showed that the models with real rigidity differ substantially from those that have only nominal rigidity. In the first case, the effects of money supply shocks on real variables last considerably longer.

The role of real and nominal rigidities in macroeconomic modeling as a way to increase outputand inflation persistence was analyzed by Silveira (2008) for the Brazilian economy. The author estimated models in which these two forms of rigidity were included by means of endogenous persistence mechanisms. The author's choice of these models derived from the studies conducted by Christiano *et al*. (2005) and Smets and Woulters (2004), for whom endogenous persistence mechanisms should improve basic new Keynesian models so that they produce output and inflation persistence.

Several attempts have been made to improve the generation of persistence in response to monetary policy shocks. The different studies that were undertaken fed the perception that one way to solve the problem is by including real rigidity in the models. Therefore, we analyzed the model developed by Dib (2003) and estimated it for the Brazilian economy. Our purpose was to investigate whether, in the Brazilian case, the inclusion of real rigidity contributes to an increase in nominal rigidity, and whether the presence of these forms of rigidity increases the real effects of money supply, money demand and technology shocks on output, real wages, hours worked, and inflation rate. We also evaluated the contribution of each type of shock to fluctuations in output, inflation rate and money supply growth rate.

The choice of the model was based primarily on the importance of including real and nominal rigidities in a model estimated for Brazil. Nominal rigidity is easily observed, as Brazil has a highly indexed pricing system, causing inflation rates to change rather slowly. Real rigidity, in turn, is present in the labor market due to the high level of protection, which considerably decreases its flexibility. The strict current labor laws generate disincentive to turnover, which results in lower employee mobility.

A good indicator of this situation is the Employment Protection Index (EPI), calculated by the Organization for Economic Cooperation and Development (OECD) for 40 countries, which includes 21 items that quantify costs and procedures related to the hiring and firing of employees. This index ranges from zero to six, where zero indicates the lowest level of protection. In 2008, Brazil had an index of 2.75, which placed it in the 9th position among countries with the most protected labor markets. Canada, the country for which Dib (2003) estimated the model applied in our paper, holds the 38th position, with an EPI of 0.75. The EPI ranking is shown in Table 1.

Table 1 – Employment Protection Index

Position	Country	EPI
1st	Turkey	3.72
2nd	Indonesia	3.68
3rd	Luxembourg	3.25
4th	Portugal	3.15
5th	Mexico	3.13
6th	France	3.05
7th	Spain	2.98
8th	India	2.77
9th	Brazil	2.75
⋮	⋮	⋮
38th	Canada	0.75
39th	United Kingdom	0.75
40th	United States	0.21

Source: OECD, 2008

The present study describes the unprecedented application of the method used by Dib (2003) to the Brazilian reality. The Bayesian inference was used and the log-linearization was obtained around the stationary state of the equilibrium model described by Dib (2003) by using first-degree Taylor approximations to the variables.

This paper is organized into three sections, in addition to this introduction and to the final remarks. Section 2 briefly describes the model developed by Dib (2003) and the equilibrium equations log-linearized around the steady state. Section 3 analyzes the estimation results for the four models. Finally, Section 4 presents simulation exercises for different combinations of real and nominal rigidities in order to analyze how the economy reacts to induced shocks, the time elapsed before the variables return to their steady-state levels and the contribution of each type of shock to the fluctuations of some of predefined variables.

2 A DSGE model with real and nominal rigidities

The macroeconomic analysis using dynamic stochastic general equilibrium (DSGE) models has gained popularity among researchers. These models have been recently used by several institutions around the world as the basis for the decision-making process surrounding economic policies. One of their main advantages is that they explicitly indicate the problems with microeconomic decision-making, which give rise to the macroeconomic dynamics. According to Kremer *et al* (2006), this configuration allows linking the advances in macroeconomic theory to those in microeconomics. This way, incentive constraints, imperfect information problems and strategic interactions between agents are incorporated into the modern general equilibrium model, increasing the consistency of such models.

As Kocherlakota (2010) puts it, these models were developed as a way to solve the problems raised by the Lucas critique, according to which changes in the monetary policy regime lead to changes in supply and demand relations as well. The five fundamental characteristics of these models are the following : *(i)* they include resource and budget constraints and explain how economic agents use capital and labor inputs to create goods and the impossibility to increase spending without increasing revenues; *(ii)* they explicitly include the utility function of households and firms; *(iii)* they have a forward-looking behavior,[6] which is important because the agents' expectations for the future change their behavior in the present; *(iv)* they are explicit about the shocks that affect the economy; *(v)* they are mathematically designed to forecast the behavior of the whole economy. So, when they have all these characteristics, the models are referred to as DSGE, which means they are *dynamic*, because of the *forward-looking* behavior of agents; *stochastic*, in that they include shocks; *general*, because they include the whole economy; and, finally, *equilibrium*, because they explicitly show the constraints and utilities of households and firms[7] (KOCHERLAKOTA, 2010).

The model estimated in this paper was developed by Dib (2003) and poses the problem of a DSGE model that includes real and nominal rigidities. It assumes that the economy is composed of a representative household, a representative final goods-producing firm, several intermediate goods-producing firms, which are identical and may, therefore, be represented by a single firm, and a monetary authority.

Real rigidity is included in two different forms: by the intertemporal cost for a representative household to adjust capital, and by the costs incurred by the intermediate goods-producing firm when it adjusts its labor input. Moreover, it is known that, in the absence of nominal frictions in the model, money is superneutral in a monopolistically competitive framework. To avoid neutrality, Dib (2003) introduced nominal rigidity in the model by means of the costs that the intermediate goods-producing firm pays to adjust its price. Adjustment costs are given by the following equations:

Capital adjustment cost: $CAC_t = \frac{\phi_k}{2}\frac{i_t^2}{k_t}$ (1)

where i_t is investment, k_t is the capital and $\phi_k > 0$ is the capital adjustment cost parameter. In this format, the cost to adjust capital stocks increases according to the desired adjustment speed, encouraging households to change investments gradually.

Price adjustment cost: $CAP_t = \frac{\phi_p}{2}\left(\frac{p_t}{p_{t-1}} - 1\right)^2 y_t$ (2)

where y_t is the final good produced, p_t is the price of the final good and $\phi_p \geq 0$ is the price adjustment cost parameter. The term in brackets in equation (2) is the price variation rate of the economy. Therefore, the greater the value of ϕ_p, the slower prices tend to be adjusted in an attempt to avoid that costs, when adjusted, become too high.

Employment adjustment cost: $EAC_t = \frac{\phi_h}{2}\left(\frac{h_t}{h_{t-1}} - 1\right)^2 y_t$ (3)

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[6] This characteristic is known in the international literature as *"forward looking"*.

7 For further information on DSGE models, see Kremer et al (2006).

where h_t is the amount of hours worked and $\phi_h \geq 0$ is the employment adjustment cost parameter. Once the cost to adjust employment in response to aggregate shocks increases with the speed of the desired adjustment, firms have an incentive to make gradual changes and promote smooth intertemporal changes in their labor demand.

The symmetric equilibrium of this model satisfies the first-order conditions of the household and of the intermediate goods-producing firms; the aggregate resource constraint; the rule to money supply; and the stochastic processes of money supply, money demand and technology shocks. Therefore, it is composed of 14 equations and 14 variables, as described next:[8]

$$\frac{\tilde{c}_t^{-\frac{1}{\gamma}}}{\tilde{c}_t^{\frac{\gamma-1}{\gamma}}+b_t^{\frac{1}{\gamma}}\tilde{m}_t^{\frac{\gamma-1}{\gamma}}} = \tilde{\lambda}_t \tag{4}$$

$$\frac{b_t^{\frac{1}{\gamma}}\tilde{m}_t^{-\frac{1}{\gamma}}}{\tilde{c}_t^{\frac{\gamma-1}{\gamma}}+b_t^{\frac{1}{\gamma}}\tilde{m}_t^{\frac{\gamma-1}{\gamma}}} = \tilde{\lambda}_t - \beta E_t\left(\frac{\tilde{\lambda}_{t+1}}{g\pi_{t+1}}\right) \tag{5}$$

$$\frac{\eta}{1-h_t} = \tilde{\lambda}_t\tilde{w}_t \tag{6}$$

$$E_t\left[\frac{\tilde{\lambda}_{t+1}}{\tilde{\lambda}_t}\left(r_{t+1}+\frac{\phi_k}{2}\left(\frac{\tilde{\imath}_{t+1}}{\tilde{k}_{t+1}}\right)^2+(1-\delta)\left(1+\phi_k\frac{\tilde{\imath}_{t+1}}{\tilde{k}_{t+1}}\right)\right)\right] = \frac{g}{\beta}\left(1+\phi_k\frac{\tilde{\imath}_t}{\tilde{k}_t}\right) \tag{7}$$

