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THE EFFECT OF ADVERSE OIL PRICE SHOCKS ON MONETARY POLICY AND OUTPUT USING A DYNAMIC SMALL OPEN ECONOMY GENERAL EQUILIBRIUM MODEL WITH STAGGERED PRICE FOR BRAZIL

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Resumen

El objeto de este estudio es usar un modelo económico construido para Brasil, basado en un modelo de optimización dinámico de equilibrio general, a fin de realizar simulaciones numéricas para derivar la capacidad de una economía artificial para explicar el impacto de intervenciones de política monetaria sobre indicadores económicos de corto plazo en Brasil, tales como tasa de inflación, brecha de actividad, tasa de interés y nivel de actividad económica frente a un choque petrolero negativo. Se trata de una extensión de Bugarin et al. (2005) concentrado en las consecuencias de las alzas energéticas con distintas reglas de política monetaria. Siguiendo a Hall (1988 y 1990) y Finn (2000), se considera que un aumento de las tarifas energéticas actúa como un choque negativo de productividad. El modelo provee una descripción accesible de una economía artificial con agentes racionales forward-looking en una economía pequeña y abierta con rigidez de precios que genera inercia inflacionaria y desinflaciones recesivas. También introducimos al modelo especificaciones alternativas de las funciones de reacción de la política monetaria con el fin de realizar un análisis de sensibilidad y medir la respuesta de dichas intervenciones frente al choque negativo de productividad. Los resultados preliminares sugieren que introducir persistencia de hábitos en la hipótesis del consumo no hace mucha diferencia. Sin embargo, la introducción de distintas funciones de reacción monetarias sí altera la respuesta del producto, la inflación y la tasa de interés nominal. Un resultado común es una reducción del producto potencial en todos los modelos. Además, el único caso en el que se observa un estrechamiento de la brecha de actividad es cuando se usa la regla de Taylor que considera la brecha de actividad y tasas de interés pasadas con alta persistencia.

Abstract

The aim of the present research is to use a model economy built for Brazil, based on an optimizing dynamic general equilibrium model, in order to perform numerical simulations to derive the ability of the artificial economy to explain the impact of monetary policy interventions on Brazilian short run economic performance in terms of the inflation rate, output gap, interest rate and level of economic activity in the face of an adverse oil shock. It is an extension of Bugarin et al. (2005) concentrating on the consequence of energy price increases, facing different monetary policy rules. Following Hall (1988 e 1990) and Finn (2000) it is considered that an increase in energy prices acts like a negative productivity shock. The model provides an accessible description of an artificial economy with a tractable micro-founded dynamic setting with forward looking rational agents in a small open economy with a staggered pricing mechanism that generates inflation inertia and recessionary disinflations. Alternative specification of monetary reaction functions are introduced into the model economy in order to perform a sensitivity analysis of derived impulse responses to those interventions facing the negative productivity shock. The preliminary results suggest that the introduction of habit persistence into the consumption hypothesis does not make much difference. However the introduction of different monetary reaction functions does alter the impulse response of output, inflation rate, and nominal interest rate. A common result is the decline in potential output for all models. Additionally, the only case where a reduction in the output gap is observed is when using the Taylor rule that takes into consideration the output gap and past interest rates with high persistence.

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1. Introduction

Modeling economic dynamics is important for those who rely on macroeconomic analysis, especially the monetary authority. The behavior of the economy, and its dynamic responses to policy and external shocks are relevant to understanding how the economy reacts to different shocks in different situations. For example, given a set of conditions and a characterization of how different monetary policy rules will affect the reaction function of the economy. This paper attempts to evaluate the effect of oil price increases on a Brazilian model economy using a dynamic general equilibrium framework. It is part of ongoing research based on Bugarin et al (2005), aimed at building a model economy for monetary policy analysis based on an optimizing dynamic general equilibrium model. Its main characteristic consists of forward-looking agents facing a staggered price setting in a small open economy.

The pioneering theoretical work can be traced back to Taylor (1988, 1993). Svensson and van Wijnbergeh (1989), Obstfeld and Rogoff (1995, 1996), Betts and Devereux (1997. 1998), Kollmann (1997, 1999), Gali and Monacelti (1999). Ghironi (1999), Benigno and Benigno (2000), Chari, Kehoe and McGrattan (2000), Smets and Woutcrs (2000), Corsetti and Pesenti (2001).

Following Bugarin et al. (2005), the special feature of this line of modeling is to construct a tractable micro-founded dynamic setting with forward-looking rational agents in a small open economy, which, through estimation or calibration processes, enables us to derive qualitative and quantitative assessments of an increase in energy prices into the model economy. Here it uses the popular judgment that considers increases in energy prices as an adverse technology shock as suggested by Hall (1988, 1990), Kim and Loungani (1992), Rotemberg and Woodford (1996) and Finn (2000). This assumption allows us to extend the model built by Bugarin et al. (2005) in circumstances of an increase in oil prices.

As suggested by McCallum and Nelson (1998), Nelson (200 I), and Fraga, Goldfajn and Minella (2003), the openness of the economy is introduced by means of intermediate goods imports into the domestic economy's productive process.[1] This characterization has two main advantages. First, it leads to a c1eaner and simpler theoretical structure compared to the usual alternative treatment of imports as consumption goods. Second, it better captures the dynamic

[1] See Calvo, Celasun and Kumhof (2003) for a model with tradable and non-tradable consumption goods.

features presented in the data, namely the lagged correlation between the inflation rate and changes in the exchange rate, as well as the share of imports as a major item (60.6%) in imports for Brazil.[2]

The preliminary results suggest that the introduction of habit persistence into the consumption hypothesis does not make much difference. However, the introduction of different monetary reaction functions does alter the impulse response of output, the inflation rate, and the nominal interest rate. A common result is the decline in potential output for all models. Additionally, the only case where a reduction in the output gap is observed is when using the Taylor rule that takes in consideration the output gap and past interest rates with high persistence.

The present study is divided into the following sections. Section 2 introduces the model economy, defines the dynamic equilibrium concept and characterizes the state space representation of the artificial economy. Section 3 presents the detailed description, or the parameterization process. The model's behavioral, technological as well as policy determined sets of parameters are set based on calibration or time series estimation. Section 4 presents the impulse responses to the exogenous shock to the artificial economy, which can be alternatively attributed to technology, aggregate demand, UIP, monetary policy rule, external income or fiscal innovation processes, and then summary statistics. The numerical computation of the equilibrium is based on the Schur decomposition in order to account for forward-looking endogenous variables. Section 5 presents a summary and conclusions. The main results are summed up in the last section in order to identify potential extensions to future research.

2. The Artificial Economy

The benchmark model follows closely the one introduced by McCallum and Nelson (1998) and McCallum (2001). Its main feature includes an open economy where optimal behavior of consumers/producers lead to equilibrium transition paths of endogenously determined variables. Some of theses variables, like for instance the aggregate supply of the economy, behaves in a forward-looking manner to take into consideration staggered pricing mechanism that generates inflation inertia and recessionary disinflations in the economy that allow the monetary policy interventions as well as the exogenous stochastic processes to produce, in equilibrium, real effects in the short run.

[2] Source: Banco Central do Brasil

Moreover, the monetary policy intervention is modeled by means of alternative Taylor type rules, which determine a reaction of the nominal interest rate to predetermined as well as forward-looking variables. These rules are based on research results presented by Fraga et ali (2003), Minella et ali (2003) and Alves and Muinhos (2002)

2.1 The Representative Household (Consumer-Producer) Problem

There is a continuum of households acting as consumers-producers over the interval [0,1] deriving utility from a stream of optimally chosen sequence of consumption, C , and real balance holdings, *M/P*. Hence we can formally write down the problem faced by these agents as follows.

$$\max E_0 \sum_{t=0}^{\infty} \beta^{\,t} \left[u\left(C_{t+j}, C_{t+j-1}, M_{t+j} / P_{t+j}^{A} \right) \right] \qquad (1)$$

subject to the available CES production technology using labor, N , and imported intermediate goods, *IM*, as inputs of the production process, i.e.