$$g\tilde{k}_{t+1} = (1-\delta)\tilde{k}_t + \tilde{\imath}_t \tag{8}$$

$$\tilde{y}_t = A_t\tilde{k}_t^{\alpha}\, h_t^{1-\alpha} \tag{9}$$

$$\frac{\alpha\tilde{y}_t}{\tilde{k}_t q_t} = r_t \tag{10}$$

$$\frac{(1-\alpha)\tilde{y}_t}{q_t} = \tilde{w}_t h_t + \phi_h\left(\frac{h_t}{h_{t-1}}-1\right)\frac{h_t\tilde{y}_t}{h_{t-1}} - \beta\phi_h E_t\left[\left(\frac{h_{t+1}}{h_t}-1\right)\frac{h_{t+1}+\tilde{y}_{t+1}}{h_t}\frac{\tilde{\lambda}_{t+1}}{\tilde{\lambda}_t}\right] \tag{11}$$

$$q_t^{-1} = \frac{\theta-1}{\theta} + \frac{\phi_p}{\theta}(\pi_t-1)\pi_t - \frac{\beta\phi_p}{\theta}E_t\left[(\pi_{t+1}-1)\frac{\pi_{t+1}\tilde{y}_{t+1}\tilde{\lambda}_{t+1}}{\tilde{y}_t\tilde{\lambda}_t}\right] \tag{12}$$

$$\tilde{y}_t = \tilde{c}_t + \tilde{\imath}_t + \frac{\phi_k}{2}\frac{\tilde{\imath}_t^2}{\tilde{k}_t} + \frac{\phi_p}{2}(\pi_t-1)^2\tilde{y}_t + \frac{\phi_h}{2}\left(\frac{h_t}{h_{t-1}}-1\right)^2\tilde{y}_t \tag{13}$$

$$\mu_t = \frac{g\tilde{m}_t\pi_t}{\tilde{m}_{t-1}} \tag{14}$$

$$\log(A_t) = (1-\rho_A)\log(A) + \rho_A\log(A_{t-1}) + \varepsilon_{At} \tag{15}$$

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[8] **Variables:** c_t = household consumption $b_t =$ money demand shock; $m_t =$ real money supply; $\lambda_t =$ marginal utility of real income; $\pi_t =$ gross inflation rate at time t (p_t/p_{t-1}); $h_t =$ hours worked; $w_t =$ real wage; $r_t =$ real rate of capital loan; i_t = investments; k_t = capital; $y_t =$ final product; $q_t =$ measure of gross markup price over marginal cost (λ/ξ); A_t = technology shock; μ_t = money supply growth rate (M_t/M_{t-1}). Parameters: γ is the constant elasticity of substitution between consumption and real money (> 0); β is the discount factor of the household utility function $[\in (0,1)]$; g is the labor productivity growth rate (≥ 1); η denotes the weight attributed to leisure in the household utility function (> 0); δ is the constant rate of capital depreciation $[\in (0,1)]$; α indicates the share of capital in production $[\in (0,1)]$; θ measures the degree of monopoly power of the intermediate goods market; ω_A indicates whether the monetary policy is affected by technology shocks; ω_b indicates whether the monetary policy is affected by money demand shocks; ρ_A, ρ_b and ρ_μ are autoregressive parameters.

$$\log(b_t) = (1-\rho_b)\log(b) + \rho_b \log(b_{t-1}) + \varepsilon_{bt} \tag{16}$$

$$\log(\mu_t) = \left(1-\rho_\mu\right)\log(\mu) + \rho_\mu \log(\mu_{t-1}) + \omega_A \varepsilon_{At} + \omega_b \varepsilon_{bt} + \varepsilon_{\mu t} \tag{17}$$

Equations (4) through (8) show the first-order conditions of the representative household. As demonstrated by Dib (2001), equations (4) and (6) equate the marginal rate of substitution between consumption and labor with real wage. Equation (5) shows that the marginal utility of money balance is equal to the difference between current marginal utility of consumption and the expected future marginal utility of consumption adjusted by the expected inflation rate. Equation (7) is the optimal intertemporal allocation of wealth.

Equations (9) through (12) correspond to the first-order conditions of the intermediate goods-producing firm. Analyses show that equations (10) and (11) equate the marginal rate of substitution between capital consumption and labor with real wage. With employment adjustment costs, the price of labor consists of the real wages paid to the household and of the marginal labor adjustment cost in the current and future periods. Equation (12) represents the adjustment of the nominal prices of goods produced by the intermediate goods-producing firm over time. Finally, equations (13) and (14) describe the aggregate resource constraints and the money supply rule, and equations (15) through (17) represent the stochastic processes.[9]

The model described above is nonlinear and requires complex mathematical operations. Therefore, it was necessary to calculate its log-linear approximation around the steady state, following the work of Zietz (2006). The author states that log-linearization, based on first-order Taylor approximations, helps to reduce mathematical complexity in systems of numerically specified equations that need to be solved simultaneously. For this purpose, the method converts nonlinear equations into linear equations in terms of log-deviations of steady-state values from the associated variables. After defining the log-deviation of a variable x from its steady-state value as $\bar{x}_t = log(x_t/x)$, the log-linearized approximation around the steady state for equations (4) through (17) is given respectively by:

$$-\left((1-\psi)c^{-(1-\psi)} + \psi\lambda c^{\psi}\right)\bar{c}_t = \left(\lambda\left(c^{\psi} + b^{(1-\psi)}m^{\psi}\right)\right)\bar{\lambda}_t + \left((1-\psi)\lambda b^{(1-\psi)}m^{\psi}\right)\bar{b}_t + \left(\psi\lambda b^{(1-\psi)}m^{\psi}\right)\bar{m}_t \tag{18}$$

$$\left(\psi b^{(1-\psi)}m^{-(\psi-1)}\right)\left(\frac{\beta\lambda m}{g\pi} - \lambda m\right)\bar{m}_t + \left((1-\psi)b^{(1-\psi)}m^{-(1-\psi)}\right)\bar{m}_t + \left((1-\psi)b^{(1-\psi)}m^{-(1-\psi)}\right)\left(1 - \lambda m + \frac{\beta\lambda m}{g\pi}\right)\bar{b}_t +$$

$$\left(\psi\lambda c^{\psi}\right)\left(\frac{\beta}{g\pi} - 1\right)\bar{c}_t - \lambda\left(c^{\psi} + b^{(1-\psi)}m^{\psi}\right)\bar{\lambda}_t = -\mathrm{E}_t\left[\bar{\lambda}_{t+1} - \bar{\pi}_{t+1}\right]\left(\frac{\beta\lambda c^{\psi}}{g\pi}(1 + \psi\bar{c}_t) + \frac{\beta\lambda b^{(1-\psi)}m^{\psi}}{g\pi}\left(1 + \psi\bar{m}_t + (1-\psi)\bar{b}_t\right)\right) \tag{19}$$

$$\left(\frac{h}{h-1}\right)\bar{h}_t = \bar{\lambda}_t + \bar{w}_t \tag{20}$$

$$E_t[r\bar{r}_{t+1} - \frac{i\phi_k}{k}\left(\frac{i}{k} + (1-\delta)\right)\bar{k}_{t+1} + \frac{i\phi_k}{k}\left(\frac{i}{k} + (1-\delta)\right)\bar{\imath}_{t+1} + \left(r + (1-\delta)\right)\bar{\lambda}_{t+1} +$$

$$\frac{i\phi_k}{k}\left(\frac{i}{2k} + (1-\delta)\right)\bar{\lambda}_{t+1} - \left(r + (1-\delta)\right)\bar{\lambda}_t - \frac{i\phi_k}{k}\left(\frac{i}{2k} + (1-\delta)\right)\bar{\lambda}_t] = \frac{gi\phi_k}{\beta k}\left(\bar{\imath}_t - \bar{k}_t\right) \tag{21}$$

$$\bar{k}_{t+1} = \left(\frac{1-\delta}{g}\right)\bar{k}_t + \left(\frac{g-1+\delta}{g}\right)\bar{\imath}_t \tag{22}$$

$$\bar{y}_t = \bar{A}_t + \alpha\bar{k}_t + (1-\alpha)\bar{h}_t \tag{23}$$

[9] For the description and complete derivation of the model, see Dib (2001) and Dib (2003).

$$\bar{r}_t = \bar{y}_t - \bar{k}_t - \bar{q}_t \quad (24)$$

$$\left(\frac{(1-\alpha)y}{q}\right)\bar{q}_t - \left(\frac{(1-\alpha)y}{q}\right)\bar{y}_t + (wh + y\phi_h)\bar{h}_t + wh\bar{w}_t - y\phi_h\bar{h}_{t-1} = \beta y\phi_h E_t\left[\bar{h}_{t+1} - \bar{h}_t\right] \quad (25)$$

$$-\frac{1}{q}\bar{q}_t = \frac{\pi\phi_p}{\theta}(2\pi - 1)\bar{\pi}_t - \frac{\beta\phi_p(\pi^2-\pi)}{\theta}E_t\left[2\bar{\pi}_{t+1} + \bar{y}_{t+1} + \bar{\lambda}_{t+1} - \bar{y}_t - \bar{\lambda}_t\right] \quad (26)$$

$$\bar{y}_t = \frac{c}{y}\bar{c}_t + \left(\frac{i}{y}\left(1 + \frac{i\phi_k}{k}\right)\right)\bar{\iota}_t + \left(\phi_p\pi(\pi - 1)\right)\bar{\pi}_t + \left(\frac{\phi_p(\pi-1)^2}{2}\right)\bar{y}_t - \left(\frac{i^2\phi_k}{2ky}\right)\bar{k}_t \quad (27)$$

$$\bar{m}_{t-1} = \bar{m}_t + \bar{\pi}_t - \bar{\mu}_t \quad (28)$$

$$\bar{A}_t = \rho_A\bar{A}_{t-1} + \varepsilon_{At} \quad (29)$$

$$\bar{b}_t = \rho_b\bar{b}_{t-1} + \varepsilon_{bt} \quad (30)$$

$$\bar{\mu}_t = \rho_\mu\bar{\mu}_{t-1} + \omega_A\varepsilon_{At} + \omega_b\varepsilon_{bt} + \varepsilon_{\mu t} \quad (31)$$

where $\left(\frac{\gamma-1}{\gamma}\right) = \psi$.

In the present paper, four versions of this model were estimated using different combinations of price, capital and employment rigidities. The first model estimated was a standard sticky price (SSP) model, in which there is a price adjustment cost ($\phi_p \neq 0$) but no capital or employment adjustment costs ($\phi_k = \phi_h = 0$). This model was estimated by Ireland (1997) for the US economy and by Dib (2003) for the Canadian economy. In the second model, with price and capital rigidities (PCR), there is price adjustment cost ($\phi_p \neq 0$), capital adjustment cost ($\phi_k \neq 0$), but no employment adjustment cost ($\phi_h = 0$). After that, a model with price and employment rigidities (PER) was estimated, in which there is price adjustment cost ($\phi_p \neq 0$), employment adjustment cost ($\phi_h \neq 0$), but no employment adjustment cost ($\phi_k = 0$). Finally, a model with price, capital and employment adjustment costs (PCER) was estimated, in which the parameters, ϕ_p, ϕ_k and ϕ_h are different from zero. The last three models were estimated by Dib (2003) for the Canadian economy using Bayesian inference.[10]

3 Empirical results

The model was estimated based on the observation of output series, price level, and money stock, using data for the Brazilian economy. The sampling period covered the first quarter of 2000 through the first quarter of 2010, when the behavior of the Brazilian economy was more stable. In addition, based on the performance of some macroeconomic variables and on previous academic studies, it was possible to calibrate some of the parameters of the model under analysis. Both procedures are described in the subsections ahead.

3.1 Calibration procedure

First, it is assumed that the long-term real interest rate for Brazil is about 1.9% per quarter, which corresponds to 8% per year. According to the economic theory, the intertemporal household discount rate in steady state is given by $\beta = 1/(1 + r)$; therefore, a value of 0.98 was used for this rate. This result is close to the one used by Santos and Leon (2010) for the Brazilian economy.

[10] For further information on “Bayesian inference”, see Lancaster (2004) and Kim and Nelson (1960).

The consumption velocity of money in steady state was based on the average consumption velocity of M3 in Brazil from 2000/I to 2010/I. Therefore, the parameter b – which determines money consumption in the steady state - was set at 0.58. M3 was used as a base, instead of M2, due to the high degree of indexation in Brazil. The parameter α, which corresponds to the share of fixed capital in production, was calibrated at 0.17 based on the mean fixed capital ratio in the Brazilian GDP for the estimation period. Based on the paper by Bond *et al* (2007), the parameter δ was set at 0.05, that is, the rate of capital depreciation was calculated at 5% per year.

The Bayesian estimation method, used in this paper, requires that the a priori beliefs about the parameters to be estimated be specified. As explained in the next subsection, diffuse a priori distributions were used as initial data, in which only parameter variation intervals are selected. An important constraint is that the value indicated in the initial hunch about the parameter should be within this interval. One of the assumptions of the model estimated here is that the parameter g, which corresponds to the economic growth rate, is equal to or greater than 1. Thus, for this parameter, the domain of the uniform a priori distribution is $[1, \infty)$ and the initial hunch could be any number greater than 1. However, after several attempts, it was perceived that only value 1 could be used as an initial hunch for the parameter g because values different from 1 would compromise the stability of the model and make estimation impossible. So, the domain of the a priori distribution of g was redefined to lie between $(0, \infty)$, in order to check whether the mean value chosen for this parameter in the a posteriori distribution would be equal to or greater than 1, not violating the model's assumption for this parameter. Nevertheless, when this procedure was adopted, it converged to values between 0 and 1, which violates one of the model's assumptions. Therefore, it was set at 1.

Finally, according to Dib (2003), the parameter θ, which measures the degree of monopoly power of the intermediate goods-producing firms, was set at 6. Then, the result of the markup price $\theta/(\theta - 1)$ matches the value of 1.2 described in Rotemberg and Woodford (1995). The calibrated values for the model's parameters are shown in Table 2.

Table 2 – Calibrated values for the parameters of the original model

Parameters	$\boldsymbol{\beta}$	$\boldsymbol{b}$	$\boldsymbol{\alpha}$	$\boldsymbol{\delta}$	g	$\boldsymbol{\theta}$
Values	0.98	0.58	0.17	0.05	1.00	6.00

Source: Data obtained by the authors

During log-linearization around the steady state, parameters other than those already included in the nonlinear version of the model were added. These parameters correspond to the steady-state value of some variables and were calculated according to the initial hunches for the other parameters using the steady-state ratios, obtained from equations (4) through (17). The calibrated values for the model's additional parameters are shown in Table 3.

Table 3 – Calibrated values for the additional parameters of the log-linearized model

Parameters	$\boldsymbol{h}$	$\boldsymbol{\lambda}$	$\boldsymbol{c}$	$\boldsymbol{m}$	$\boldsymbol{y}$	$\boldsymbol{q}$	$\boldsymbol{w}$	$\boldsymbol{\pi}$	$\boldsymbol{i}$	$\boldsymbol{k}$	$\boldsymbol{r}$
Calibrated values	0.2019	4.7400	0.2083	0.1332	0.2314	1.2000	0.7930	1.0000	0.0226	0.4511	0.0727

Source: Data obtained by the authors

3.2 Estimation procedure

As previously mentioned, the model was estimated based on three log-linearized quarterly series of the Brazilian economy: output, price level, and money stock. The output series was obtained from the real per capita GDP, which was calculated using the nominal GDP series deflated by the implicit GDP deflator and divided by the population. The implicit GDP deflator was used for the price level of the economy. As the GDP is not published on a quarterly basis, an approximate calculation was made according to the quarterly chain-linked GDP series and the quarterly GDP series at current values. Given that the former expresses real output variation, and the latter, its nominal variation, it is assumed that the difference between them results in the variation of the implicit GDP deflator, based on which an index number series was built for this variable. Finally, a money stock series was built using real M2 per capita, calculated from the nominal M2 series deflated by the implicit GDP deflator and expressed in terms of per capita values divided by the resident population.

The sampling period extended from the first quarter of 2000 to the first quarter of 2010, and included 41 observations. The series used are available from the Central Bank of Brazil (CBB) and from the Brazilian Institute of Geography and Statistics (IBGE). The annual series published by the IBGE was interpolated so as to obtain the quarterly data on the population.

The series were seasonally adjusted by the means, which were smoothed by the Hodrick-Prescott (HP) filter with $\lambda =$1,600. The estimation procedure was implemented using the Dynare software for Matlab which, for having several built-in routines, allowed reducing computational costs.

3.2.1 Definition of a priori distributions

In Bayesian inference, the first step in the estimation procedure is the selection of independent a priori distributions for the model's parameters. Parameter constraints, such as non-negativity and domain, affect the selection of these distributions.

As the information set to determine some parameter characteristics is restricted, the use of diffuse a priori distributions is common. Hence, uniform distributions were chosen. In these distributions, only the interval of variation of the parameter to be estimated is calculated and all the values within this interval have the same likelihood to occur, whereas the values outside the interval have zero likelihood.

The parameter γ, which expresses the constant elasticity of substitution between consumption and real money, should be positive ($\gamma > 0$). As a result, the domain of the parameter ψ, defined as $\psi = ((\gamma - 1)/\gamma)$, is the set of real numbers. In the four models estimated here, the uniform distribution between -1 and 1 was used. This interval was chosen because the mean value for this parameter was close to zero, which was found during the estimation procedure. In addition, different intervals resulted in instability of the other parameters.

Because it is necessary to ensure stationarity for the equations that represent the exogenous processes in the four models, uniform distributions between 0 and 1 (1 being excluded from the domain) were defined for the autoregressive parameters ρ_A, ρ_b and ρ_μ. The parameters ω_A and ω_b indicate whether the monetary policy is purely exogenous (when equal to zero), or whether it is affected by technology shocks and by money demand shocks (when different from zero). Initially, its domain includes the whole set of real numbers. Table 4 shows the interval chosen for these parameters in each of the models. These intervals are different from each other because of the paths indicated in the different adjustment attempts performed during the estimation procedure.

Inverse gamma distributions with infinite variance were defined for the standard deviations of the shocks. As these variables assume the value of zero in steady state, inverse gamma distributions are widely used in DSGE models because they include the whole set of positive real numbers, placing a greater weight upon values close to zero. The mean values chosen for these parameters in the four models are shown in Table 4, and may differ from each other because of adjustment issues, as explained above.