$$Y_t = \left[\alpha_1 \left(A_t N_t^d \right)^{v_1} + \left(1 - \alpha_1\right)\left(IM_t^d \right)^{v_1} \right]^{\frac{1}{v_1}} \qquad (2)$$

and, (real) budget constraint:

$$\begin{aligned} &(P_t / P_t^A) DY_t^d + (P_t / P_t^A) EX_t^d - C_t + \left(W_t / P_t^A \right)\left(N_t^S - N_t^d \right) + TR_t - (M_t - M_{t-1}) / P_t^A - \\ &- B_{t-1}(1 + r_t)^{-1} + B_t - Q_t IM_t^d - Q_t B_{t+1}^{*}(1 + \kappa_t)^{-1} + Q_t B_t^{*} = 0 \end{aligned} \qquad (3)$$

where,

(i) the instantaneous utility function is assumed to be separable across consumption and money balances and captures the habit formation as depicted below:

$$u\left(C_t, C_{t-1}, M_t / P_t^A \right) = \exp(v_t)(\sigma / (\sigma - 1))(C_t / C_{t-1}{}^{h})^{\frac{\sigma - 1}{\sigma}} + (1 - \gamma)^{-1} (M_t / P_t^A)^{1-\gamma} \qquad (4)$$

with $\sigma > 0$, $\sigma \neq 1$, $\gamma \neq 1$, h $h \in [0,1)$ and $0 < \beta < 1$. Using Dixit-Stiglitz (1977) composite consumption index, $C_t = \left[\int_0^1 C_t(j)^{\frac{\theta - 1}{\theta}} dj \right]^{\frac{\theta}{\theta - 1}}$, $\theta > 1$ with all j goods differentiated from each other;

(ii) technology parameters are such that $\alpha_1 \in (0,1]$, $v_1 \in (-\infty,+\infty)$, A_t representing a technology shock parameter, N_t^d the labor demanded at time t and IM_t^d the imported input in production purchased by the household;

(iii) given the monopoly power to each specific home production, P_t denotes the good's price as a choice variable. The household takes the domestic aggregate price level P_t^A, the nominal exchange rate S_t and the foreign price level P_t^* as given. Moreover, since the household cannot price discriminate between domestic and foreign consumers, the price of that good for foreigners is given by P_t/S_t.

(iv) DY_t^d denotes the domestic demand for the particular good. Note that if we define the foreign demand for the same good as EX_t^d, then total production of the specific good is $Y_t^d = DY_t^d + EX_t^d$. The aggregate domestic demand then is given by $DY_t^d = (P_t / P_t^A)^{-\theta} DY_t^A$, where $P_t^A = \left[\int_0^1 P_t(j)^{1-\theta} dj \right]^{\frac{1}{1-\theta}}$ and DY_t^A is the aggregate of DY_t^d. It is also assumed that the foreign demand for the respective household is given by $EX_t^d = (P_t / P_t^A)^{-\theta} EX_t^A$ where EX_t^A is the aggregate export of the economy, such that aggregate export demand is positively related to the real exchange rate, $Q_t = S_t P_t^* / P_t^A$, i.e. $EX_t^A = (S_t P_t^* / P_t^A)^{\eta} Y_t^{*b}$ where $\eta > 0, b > 0$.[3]

(v) each household is endowed with one unit of workable time per period, supplies it inelastically, i.e. N_t^S, facing a nominal wage W_t.

(vi) as a producer, each household chooses labor as well as imported input in an optimal manner, N_t^d and IM_t^d.

(vii) Government issues domestic debt. This asset could be considered as a perfect substitute of domestic private security which can be purchased at $1/(1+r_t)$ per unit at time t. Households also can purchase foreign bonds at a price, in units of foreign output, given by $1/(1+\kappa)(1+r_t^*)$. The domestic and foreign bonds purchased by the household at time t is expressed as B_t and B_t^* respectively. We also assume that the transversality conditions for assets hold, as well as government budget constraint and bond market clearing condition.

[3] Since it is assumed a small open economy, the effect on domestic production on foreign price index is negligible.

2.2 Optimality Conditions

The above characterization allows us to derive the following first order conditions, where ξ_t and λ_t denotes the Lagrange multipliers for the technology constraint and the budget constraint respectively.

(a) as consumer choosing optimally consumption and saving, in other words, with respect to C_t, M_t/P_t^A, B_{t+1} and $B_{t+1}{}^*$:

$$\exp(v_t)(1/C_{t-1}{}^{h})^{\frac{\sigma-1}{\sigma}} C_t^{\frac{-1}{\sigma}} - \beta h \exp(v_{t-1}) C_t^{\frac{h-\sigma h-\sigma}{\sigma}} C_{t+1}^{\frac{\sigma-1}{\sigma}} - \lambda = 0 \qquad (5)$$

$$\left(\frac{M_t}{P_t^A}\right)^{-\gamma} + \lambda_t E_t\left[\frac{1}{(1+r_t)}\left(\frac{P_t^A}{P_{t-1}^A}\right) - 1\right] = 0 \qquad (6)$$

$$\lambda_t - \beta E_t \lambda_{t+1}(1+r_t) = 0 \qquad (7)$$

$$Q_t \lambda_t - \beta E_t \lambda_{t+1}(1+\kappa_t)(1+r_t^*) = 0 \qquad (8) \quad \text{and,}$$

(b) as a producer, choosing optimally production inputs N_t^d and IM_t^d:

$$\left[\left(\frac{\lambda_t}{\xi_t}\right)\left(\frac{W_t}{P_t^A}\right)\right]^{\frac{1}{1-v_1}} - \alpha_1^{\frac{1}{1-v_1}} A_t^{\frac{v_1}{1-v_1}}\left(\frac{Y_t}{N_t^d}\right) = 0 \qquad (9)$$

$$\left[\left(\frac{\lambda_t}{\xi_t}\right) Q_t\right]^{\frac{1}{1-v_1}} - (1-\alpha_1)_1^{\frac{1}{1-v_1}}\left(\frac{Y_t}{IM_t^d}\right) = 0 \qquad (10)$$

Observe that under price flexibility the mark-up is constant equal to $\frac{\lambda_t}{\xi_t} = \frac{\theta}{\theta-1}$.

2.3 Uncovered Interest Parity

If one defines domestic and foreign interest rate as $R_t = r_t + E_t \Delta p_{t+1}$ and $R_t{}^* = r_t{}^* + E_t \Delta p_{t+1}{}^*$ respectively, where $p_t = \log P_t^A$, $p_t{}^* = \log P_t{}^*$ and Δ indicates the first difference operator, first order conditions (7) and (8) above imply that uncovered interest parity holds in equilibrium, i.e.

$$R_t = R_t{}^* + E_t \Delta s_{t+1} + \kappa_t \qquad (11)$$

where $s_t = \log S_t$.

2.4 Price Adjustment Decision

The above household characterization give him/her market power to decide its own price P_t. Taking log of domestic and foreign demand for the household specific good, as presented in (iv) above, we have:

$$dy_t^d = dy_t^A - \theta(p_t - p_t^A) \qquad (12)$$

$$ex_t^d = ex_t^A - \theta(p_t - p_t^A) \qquad (13)$$

implying the following relationship between the log of relative output y_t-y_t^A and the log of relative price p_t-p_t^A:

$$y_t - y_t^A = -\theta(p_t - p_t^A) \qquad (14)$$

Following Calvo (1983) it is assumed that the households have to set their respective prices according to the pricing equation below.

$$\Delta p = \beta E_t \Delta p_{t+1} + \omega ygap_t \qquad (15)$$

setting $w = 0.02$.

2.5 Flexible Price Output

Under price flexibility, labor input equals $N_t = N_t^S = 1$ for all t, then the flexible price output is given by:

$$\overline{Y}_t = \left[\alpha_1 (A_t)^{v_1} + (1-\alpha_1)\left(\overline{IM}_t^d\right)^{v_1}\right]^{\frac{1}{v_1}} \qquad (16)$$

and taking a log linear approximation:

$$y_t = (1-\delta_1)\alpha_1 + \delta_1 \overline{m}_t \qquad (17)$$

where, using the Euler equation (5), $\delta = (1-\alpha_1)\left(\frac{\overline{IM}^{SS}}{\overline{Y}^{SS}}\right)^{v_1} = \frac{\theta}{\theta-1}\left(\frac{Q^{SS}IM^{SS}}{Y^{SS}}\right)$, ss denoting steady state values.