Table 4 – A priori distribution of parameters

	SSP Model			PCR Model			PER Model			PCER Model		
	Domain	Mean	Variance	Domain	Mean	Variance	Domain	Mean	Variance	Domain	Mean	Variance
ψ*	[-1.1]	0.0000	0.5774	[-1.1]	0.0000	0.5774	[-1.1]	0.0000	0.5774	[-1.1]	0.0000	0.5774
ϕ_p*	(0.10]	5.0000	2.8868	(0. 50]	25.0000	14.4338	[20.70]	45.0000	14.4338	(10.40]	25.0000	8.6603
ϕ_k*	---	---	---	(0. 10]	5.0000	2.8868	---	---	---	(0.5]	2.5000	1.4434
ϕ_h*	---	---	---	---	---	---	(0.10]	5.0000	2.8868	(0.20]	10.0000	5.7735
ω_A*	[-7.7]	0.0000	4.0415	[0.3]	1.5000	0.8660	[-3.3]	0.0000	1.7321	[-1.1]	0.0000	0.5774
ω_b*	[-5.5]	0.0000	2.8868	[-5.5]	0.0000	2.8868	[-1.1]	0.0000	0.5774	[-1.1]	0.0000	0.5774
ρ_A*	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887
ρ_b*	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887
ρ_μ*	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887	[0.1)	0.5000	0.2887
σ_A**	$\Re^+$	0.0200	Infinite	$\Re^+$	0.0500	Infinite	$\Re^+$	0.0200	Infinite	$\Re^+$	0.2000	Infinite
σ_b**	$\Re^+$	0.0200	Infinite	$\Re^+$	0.0500	Infinite	$\Re^+$	0.0200	Infinite	$\Re^+$	0.5000	Infinite
σ_μ**	$\Re^+$	0.0200	Infinite	$\Re^+$	0.0500	Infinite	$\Re^+$	0.0200	Infinite	$\Re^+$	0.0200	Infinite

Note: A priori distribution: * Uniform; ** Inverse gamma.

Source: Data obtained by the authors.

By definition, the price adjustment cost parameter ϕ_p found in all of the estimated models may be equal to or greater than zero. A uniform distribution between 0 and 10 was used for the estimation of the SSP model. Because the value of price adjustment cost is expected to increase when the capital adjustment cost is included in the model, a uniform distribution between 0 and 50 was used in the PCR model. The same is expected for the PER model, which, in addition to price adjustment cost, contains employment adjustment costs. Therefore, a uniform distribution between 20 and 70 was used for ϕ_p. Finally, in the PCER model, which contains the three types of adjustment costs, a uniform distribution between 10 and 40 was used for ϕ_p.

The capital adjustment cost parameter, ϕ_k, is found in two of the four models: PCR and PCER. In the first one, the uniform a priori distribution was assumed to be within the interval 1 to 10. In the second one, it was set within the interval 0 to 5. As to the employment adjustment cost parameter, ϕ_h, found in the PER and PCER models, a priori distributions were defined between 0 and 10 and 0 and 20. All a priori distributions are summarized in Table 4.

3.2.2 A posteriori distributions

After defining the a priori distributions, the next step consisted in using the data to change initial assumptions. For that purpose, the Metropolis-Hastings algorithm was used. Results[11] are shown in Table 5 and in Appendices A1 to A4. In the SSP and PCR models, the results found for ψ indicate that the mean value of the parameter γ is 1.01. Thus, the interest elasticity of money demand, $-\gamma$, is equal to -1.01. The values found for ψ in the PER and PCER models change marginally and, therefore,

[11] Table 5 shows the means for the a posteriori distributions and the 90% confidence interval for the estimated parameters. Appendices A1 through A4 show the a priori distributions (gray), the a posteriori distributions (black) and the mode of the a posteriori distributions (green dashed line).

do not result in significant variations of γ. These results are substantially higher than those found by Dib (2003) for Canada, which indicates that, in Brazil, less significant changes in interest rates are necessary for the monetary base to change.

In the SSP model, the results for the parameters ω_A and ω_b indicate that the Brazilian monetary policy is negatively affected by both technology shocks ($\omega_A = -2.6417$) and money demand shocks ($\omega_b = -0.8092$). So, in this model the response to technology shocks is countercyclical and the response to money demand shocks is procyclical. Nevertheless, when capital adjustment cost was added to the model, the values estimated for the parameters ω_A and ω_b changed significantly in comparison with those found for the SSP model, which indicates that, when there is price and capital rigidity, the Brazilian monetary policy is positively affected by both technology shocks ($\omega_A = 1.0532$) and money demand shocks ($\omega_b = -0.2573$). Therefore, contrary to what was found for the SSP model, in the PCR model the response of the monetary authority to technology shocks is procyclical, and to money demand shocks, countercyclical. The values in the 90% confidence interval of the PCR model showed that the technology shock may have a null impact on the money supply, and that the possibility that the money demand shocks have a negative impact on money supply is not ruled out. Table 5 shows that, although the values found for these parameters in the PER and PCER models change in relation to those found in the PCR model, they do not change the direction of responses to shocks.

In the four models, the mean values estimated for the autoregressive parameters indicate that the technology shocks, money demand shocks, and money supply shocks do not tend to be very persistent. Also, the parameters of standard deviations of technology shocks (σ_A), money demand shocks (σ_b) and money supply shocks (σ_μ) had low mean values, which indicates that these shocks are not highly volatile.

In the SSP model, the mean value of the price adjustment cost parameter ϕ_p was 1.972. According to equation (2) and assuming that the inflation rate for Brazil equals the target (4.5%), a price adjustment cost of 1.972 means that a 1% change in nominal prices involves the payment of a very low cost, about 0.012% of real GDP per quarter. As expected, after including capital adjustment cost in the model, the price adjustment cost had a greater mean value. This way, the mean value of the parameter ϕ_p in the PCR model was 3.7785. With this change, the variation of 1% in nominal prices increases cost to about 0.023% of real GDP per quarter. The results found for the PER model indicate that the impact of including the employment adjustment cost on the price adjustment cost is greater than that of including the capital adjustment cost.

In the PER model, ϕ_p had a considerably higher mean than the values found in the two previous models, which was 29.8379. Therefore, in Brazil, employment adjustment costs considerably increase the price adjustment cost. In addition, this result indicates that a 1% change in the nominal prices results in the payment of a cost of about 0.18% of real GDP per quarter. Finally, when the presence of the three adjustment costs is evaluated in the PCER model, ϕ_p has a mean of 15.5093, which is lower than the value found in the PER model. Although the magnitude of parameters is different, this trend is also seen in the paper written by Dib (2003), and this price adjustment cost implies that a change of 1% in nominal prices results in the payment of a cost of about 0.0095% of the real GDP per quarter.

In the PCR model, the mean value of the capital adjustment cost parameter, ϕ_k, was 1.4592. According to equation (1) and using the steady-state values of the variables k and i, shown in Table 3, the mean value estimated for ϕ_k has a mean capital adjustment cost of about 0.08% of the quarterly GDP. This parameter has a higher mean value in the PCER model, 2.3935, which results in a mean capital adjustment cost of about 0.14% of the quarterly GDP. Hence, we conclude that the inclusion of real rigidity in the form of employment adjustment cost in a model of nominal rigidity and real rigidity in the form of capital adjustment cost increases the magnitude of the latter.

Table 5 – Estimated parameters

	SSP Model		PCR Model		PER Model		PCER Model	
	Mean	**90%CI**	**Mean**	**90%CI**	**Mean**	**90%CI**	**Mean**	**90%CI**
ψ	0.0072	[0.0014; 0.0164]	0.0072	[0.0000; 0.0153]	0.0042	[0.0000; 0.0107]	0.0003	[0.0000; 0.0013]
ϕ_p	1.9720	[1.3058; 2.6162]	3.7785	[2.0726; 5.4454]	29.8379	[20.6664; 37.8774]	15.5093	[10.0035; 21.6254]
ϕ_k	---	---	1.4592	[1.0633; 1.8419]	---	---	2.3935	[1.0385; 3.6398]
ϕ_h	---	---	---	---	8.4610	[6.7682; 10.0000]	5.5384	[0.2737; 12.8437]
ω_A	-2.6417	[-4.6383; -0.6967]	1.0532	[0.0007; 1.8839]	1.4127	[0.5615; 2.3025]	0.5638	[0.1456; 0.9989]
ω_b	-0.8092	[-1.3480; -0.2926]	0.2573	[-0.2125; 0.7499]	0.5406	[0.2272; 0.9091]	0.1190	[0.0319; 0.1952]
ρ_A	0.0198	[0.0000; 0.0449]	0.5603	[0.3324; 0.7922]	0.2958	[0.0879; 0.5037]	0.3315	[0.0524; 0.5797]
ρ_b	0.3259	[0.0081; 0.5590]	0.0000	[0.0000; 0.0001]	0.4345	[0.1649; 0.1649]	0.0003	[0.0000; 0.0005]
ρ_μ	0.1842	[0.0000; 0.3451]	0.1111	[0.0000; 0.2292]	0.1254	[0.0001; 0.2537]	0.0883	[0.0000; 0.2100]
σ_A	0.0057	[0.0039; 0.0075]	0.0108	[0.0083; 0.0132]	0.0122	[0.0099; 0.0145]	0.0285	[0.0237; 0.0327]
σ_b	0.0174	[0.0128; 0.0217]	0.0321	[0.0158; 0.0483]	0.0333	[0.0188; 0.0471]	0.1487	[0.0957; 0.1936]
σ_μ	0.0325	[0.0262; 0.0390]	0.0349	[0.0275; 0.0422]	0.0331	[0.0267; 0.0392]	0.0307	[0.0247; 0.0363]

Source: Data obtained by the authors

.

Finally, in the PER model, the mean value of the employment adjustment cost parameter, ϕ_h, was 8.461. According to equation (3) and considering that the mean rate of quarterly variation of hours worked in Brazil is 1.4%, a 1% change in the number of hours worked generates a cost of about 0.09% of the quarterly GDP.[12] In the estimations made by Dib (2003) for Canada, the impact of including real rigidity in the form of employment adjustment cost over the price adjustment cost is higher. In that country, the SSP model has a ϕ_p of 2.8, vis-à-vis 44.07 in the PER model, whereas in Brazil, it goes from 1.972 to 29.8379, as previously mentioned. However, in the second model, the result found by the author for ϕ_h in the Canadian economy was only 1.85. Then, although the estimation of this model for the Brazilian economy points to a lower impact of this form of real rigidity over nominal rigidity in comparison with the Canadian economy, the employment adjustment cost is significantly greater in Brazil. This result is consistent with the evidence presented in the introduction of this paper, where it was demonstrated that, according to the employment protection index calculated by OCDE, Brazil has a considerably higher labor market rigidity than that found for Canada. The results for the PCER model showed a lower mean value for ϕ_h, 5.5384. This indicates that the mean cost of employment adjustment is about 0.06% of the quarterly GDP.

The estimation of the model showed that there is nominal rigidity in Brazil. Moreover, the inclusion of real rigidity in the form of capital and/or employment adjustment costs results in an increase in nominal rigidity, but this movement is more intense when real rigidity is included as employment adjustment cost. Our results suggest that, in Brazil, employment rigidity is considerably greater than capital rigidity.

[12] The mean quarterly rate of variation in hours worked for Brazil was obtained from the Ministry of Labor and Employment for the Brazilian formal labor market between 2000 and 2009. The Annual Report on Social Indicators shows the average amount of hours worked divided by the whole set of formal workers in the country. The annual variation of this variable was calculated based on these data. After obtaining the annual variation, it is possible to calculate the quarterly variation, assuming that hours worked increase evenly over the four quarters of the year.

4 Simulation evidence

This chapter addresses the second objective of this paper: to analyze the accommodation of shocks induced in the economy and to check the contribution of each type of shock to the fluctuation of some predefined variables. To do that, evidence is obtained from the simulation of the nonlinear model, represented in Section 2 by the set of equations (4) through (17).

In a simulation exercise, it is necessary to first calibrate the model's parameters. As the purpose is to analyze the impact of different combinations of rigidity upon the persistence of shocks and upon the contribution of each shock to forecast error variance, the calibration of models' parameters was based on the results obtained from the estimation of the PCER model, with changes only in those that referred to price, capital and employment adjustment costs. This procedure was adopted for the sake of simplicity.

For the Canadian economy, Dib (2003) estimated the four models with different combinations of real and nominal rigidities and found different values for ϕ_p, ϕ_k e ϕ_h across models. However, for the other parameters, the values found for the four models are very similar. As seen in the previous chapter in this paper, the values found for the parameters ρ_A, ρ_b, ρ_μ, ω_A e ω_b were different across the four models. So, as previously mentioned, once the objective of this chapter was to analyze the implications that the absence or presence of certain forms of real or nominal rigidity may have on some of the model's variables, we chose to set all the model's parameters, except those referring to price, capital and employment adjustment costs, according to the results found in the estimation of the PCER model.

Thus, simulations were performed for four situations: *(a)* model with nominal rigidity as price adjustment cost ($\phi_p = 1.972$, $\phi_k = 0$, $\phi_h = 0$); *(b)* model with nominal rigidity as price adjustment cost and real rigidity as capital adjustment cost ($\phi_p = 3.7785$, $\phi_k = 1.4592$, $\phi_h = 0$); *(c)* model with nominal rigidity as price adjustment cost and real rigidity as employment adjustment cost ($\phi_p = 29.8379$, $\phi_k = 0$, $\phi_h = 8.4610$) and *(d)* model with nominal rigidity as price adjustment cost and real rigidity as capital and employment adjustment cost ($\phi_p = 15{,}5093$, $\phi_k = 2{,}3935$, $\phi_h = 5{,}5384$). The values calibrated for the adjustment cost parameters were obtained from the estimations performed for the SSP, PCR, PER and PCER models.

4.1 Analysis of impulse-response functions

In this section, output (y), real wages (w), hours worked (h) and inflation rate (π) react to money supply, technology and money demand shocks in each combination of real and nominal rigidity. In the simulation exercise, temporary shocks are induced in the system and the impulse-response functions allow assessing the time necessary for the variables to return to their steady-state levels.

4.1.1 Response to money supply shocks

Figure 1 shows the impulse-response functions for 1% increases in the money supply growth rate for the variables mentioned in each one of the different combinations in the presence of real and nominal rigidity. The analysis of how output responds to money supply shocks reveals that, in the model with only price adjustment cost, the impact corresponds to only 0.002% and the variable returns to its steady-state level in the second quarter, showing little persistence. The inclusion of capital rigidity does not significantly affect this result: the variable returns to its steady-state level in about three quarters. In the model with price and employment adjustment costs, the persistence of a money supply shock over input is greater, and the variable takes about eight quarters to return to its steady-state level. The combination of price, capital and employment adjustment costs reduces both the impact and the persistence of a money supply shock on output in relation to the case analyzed before. The movements of hours worked are similar to those of output, as expected, because, as labor is one of the major inputs for the production process, it is natural that both variables have similar behaviors.

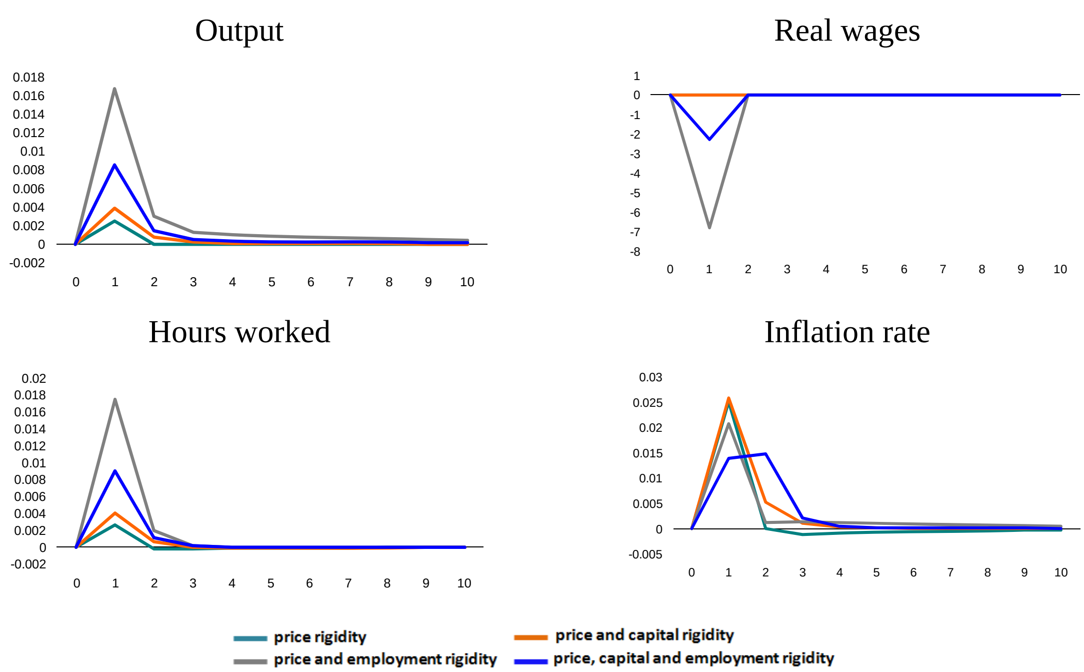


Figure 1 – Effects of money supply shock in the four models

Source: Data obtained by the authors

The impulse-response functions, shown in Figure 1, indicate that, when there is no rigidity in employment, money supply shocks do not generate an impact on real wages. When there is rigidity, real wages suffer a negative impact, which is more intense in the model with employment rigidity but without capital rigidity. This result reflects the low capacity of adjustment of the Brazilian labor market. However, the persistence generated is low and the variable returns to its steady-state level in about two quarters after the shock, in both cases.

The negative response of real wages to money supply shocks is consistent with the positive response of the inflation rate. Considering that the expansion of the monetary base is not followed by a proportional increase in output, the difference that tends to be generated between the supply of and demand for goods is expected to push up the inflation rate, which may eventually exert a negative pressure on real wages. Moreover, the model with the three types of rigidity has a significantly greater persistence of money supply shock over the inflation rate.