Defining again q_t= log Q_t, the logarithm of the real exchange rate, Q, optimality condition (10) implies:

$$im_t = y_t - \frac{1}{1-v_1}\log\left(\frac{\lambda_t}{\xi_t}\right) - \frac{1}{1-v_1}q_t + \frac{1}{1-v_1}\log(1-\alpha_1) \tag{18}$$

Using the fact that under price flexibility the mark-up is constant, i.e. $\frac{\lambda_t}{\xi_t} = \frac{\theta}{\theta-1}$, the corresponding log of imports at the flexible price output is given by[4]:

$$\overline{im}_t = \overline{y}_t - \frac{1}{1-v_1}q_t \tag{19}$$

Thus, the flexible price output is function of the technology shock as well as the real exchange rate, i.e.

$$\overline{y}_t = \alpha_1 - \frac{1}{(1-v_1)(1-\delta_1)}\frac{\theta}{(\theta-1)}\frac{Q^{SS}IM^{SS}}{Y^{SS}}q_t \tag{20}$$

This relationship indicates that in this model exchange rate has an impact on domestic prices: changes in the (log) nominal exchange rate s_t, that affect the (log) real exchange rate, q_t, lead to changes in p_t through $E_{t-1}\overline{p}_t$.

2.6 Log-Linearization

(a) Log-linearizing Euler equation (5), without considering the constant term, we have:

$$\log\lambda_t = \left(\frac{\beta h^2\sigma + \beta h\sigma - \beta h^2 - 1}{\sigma(1-\beta h)}\right)c_t - h\frac{\sigma-1}{\sigma(1-\beta h)}c_{t-1} - \beta h\frac{\sigma-1}{\sigma(1-\beta h)}E_t c_{t+1} + \frac{1-\beta h\rho}{1-\beta h}v_t \tag{21}$$

(b) Log-linearizing (7) in turn give us expression:

$$\log \lambda_t = E_t \log \lambda_{t+1} + R_t - E_t \Delta p_{t+1} \tag{22}$$

From above two conditions, the corresponding expectational difference equation for consumption changes with habit persistence is given by[5]:

$$\begin{aligned} &\beta(h-\sigma h)E_t \Delta c_{t+2} + (1+\beta h^2 - \sigma\beta h^2 - \sigma\beta h)E_t \Delta c_{t+1} + \sigma(1-\beta h)E_t \Delta p_{t+1} = \\ &= (h-\sigma h)\Delta c_t + \sigma(1-\beta h)R_t - \sigma(1+\rho-\beta h\rho^2 + \beta h\rho) \end{aligned} \tag{23}$$

(c) In order to complete the log-linearized first order conditions we have to add the following set of equations:

export function $\quad ex_t = \eta q_t + by_t^* \quad (24)$

real exchange rate $\quad q_t = s_t - p_t + p_t^* \eta q_t \quad (25)$

flexible price output $\quad \bar{y}_t = a_t - \omega q_t \quad (26)$

UIP $\quad R_t = R_t^* + E_t s_{t-1} - s_t + \kappa k_t \quad (27)$

nominal aggregate domestic production $\quad x_t = p_t + y_t \quad (28)$

output gap $\quad y'_t = y_t - \bar{y}_t \quad (29)$

aggregate domestic output consistency $\quad y_t = \frac{C^{SS}}{Y^{SS}} c_t + \frac{EX^{SS}}{Y^{SS}} ex_t + [1 - \frac{C^{SS}}{Y^{SS}} - \frac{EX^{SS}}{Y^{SS}}] g_t \quad (30)$

expected aggregate supply $\quad E_t y'_{t+1} = \phi\, y'_t \quad (31)$

import input function $\quad im_t = y_t + \frac{1}{\theta(1-v_1)} y'_t - \frac{1}{1-v_1} q_t \quad (32)$

where,

---

[4] Neglecting constant term.

$$\phi = \frac{1-(1-4\alpha^2\beta)^{1/2}}{2\alpha\beta}, \alpha = \frac{c}{1+c+c\beta} \text{ and } \omega = \frac{\delta_1}{(1-v_1)(1-\delta_1)}.$$

2.7 Foreign Exogenous Variables

We assume that both foreign interest rate R_t^* as well as price level P_t^* are constant for all t, and that the log of external output follows an AR(1) stable process, i.e.:

$$y_t^* = \rho_{y*} y_{t-1}^* + \varepsilon_t^*, \quad \varepsilon_t^* \approx N(0, \sigma_{\varepsilon*}^2) \qquad (33)$$

2.8 Adverse technological innovation as proxy for oil price increase

In order to capture the impact of oil price increase, it is assumed that it works as an adverse technological innovation as suggested by Hall (1988) and Finn (2000)., i.e.

$$a_t = \rho_a a_{t-1} + e_{at}, \quad e_{at} \approx N(0, \sigma_{ea}^2) \qquad (34)$$

Therefore, in our model economy oil shocks will enter as a negative unitary shock e_{at}.

Based on previous studies, the next sub-section introduces the monetary reaction functions considered in our study.

2.9 Taylor Type Monetary Policy Rules

Alternative specification of monetary reaction functions were introduced into the model economy in order to perform a sensitivity analysis of derived impulse response to those interventions and to test robustness of the responses. The choice of the adopted monetary policy reaction functions are based on the existing literature for the Brazilian economy. All the reaction functions are built on a basic Taylor Rule where the monetary authority would react adjusting the nominal interest rate, R according to past interest rate, to expected deviation of future inflation rate form the target, $E(\pi_{t-1} - \pi^*)$, and to observed (past) output gap, y'_{t-1}, smoothing it out around a

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[5] For h=0 the equation correspond to the case of non-h $ex_t = \eta q_t + by_t^*$ habit persistence as presented by Woodford (1996).

long run equilibrium rate given by the parameter μ_0. Coefficients vary to different estimations and specifications in this basic model.

(i) Rule 1

Is based on Alves e Muinhos (2003). They estimate a Taylor Rule for the Brazilian economy using a model specification very similar to the one used in Fraga et Ali (2003) and Minella et ali (2002 e 2003). According to the authors an optimal monetary policy reaction function, using Bacen´s inflation expectation can be summarized as follows.

$$R_t = \mu_1 R_{t-1} + \mu_2 E_t(\pi_{t+j} - \pi^*)\rho + \mu_3 y''_{t-1} + \varepsilon_{mr}, \quad e_{mr} \approx N(0, \sigma^2_{mr}) \qquad (35a)$$

(ii) Rule 2

This rule follows the results of Minella et ali (2003), and also Fraga et ali (2003) estimations without output gap, once the estimations with output gap present contra intuitive estimators for the parameters of the output gap.

$$R_t = \mu_1 R_{t-1} + \mu_2 E_t(\pi_{t+j} - \pi^*)\rho + \varepsilon_{mr}, \quad e_{mr} \approx N(0, \sigma^2_{mr}) \qquad (35b)$$

(iii) Rule 3

This rule follows the simulations done by Minella et ali (2003), where the monetary authority react only to expected inflation deviation from the target, that means:

$$R_t = \mu_2 E_t(\pi_{t+j} - \pi^*)\rho + \varepsilon_{mr}, \quad e_{mr} \approx N(0, \sigma^2_{mr}) \qquad (35c)$$

2.10 The Model Economy in State Space Representation

Pulling conditions (22), (23) and (25) to (32) with alternative policy rules (35a) to (35c) above, we can rewrite the system of equations which describes the equilibrium motion of this model economy as follows.

$$\mathbf{A}_{(24 \times 24)} E_t \mathbf{y}_{t+1} = \mathbf{B}_{(24 \times 24)} \mathbf{y}_t + \mathbf{C}_{(24 \times 6)} \mathbf{z}_t \qquad (36)$$

where $\mathbf{y}_t = [y_E \; y_P]$

$$Y_E = [y_t, \widetilde{y}_t, y'_t, R_t, q_t, s_t, c_t, \log \lambda_t, ex_t, \Delta x_t, p_t, \Delta p_t, \Delta p_{t+1}, im_t]_0$$

$$Y_E = [c_{t-1}, R_{t-1}, y_{t-1}, E_{t-1}\Delta x_t, E_{t-1}y'_t, E_{t-1}y_t, \Delta p_{t-1}, p_{t-1}, E_{t-1}\Delta p_{t+1}, E_{t-1}\Delta p_t]$$

and $\mathbf{z}_t = [a_t, v_t, \varepsilon_{mr,t}, \kappa_t, y_t^*, g_t]$ vector of 6 exogenous shock processes.

Moreover, the dynamics of $\mathbf{z}_t$ can be summarized as:

$$\mathbf{z}_t = \mathbf{a}\ \mathbf{z}_{t-1} + \mathbf{u}_t \qquad (37)$$

where the elements of **a** are given by coefficients of processes (24) to (32), assuming constant R_t^* and P_t^*.