4.1.2 Response to technology shocks

Figure 2 shows the impulse-response functions for a 1% positive technology shock in the four combinations of real and nominal rigidity. In the model with only price rigidity, the output is unstable when the shock occurs. The model with price and capital adjustment costs has a similar, though smoother, behavior. As to the model with price and employment adjustment costs, output responds positively to technology shocks, as expected, because improvements in technology tend to increase output. When the three forms of rigidity are included, the impact decreases. Note that output persistence over technology shocks is different in the four models, and the variable takes from six to eight quarters to return to its steady-state level.

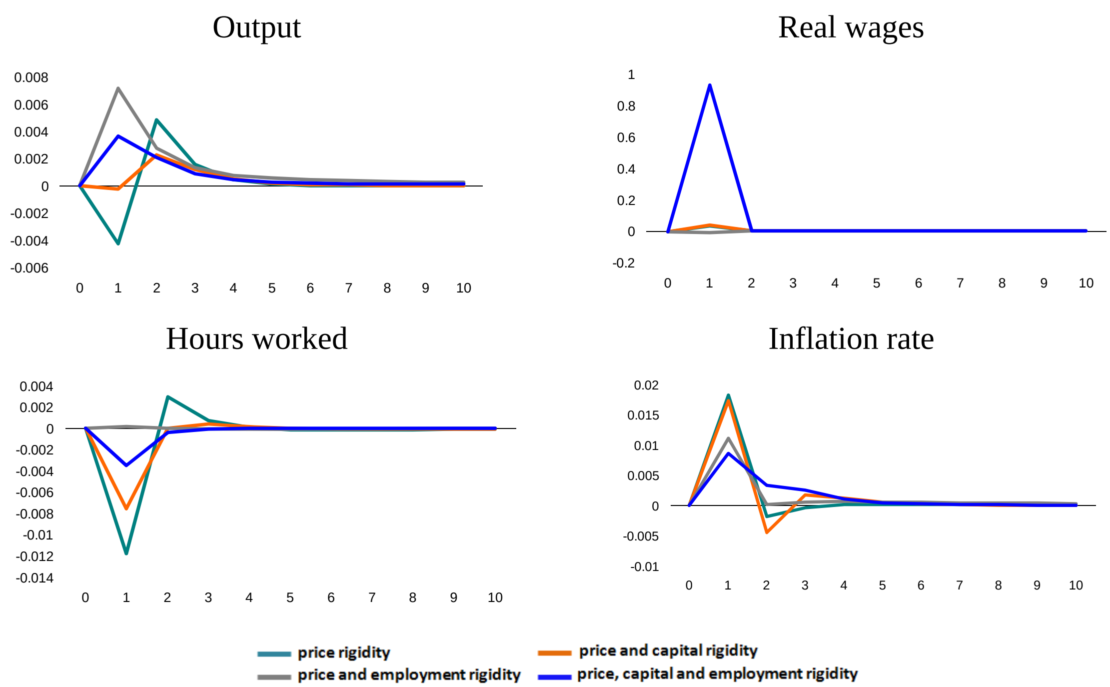


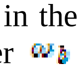
Figure 2 – Effects of technology shock in the four models

Source: Data obtained by the authors

The impact of technology on hours worked is negative, except in the model that includes price and employment adjustment costs, for which the effect of this shock is null. Improvements in technology are expected to reduce the number of hours worked in models in which the employment adjustment cost is lower. As this type of shock may enable the production of the same quantity of goods using less labor input, and there are no costs for its reduction, or the costs are low, there may be a reduction in the quantity used.

As to real wages, the simulations revealed that the technology shock only affects the model with the three types of rigidity, but the effect is not persistent and lasts about two quarters. The inflation rate responds positively to technology shocks, and the presence of the three adjustment costs makes their effect more persistent: the variable takes around five quarters to return to its steady-state level. At this point, it is important to draw attention to the fact that one of the reasons why inflation may have a positive response to technology shocks is the introduction of new products in the market. These products usually have innovative features and may have higher prices at first, which are assimilated after some time.

4.1.3 Response to money demand shocks

Figure 3 shows the impulse-response functions for a 1% positive money demand shock in the four combinations of real and nominal rigidity. As seen in the previous chapter, the parameter  estimated for the PCER model and whose value was used in the calibration of the models simulated in this chapter, indicates that the response of authorities to money demand shocks is countercyclical, increasing money supply. Figure 3 shows that the effects on output, hours worked and inflation rate are rather poor, which demonstrates the efficiency of the responses of the monetary authority in relation to these variables.

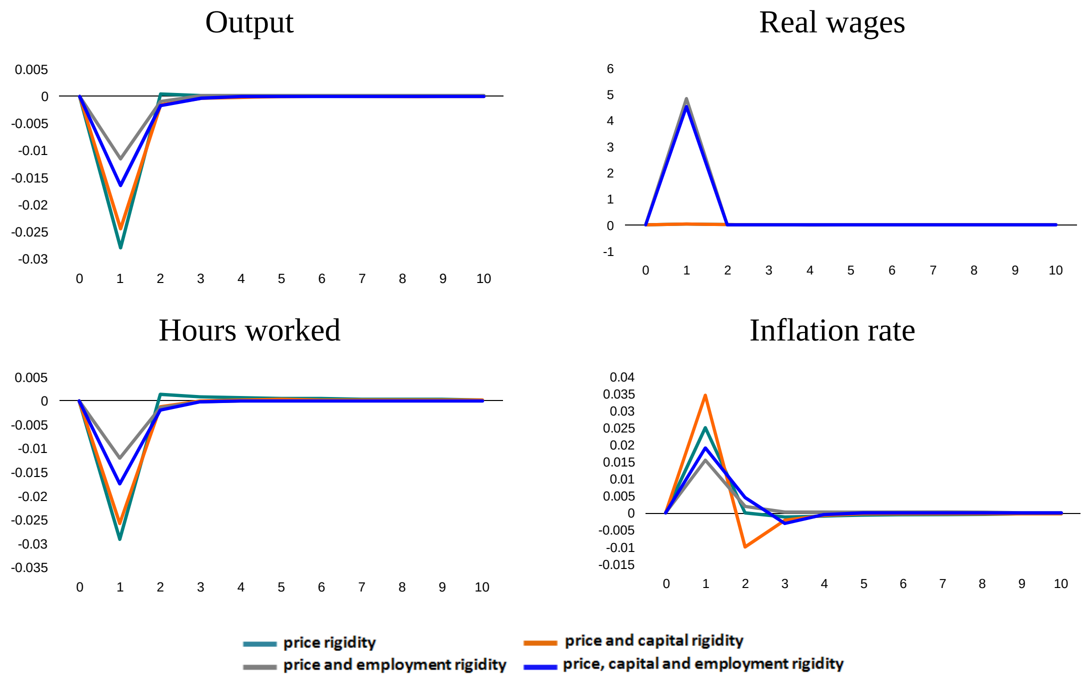


Figure 3 – Effects of money demand shock in the four models

Source: Data obtained by the authors

Conversely, the presence of real rigidity as employment adjustment costs shows that real wages respond positively to money demand shocks at first, but this movement is not persistent, and the variable returns to its steady-state level in only two quarters.

4.2 Analysis of variance decomposition

In this section, the implications of including real and nominal rigidity are assessed by forecast error variance decomposition for the following variables: output (y), inflation rate (π) and money supply growth rate (μ). In the simulation exercise, temporary shocks are induced in the system, and, using an illustrative table, it is possible to evaluate the contribution of each type of shock to the fluctuations in the variables.

According to panel A in Table 6, in the models without employment rigidity, technology shocks contribute more significantly to output variations, both in the short and the long terms. These results confirm those expected for real business cycle models, as technology shocks are the most important factor for output fluctuations. Nonetheless, when employment adjustment costs are included, this percentage drops sharply.

Panel B in Table 6 shows that, in the models without capital rigidity, inflation rate fluctuations are mostly guided by money demand shocks. On the other hand, in the models with capital rigidity, technology shocks are the key determinants for inflation rate variations. Finally, panel C in Table 6 shows that monetary growth results from money demand shocks, and this result does not rely on the combination of rigidity used to represent Brazil’s economic reality.

Table 6 – Variance decomposition (in %) in relation to money supply (MS), technology (TEC) and money demand (MD)

	Sticky prices			Rigid price and capital			Rigid price and employment			Rigid price, capital and employment		
Quarter	MS	TEC	MD	MS	TEC	MD	MS	TEC	MD	MS	TEC	MD
A. Output												
1	2.28	96.94	0.78	0.01	97.60	2.39	11.10	28.93	59.97	3.72	75.94	20.34
3	5.32	93.93	0.75	1.08	96.46	2.46	12.59	27.85	59.57	5.02	74.64	20.35
5	5.35	93.90	0.75	1.13	96.41	2.46	12.71	27.70	59.59	5.09	74.54	20.37
10	5.35	93.90	0.75	1.13	96.41	2.46	12.77	27.59	59.65	5.11	74.48	20.41
40	5.35	93.90	0.75	1.13	96.41	2.46	12.78	27.55	59.67	5.13	74.44	20.43
B. Inflation												
1	16.76	31.56	51.69	13.87	55.21	30.93	15.43	30.10	54.47	11.64	57.69	30.68
3	16.89	31.54	51.57	13.89	56.03	30.08	15.34	30.23	54.43	10.10	43.68	46.22
5	16.89	31.58	51.53	13.96	55.99	30.05	15.37	30.09	54.54	10.23	43.61	46.16
10	16.88	31.61	51.51	13.96	55.99	30.05	15.42	29.95	54.64	10.24	43.60	46.16
40	16.88	31.61	51.50	13.96	55.99	30.05	15.43	29.90	54.67	10.25	43.59	46.16
C. Monetary growth												
1	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26
3	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26
5	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26
10	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26
40	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26	17.06	20.68	62.26

6 Conclusion

This paper analyzed whether the inclusion of real rigidity in a model with nominal rigidity may increase the latter. It also evaluated whether the presence of these forms of rigidity added persistence to the real effects of money demand shock, money supply shock and technology shock over output, real wages, hours worked and inflation rate, and investigated the contribution of each type of shock to the fluctuations in output, inflation rate and money supply growth rate.