Therefore, the equilibrium rational expectation solution to (36) is then given by:

$$\mathbf{y}_t = \mathbf{P_1}\ \mathbf{k}_t + \mathbf{P_2}\ \mathbf{z}_t \qquad (38)$$

and,

$$\mathbf{K}_t = \mathbf{G}\ \mathbf{K}_{t-1} + \mathbf{N}_t \qquad (39)$$

where $\mathbf{K}_{t+1} = [\mathbf{k}_{t+1}\ \ \mathbf{z}_{t+1}]'$, $\mathbf{K}_t = [\mathbf{k}_t\ \ \mathbf{z}_t]'$ and $\mathbf{N}_t = [\mathbf{0}\ \ \mathbf{u}_t]$, expressing the endogenous variables $y_{E,t}$ in terms of predetermined endogenous variables $\mathbf{k}_t = [c_{t-1}, R_{t-1}, y_{t-1}, \Delta p_{t-1}, p_{t-1}]$ as well as exogenous stochastic processes $\mathbf{z}_t$.

3 Parameterization of the Model Economy

This section describes the procedure employed to parameterize the artificial economy constructed above. Econometric estimation of some parameters, calibration based on aggregate empirical relationships and results from previous studies on the Brazilian economy were employed as explained bellow.

1) Technology Parameters

Given the CES production function used in the model, i.e. $Y_t = [\alpha_1 (A_t)^{v_1} + (1-\alpha_1)(IM_t)^{v_1}]^{\frac{1}{v_1}}$, the following values are adopted:

$v_1 = 0.7$, estimated by Pessoa (2004)

$\alpha_1 = 0.65$, estimated by Gomes *et ali* (2003)

2) Consumption Index Parameter

The model uses the Dixit-Stiglitz (1977) composite consumption index, i.e. $C_t = [\int_0^1 C_t(j)^{\frac{\theta-1}{\theta}} dj]^{\frac{\theta}{\theta-1}}, \theta > 1$. Following McCallum (2000) we set $\theta = 6$, which implies a mark-up value of 20%, i.e. 6/(6-1) = 1.2.

3) Export Function Parameters (in log)

Given the export function $ex_t = \eta q_t + by_t^*$, the respective elasticity of exports to real exchange rate, q_t, and rest of the world income, y_t^* , were estimated. The best fit gives us the following estimated values, $\eta =$ 0.788 and $b = 0.79$. These values are very similar to the ones estimated by Pastore and Pinoti (1999) anc Faini, Pritchett and Clavijo (1992).

4) Imported Input Demand Function

The import function of the artificial economy is given by the optimality condition of monopolistically competitive firms, i.e. $imp_t = y_t + m_1 dy_t - m_2 q_t$, $m_1 = \frac{1}{\theta(1-v_1)}, m_2 = \frac{1}{1-v_1}$. Therefore, using the above parameter values, we set $m_1 = 0.556$, and $m_2 = 3.33$.

Observe that alternatively, we can estimate the real exchange rate as well as the income elasticity of imports, such that parameters θ and v_t can be calibrated accordingly. Using estimates of Faini, Pritchet and Clavijo (1992) we obtain θ=2.97 and v_t=1.91. These values are also used to perform the sensitivity analysis.

5) Preferences Parameters

Recalling that the instantaneous utility function is assumed as $u(C_t) = e^{v_t} \frac{\sigma}{\sigma - 1}\left(\frac{C_t}{C_{t-1}^h}\right)^{\frac{\sigma-1}{\sigma}}$ and taking the inter-temporal discount factor $\beta = 0.99$ as presented by Bugarin, M. et ali (2000), the consumption Euler equation give us the remaining needed parameters related to the optimal consumption decision of the households, i.e. in log we have:

$$
\begin{aligned}
&c_3 E_t c_{t+1} = c_1 c_t - c_2 c_{t-1} - \lambda_t + c_4 v_t ,\\
&c_1 = (\beta h^2 \sigma + \beta h \sigma - \beta h^2 - 1)/(\sigma(1-\beta h)),\\
&c_2 = h((\sigma - 1)/(\sigma(1-\beta h)),\\
&c_3 = \beta c_2 ,\\
&c_4 = (1/(1-\beta h))(1-\beta h \rho_v)
\end{aligned}
$$

where ρ_v denotes the persistence parameter of the shock to consumption demand which is estimated bellow. The parameters $\sigma = 0.4$ and $h = 0.8$ are set to derive the values for c_1 to c_4 following the suggestion of McCallum and Nelson. Observe that that there are in the literature relatively wide ranges of values for these parameters, which represent the risk aversion and habit persistence of households. Accordingly, we set these values rather arbitrarily so that sensitivity analysis is going to be performed later on. In particular, the value $\sigma = 0.6$ and $h = 0.6$ reported by Lam and Tkacz (2004) are considered as alternative values.

6) Monetary Policy Rule

The alternative Taylor type monetary policy rules are assumed according to specifications introduced in section 1.10 before, which give us the following parameter values present in Table 1:

Table 1: Taylor Rule Parameter

	μ_{Rt-1}	$\mu_{Exp(\pi-\pi^*)}$	μ_{ygap}
Rule 1: complete	0,80	0,26	0,16
Rule 2: without output gap	0,90	5,70	-
Rule 3: expectation only	-	1,50	-

Almeida Peres, Souza e Tabak (2003) have also estimated a Taylor rule for an open economy version in which the lagged nominal exchange rate and the contemporaneous variation in the real exchange rate are both introduced. Nevertheless in our numerical simulation we choose to restrict our analysis only to the above rules. This strategy follows the results introduced by Minella et ali

(2003) who shows that the nominal exchange rate is not significant in a Taylor rule specification for the Brazilian economy.

7) Calvo's Pricing Equation

Following Calvo (1983) the model's pricing equation is characterized as: $\Delta p_t = \beta E_t \Delta p_{t+1} + \omega ygap_t$, following McCallum (2000) we set $\omega = 0.02$.

8) Parameters for Exogenous AR(1) Stochastic Shocks Processes

The numerical characterization of the stochastic process affecting different behavioral equations of the model economy is performed recalling that these shocks are strictly considered as state variables in the economy. Therefore, it is important to remark that herein we are not interested in fitting the best time series models to the data. We are rather concerned with the numerical characterization of the AR(1) exogenous stochastic processes included in our artificial economy:

(i) Technological shock affecting potential output: following the estimations of TFP given by Alves and Muinhos (2002) this shock is characterized as an AR(1) stochastic process a persistence parameter value of ρ_{iasc}=0.9.

(ii) Technological shock affecting potential output with high persistence: this shock is characterized as an AR(1) stochastic process a persistence parameter value of ρ_{iasc}=0.99.

4. Numerical Simulations

With the model economy constructed in Section 2 and the parameterization of Section 3, several numerical simulations were performed as exercises aiming to describe the economic performance of our model economy. The algorithm used closely follows McCallum and Nelson's (1998) strategy, which uses the Schur decomposition to solve for the forward-looking endogenous variables, as suggested by Klein (2000). Moreover, McGrattan's (1999) algorithm is implemented in order to get the actual and lagged correlations of the artificially obtained series.

Particular attention is given to the impulse responses of the output gap, aggregate output, inflation rate and nominal interest rate. Moreover, the main statistics on contemporaneous standard deviations are presented.

Based on the calibration procedure introduced in Section 2, the habit persistence in consumption is captured in the model by means of the behavioral parameter 0<h<1, which enters into the instantaneous utility function, given by (4), i.e. $U(C''C,-I)= exp(v_t)(\sigma/(\sigma-1))(C_t/C_{t-1}{}^h)^{\sigma-1/\sigma}$, from which is derived the expectational Euler equation (23). In other words, "h" represents the importance of previous consumption in the utility function: close to 0 means there is no consumption in t-1 in the function. Accordingly, the closer "h" is to one, the more persistent the habit is in consumption. Following McCallum and Nelson (1998) we set h=0.8 as an alternative specification with habit persistence in consumption and h=o for the case of no persistence. In this case, the contemporaneous utility function is given by $U(C''C,-I)= exp(v_t)(\sigma/(\sigma-1))(C_t/C_{t-1}{}^h)^{\sigma-1/\sigma}$.

The impulse responses resulting from the numerical simulation tend to show similar results, independent of habit persistence, as will be shown in section 4.2.

The monetary policy intervention is captured by the alternative Taylor Rule specification (41a to 41c), as explained before. There are some differences in the reaction functions in accordance with the different Taylor Rules adopted, which will be described below in the subsections.

In order to illustrate the way that this artificial economy reacts to different shocks, we present the following figures, which show the impulse responses to unitary shocks (innovations) to technology, aggregate consumption, the monetary policy rule (a random increase in the interest rate), UIP (an increase in the risk premium), foreign income (increase in the rest of the world's income) and fiscal policy stochastic processes (increase in government consumption), taking into consideration the three different Taylor Rules described before.

4.1 Summary Statistics of Artificial Vs Real Series

This section presents the summary statistics of the artificial series simulated for several shocks, as done in Bugarin et al.(2005). These statistics are compared to the ones corresponding to the real time series data. It is important to note that the statistics obtained from empirical evidence are very sample dependent. We report below only the ones corresponding to 1996:Q1 to 2003:Q4.

Table 2 below shows the respective standard deviations. The model economy with Taylor

Rule 3 (only expectation) and habit persistence in consumption is able to better reproduce the volatility of observed inflation rates. Rule 2 (without output gap) with persistence in consumption presents the closes volatility of output gap and nominal interest rate. None of the models mimics the volatility observed in the output gap.

	Inflation Rate	Output	Output Gap	Interest Rate
Data(*)	0.012904	0.056826	0.009978	0.048025
Model with Habit Persistence, h=0				
Taylor Rule from Lagos e Muinhos	0.016410	0.097889	0.081828	0.015929
Taylor Rule without Output Gap	0.001696	0.043490	0.162603	0.015434
Simple Expectational Taylor Rule	0.006362	0.075509	0.176772	0.008976
Model with Habit Persistence, h=0,8				
Taylor Rule from Lagos e Muinhos	0.017653	0.101863	0.090790	0.019726
Taylor Rule without Output Gap	0.002082	0.049180	0.163813	0.021847
Simple Expectational Taylor Rule	0.010599	0.099702	0.187875	0.014176

(*) Times Series data on quarterly from 1996.II to 2005.I. Data source: Banco Central do Brasil

4.2 Responses to Adverse Technological Productivity Shock

Figures 1a and 2a below show the impulse response function derived from the model economy when analyzing a unitary adverse oil shock with an AR parameters of 0.9 and policy rule 1 (35a). These figures show a decrease in output and a higher decrease in potential output that result in an increase in the output gap. The use of this policy produces an initial small decrease in prices followed by an increase, and a lagged increase in the interest rate. The assumption of different habit persistences (h=0 and h=0.8) did not make any difference in the responses.

Figure 1a: Impulse Responses to Unitary Productivity Shock, h = 0 and Taylor Rule from Lagos e Muinhos (2004) with persistence parameter of AR(1): 0.9

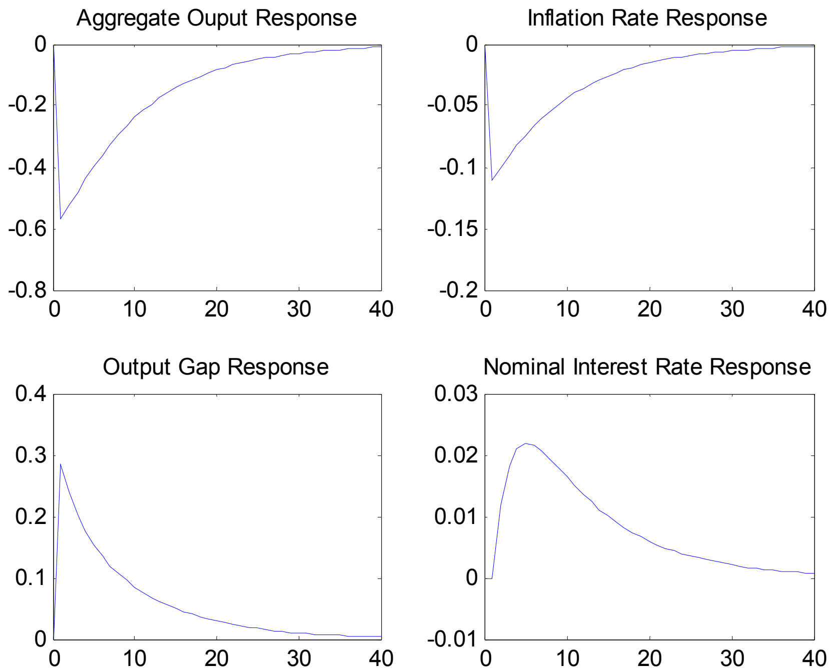
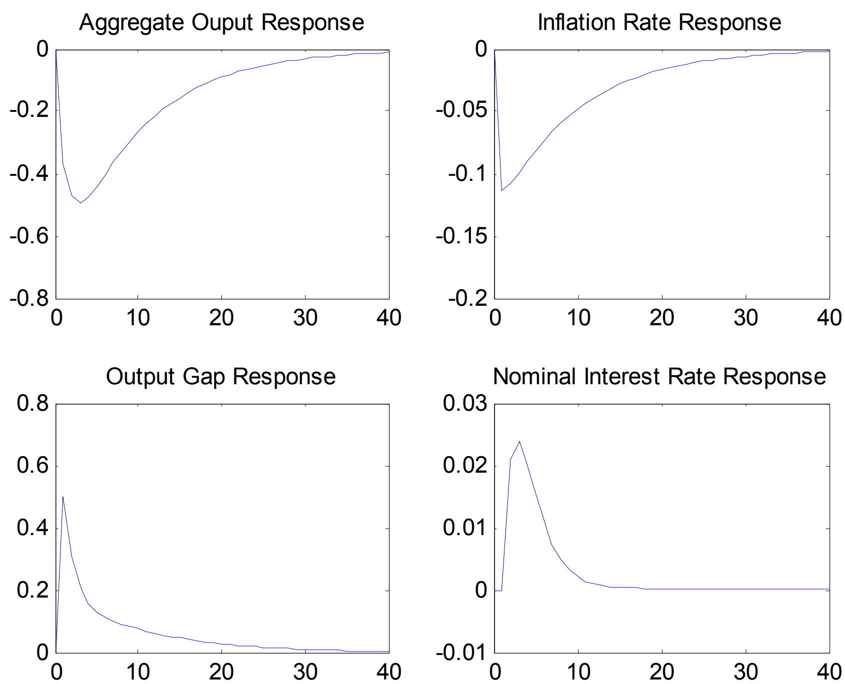


Figure 2a: Impulse Responses to Unitary Productivity Shock, h = 0.8 and Taylor Rule from Lagos e Muinhos (2004) with persistence parameter of AR(1): 0.9



Figures 3a and 4a below show the impulse response function derived from the model economy when analyzing a unitary adverse oil shock with an AR parameters of 0.9 and policy rule 2 (35b), where the reaction to the output gap was shut down. These figures show an increase in the output gap as a function of a significant decrease in potential output. Output, inflation and the interest rate, however, do not show significant variation, when the monetary authority does not react to changes in the output gap. The assumption of different habit persistences (h=0 and h=0.8) did not make any difference in the responses.

Figure 3a: Impulse Responses to Unitary Productivity Shock, h = 0 and Taylor Rule without Output Gap with persistence parameter of AR(1): 0.9