Results showed that, even in the absence of real rigidity, there is nominal rigidity in Brazil. Moreover, the inclusion of real rigidity as capital and/or employment adjustment costs contributes to the increase in nominal rigidity, and this is more intense when real rigidity is included as employment adjustment costs. In addition, the results suggest that, in Brazil, employment rigidity is considerably greater than capital rigidity.

The simulation exercises evidenced that the inclusion of real rigidity as capital and/or employment adjustment costs may increase the persistence of money supply shocks, technology shocks and money demand shocks over output, real wages, hours worked and inflation rate. In most cases, employment rigidity contributes more effectively to this result. In addition, results suggest that the response of monetary authority to money demand shocks is countercyclical, which may contribute to their moderate effect on output, hours worked, and inflation rate.

Variance decomposition revealed that, in three of the four combinations of real and nominal rigidities analyzed, technology shocks were the major factors implicated in short- and long-term output movements. Inflation rate movements are primarily linked to technology shocks and money demand shocks, but this varies according to the type of adjustment cost used in the model. Finally, the results for money supply growth rate movements are the same for the different combinations of real and nominal rigidities, and money demand shocks are the major determining factors in this case.

The limitation of the model estimated here is that it deals with a closed economy. An open-economy model could offer a different adjustment dynamics, particularly with respect to prices and employment. Another major limitation of this model is the money supply rule used. The Central Bank of Brazil does not work directly with the determination of money supply. Therefore, the use of a Taylor rule in this model, in which the main monetary policy tool is the interest rate, may bring it closer to the reality of the Brazilian economy. Our suggestion is that these issues could be investigated in future studies.

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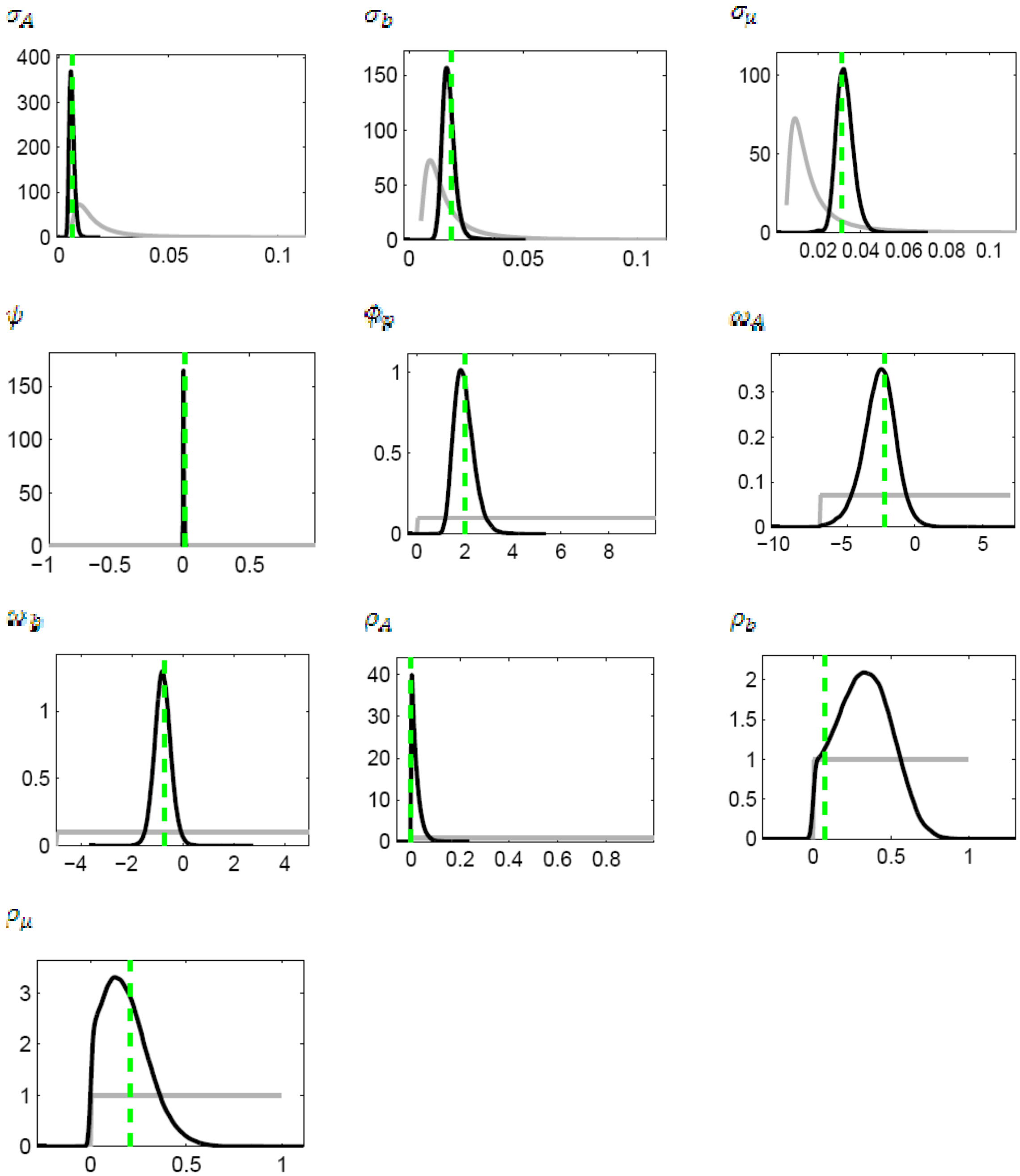
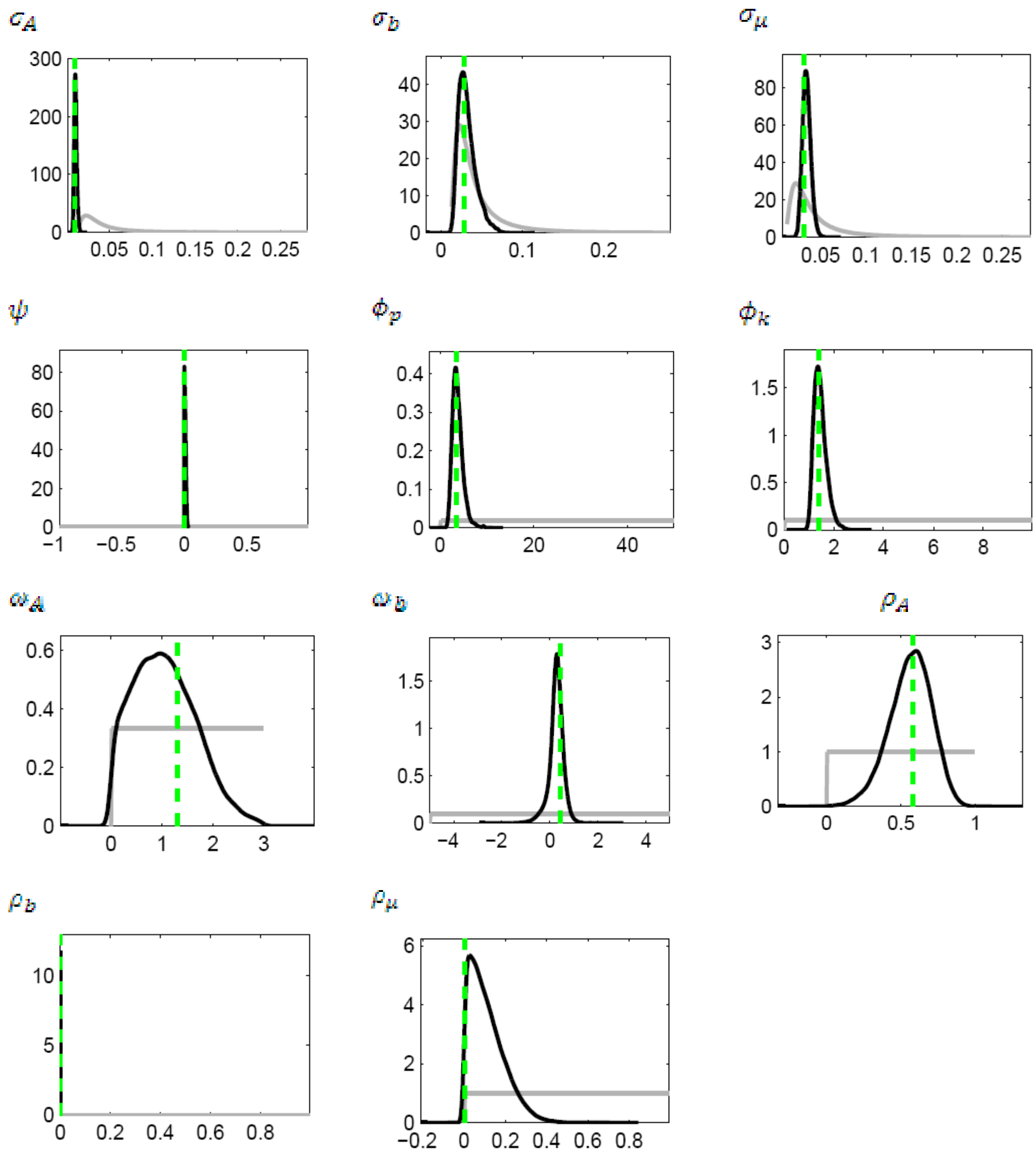
APPENDIX A1 – A posteriori distribution of parameters (SSP model)