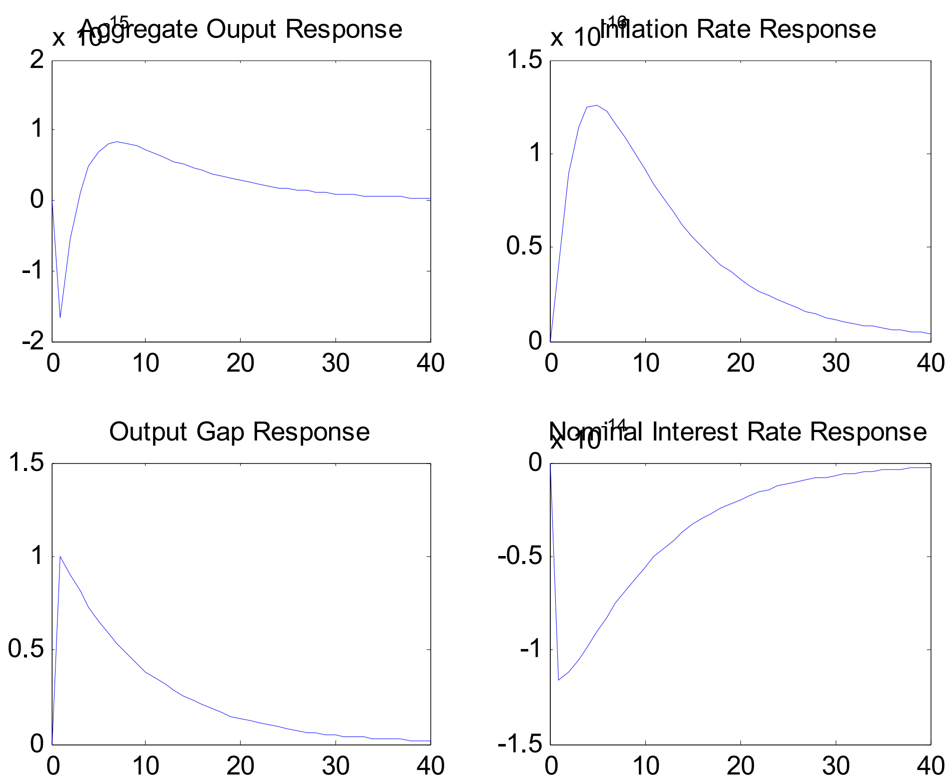
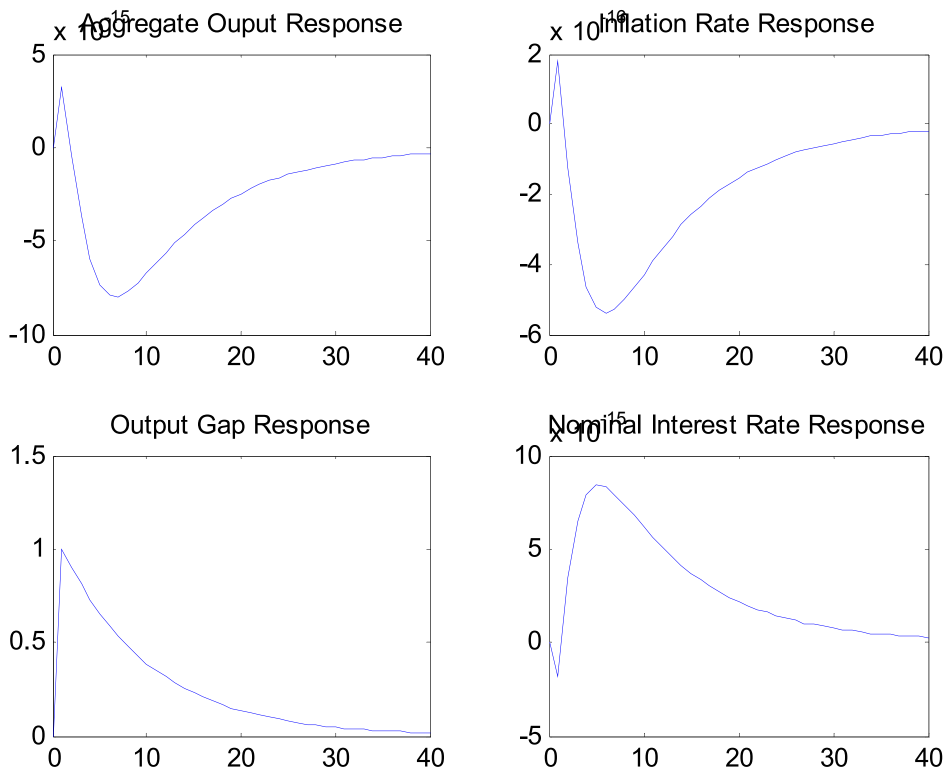


Figure 4a: Impulse Responses to Unitary Productivity Shock, h = 0.8 and Taylor Rule without Output Gap with persistence parameter of AR(1): 0.9



Figures 5a and 6a below show the impulse response function derived from the model economy when analyzing a unitary adverse oil shock with an AR parameters of 0.9 and policy rule 3 (35c), where the reaction of the monetary authority to the output gap and past interest rates was shut down. These figures show an increase in the output gap as a function of a significant decrease in potential output. Output, inflation and interest rates, however, do not show significant variation, when the monetary authority does not react to changes in the output gap. The assumption of different habit persistences (h=0 and h=0.8) did not make any difference in the responses. These results are the same as those observed with policy rule 2 (35b).

Figure 5a: Impulse Responses to Unitary Productivity Shock, h = 0 and Simple Expectational Taylor Rule with persistence parameter of AR(1): 0.9

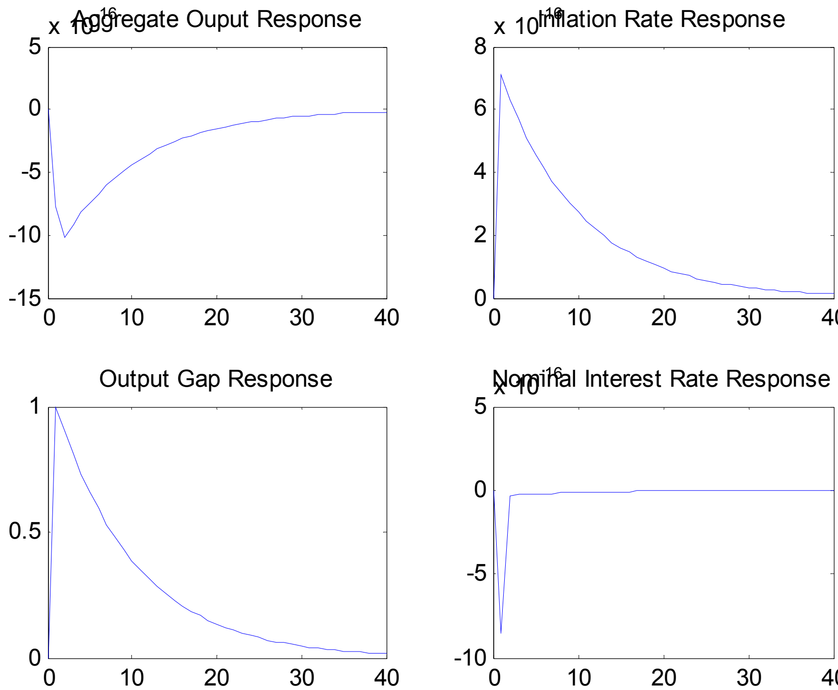
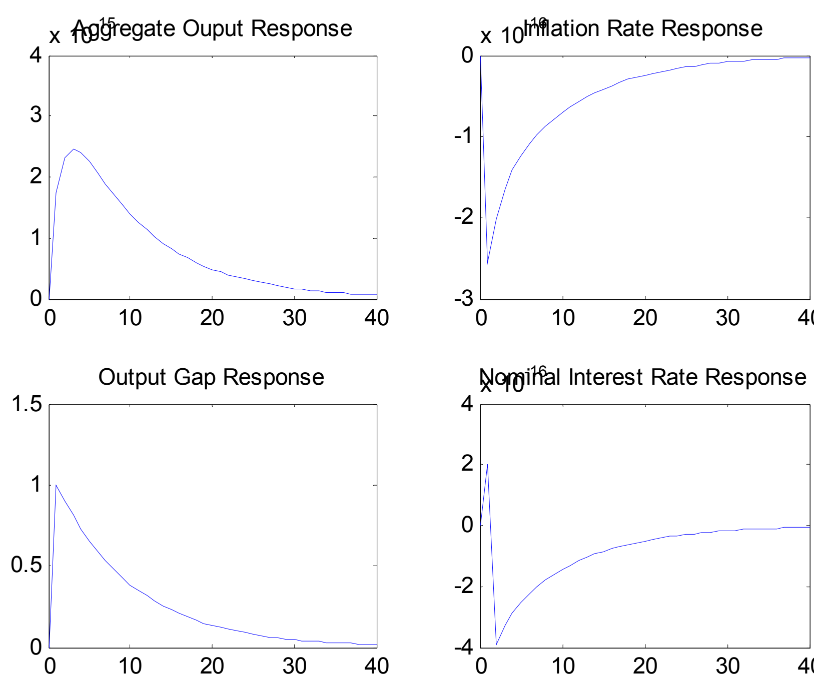


Figure 6a: Impulses Responses to Unitary Productivity Shock, h = 0.8 and Simple Expectational Taylor Rule with persistence parameter of AR(1): 0.90



Figures 1b and 2b below show the impulse response function derived from the model economy when analyzing a unitary adverse oil shock with an AR parameters of 0.99, to simulate a higher persistence of the shock, and policy rule 1 (35a). These figures show a decrease in output, the output gap (meaning that, in this case, output falls more than potential output), inflation and the interest rate. Furthermore, these figures indicate that the responses take longer periods (longer than 40 periods). The assumption of different habit persistences (h=0 and h=0.8) did not make any difference in the responses.

Figure 1b: Impulse Responses to Unitary Productivity Shock, h = 0 and Taylor Rule from Lagos e Muinhos (2004) with persistence parameter of AR(1): 0.99

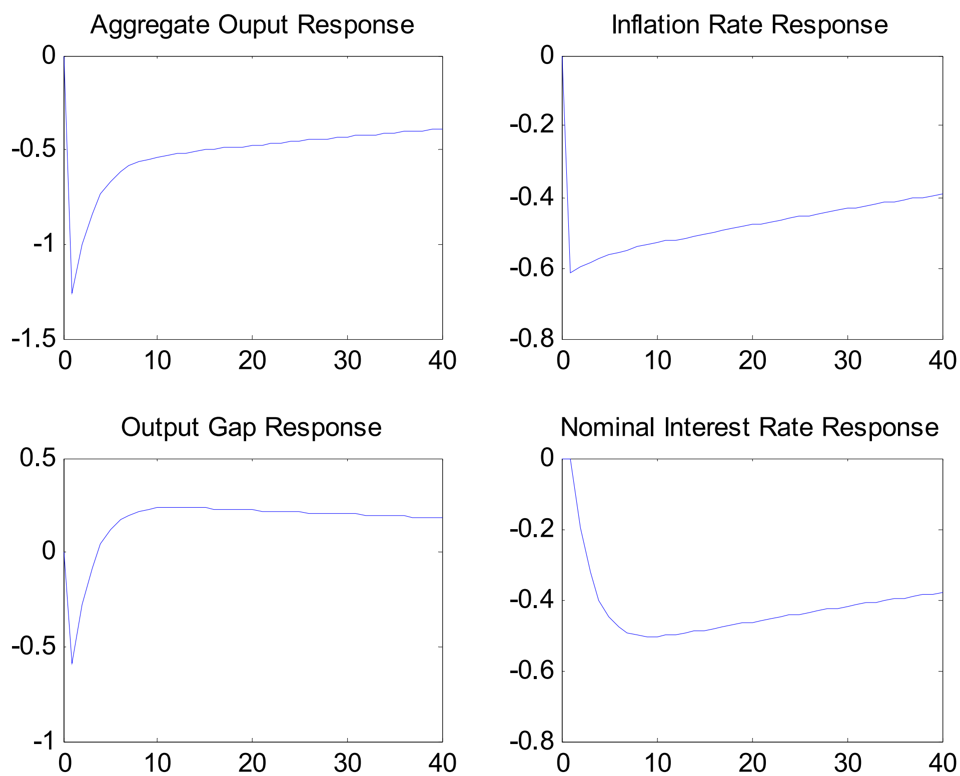
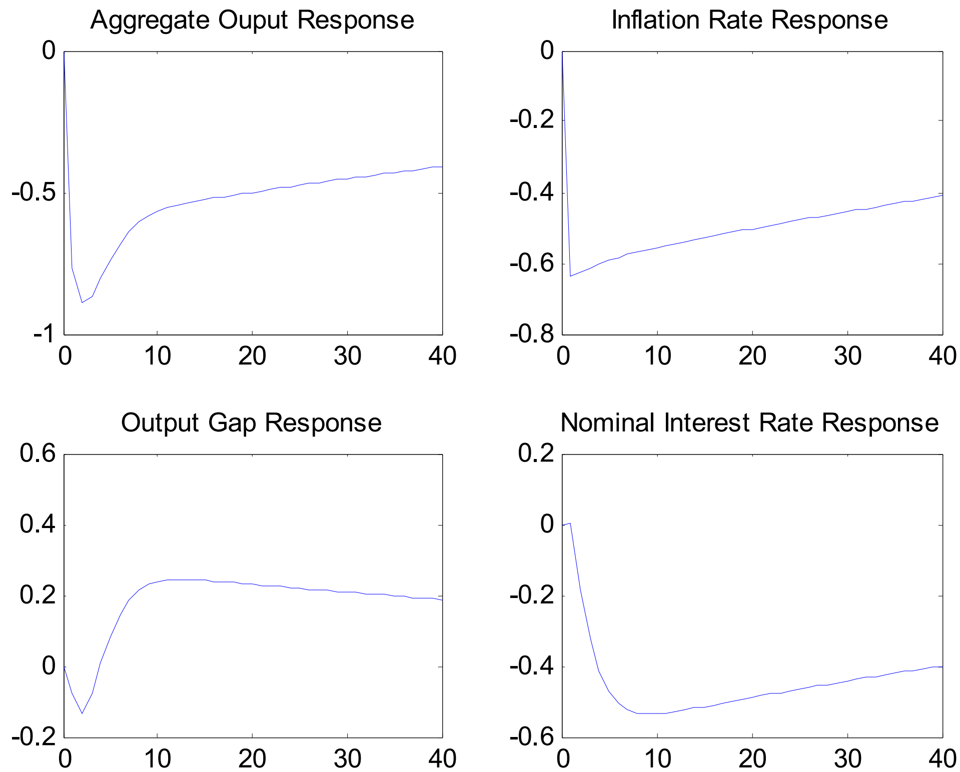


Figure 2b: Impulses Response to Unitary Productivity Shock, h = 0.8 and Taylor Rule from Lagos e Muinhos (2004) with persistence parameter of AR(1): 0.99



Figures 3b and 4b below show the impulse response function derived from the model economy when analyzing a unitary adverse oil shock with an AR parameters of 0.99 and policy rule 2 (35b), where the reaction to the output gap was shut down. These figures do not show any significant movement in output, inflation or the interest rate (movements of order 10^{-14}), while the output gap increases, revealing a reduction in potential output. As observed with rule one, this movement in the output gap does not return to equilibrium in the period of study (40 periods). The assumption of different habit persistences (h=0 and h=0.8) did not make any difference in the responses.

Figure 3b: Impulse Responses to Unitary Productivity Shock, h = 0 and Taylor Rule without Output Gap with persistence parameter of AR(1): 0.99

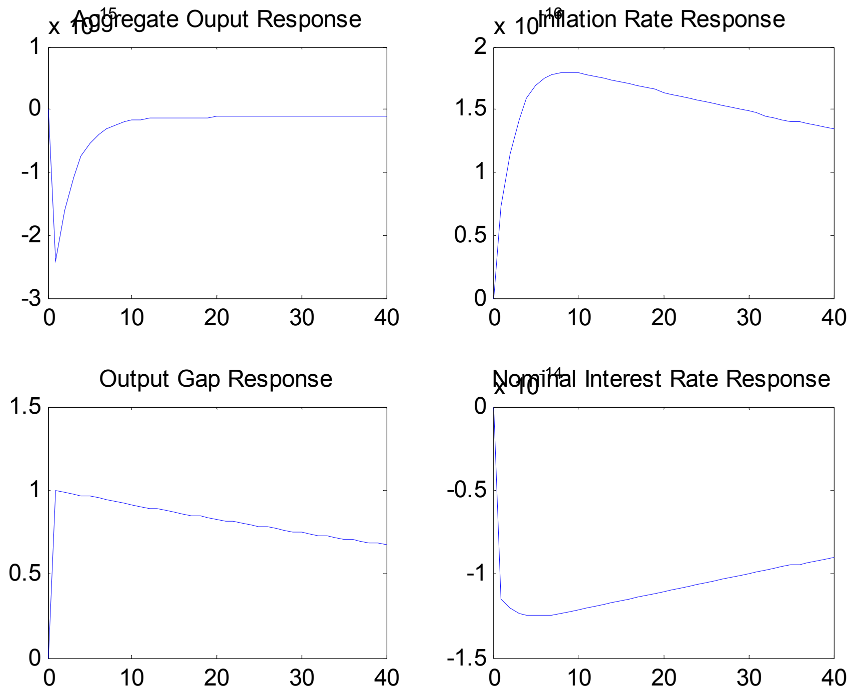
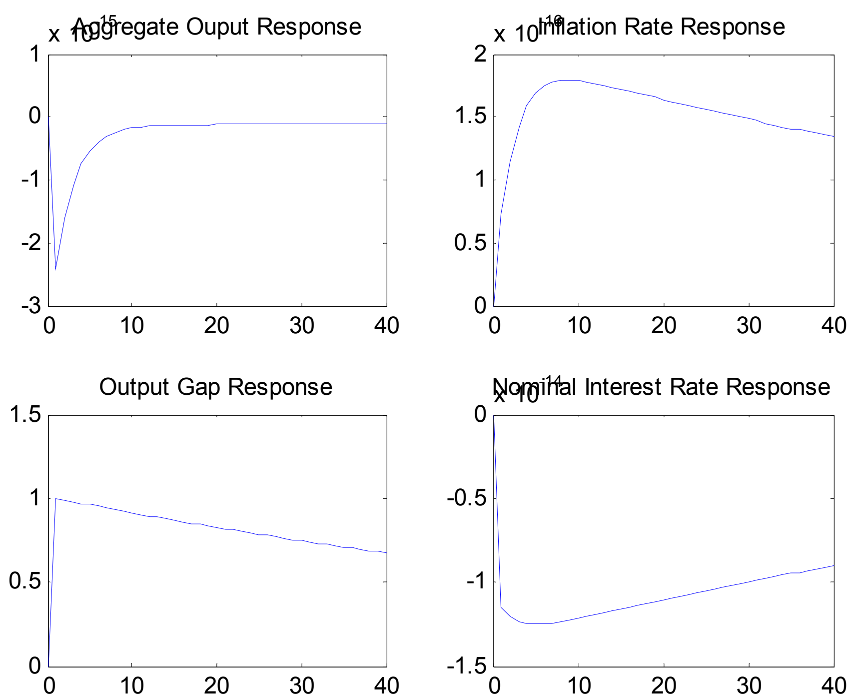