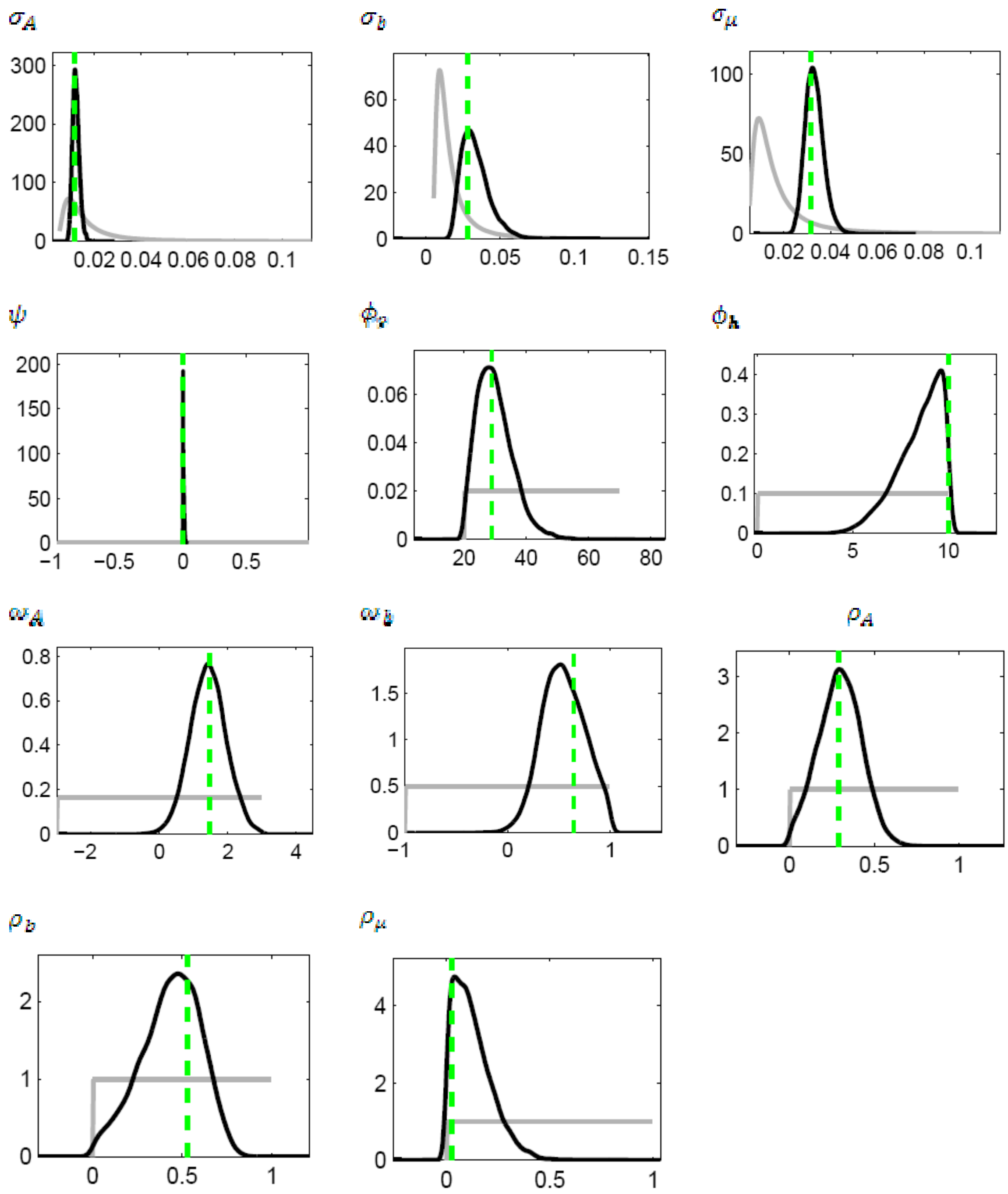
Source: Data obtained by the authors

APPENDIX A2 – A posteriori distribution of parameters (PCR Model)



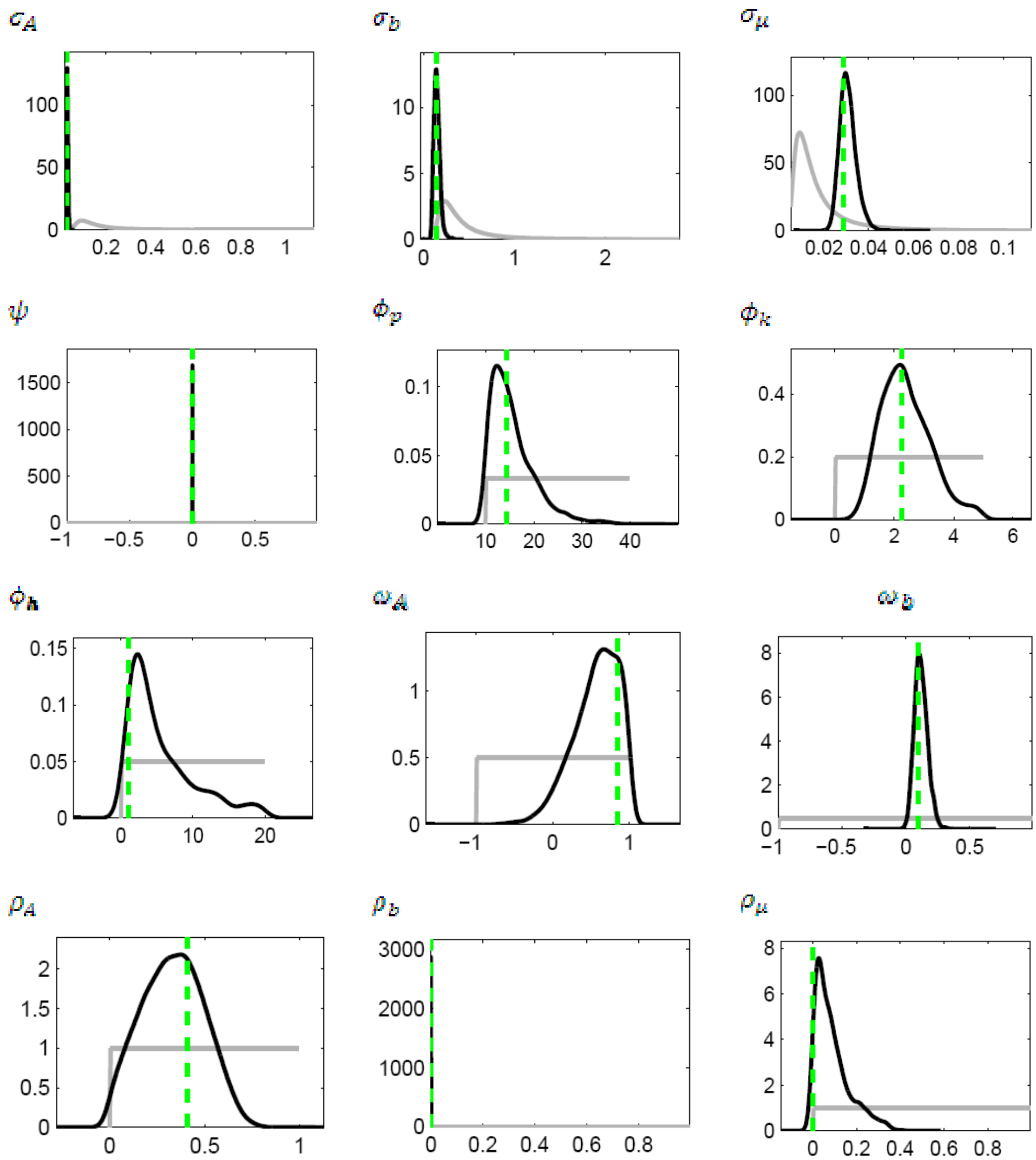
Source: Data obtained by the authors.

APPENDIX A3 – A posteriori distribution of parameters (PER Model)



Source: Data obtained by the authors.

APPENDIX A4 – A posteriori distribution of parameters (PCER Model)



Source: Data obtained by the authors.