Figure 3b: Impulse Responses to Unitary Productivity Shock, h = 0 and Taylor Rule without Output Gap with persistence parameter of AR(1): 0.99



Figures 5b and 6ba below show the impulse response function derived from the model economy when analyzing a unitary adverse oil shock with an AR parameters of 0.99 and policy rule 3 (35c), where the reaction of the monetary authority to the output gap and past interest rates where shut down. As observed with figures 3b and 4b, there are no significant movements in output, inflation and the interest rate, while the output gap increases, revealing a reduction in potential output. This movement in the output gap does not return to equilibrium in the period of study (40 periods).

Figure 5b: Impulse Responses to Unitary Productivity Shock, h = 0 and Simple Expectational Taylor Rule with persistence parameter of AR(1): 0.99

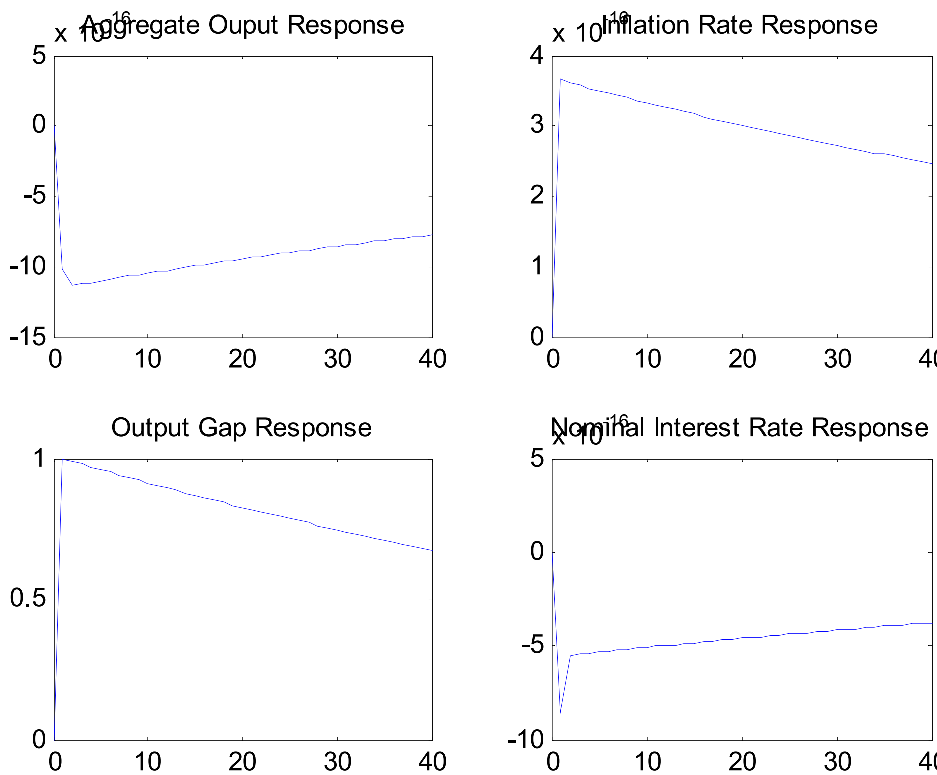
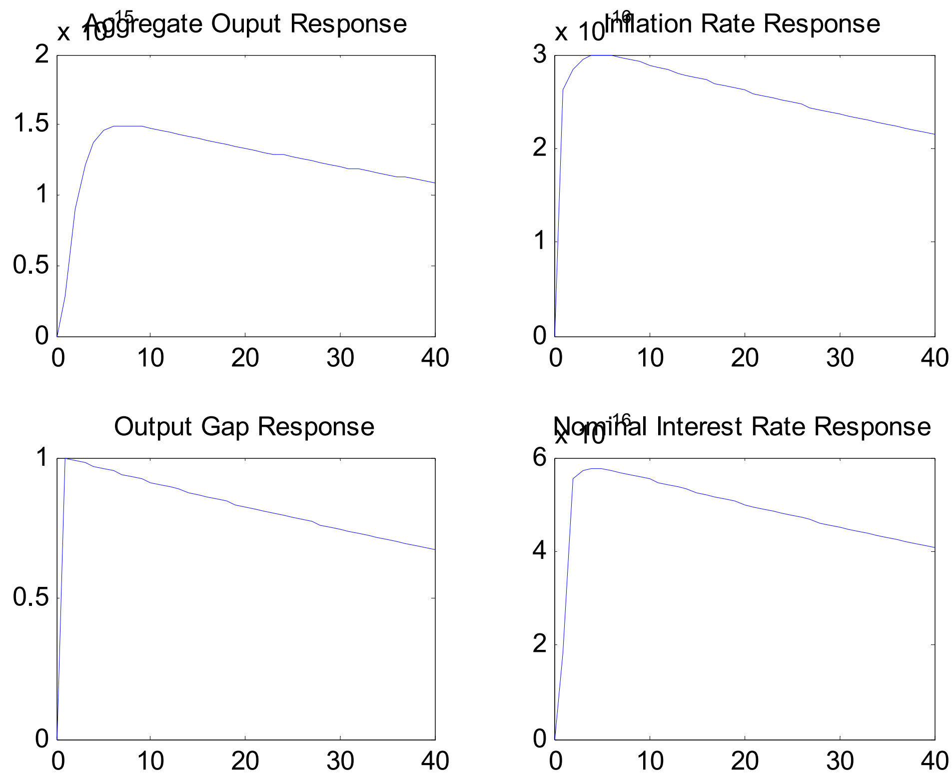


Figure 6b: Impulse Responses to Unitary Productivity Shock, h = 0.8 and Simple Expectational Taylor Rule with persistence parameter of AR(1): 0.99



5. Summary and Conclusions

The main purpose of this paper is to observe the reaction functions of a model economy for monetary policy analysis, based on an optimizing dynamic general equilibrium model, to an oil price shock. Its principal characteristic consists of forward-looking agents facing a staggered price setting in a small open economy. The special feature of this line of modeling is to construct a tractable micro-founded dynamic setting with forward looking rational agents in a small open economy, which, through estimation or calibration processes, enables us to derive qualitative and quantitative assessments of various exogenous (stochastic) interventions into the model/economy, being an extension of Bugarin et al. (2005).

The exercise presented in this paper indicates that an open economy dynamic general equilibrium model, such as the one used here, constitutes a useful laboratory for short-run analysis.

In summary, the following are the main results of the above numerical simulations:

- The existence, or not, of habit persistence does not make a significant difference in the impulse responses;

- As a result of the oil shock, potential output falls independently of the monetary policy rule adopted;

- When the monetary authority focuses on the output gap and past interest rates (rule 1), the decrease in potential output is accompanied by a decrease in output. When using AR=0.9, estimated by Alves and Muinhos (2002), the decrease in potential output was higher than the decrease in output, leading to an increase in the output gap. The opposite was observed when technological progress was more persistent. Interest rates increase in the first case and decrease in the second. With this rule, inflation presents an initial decrease, returning to equilibrium with AR=0.9;

- When the monetary authority does not put any weight on the output gap (rules 2 and 3), the only significant movement observed was an increase in the output gap (indicating a reduction in potential output). Output, inflation and interest rates did not show any significant movement, independent of persistence;

Therefore, the main conclusion of this work is that potential output decreases in the case of an adverse oil shock. But this decrease will have different impacts on output, inflation and interest rates, depending on the monetary policy rules adopted. Additionally, a higher persistence of the technological shock presents a reduction in the output gap as a response, and does not converge to equilibrium in the 40 periods analyzed.

Additional research should be done to estimate the Central Bank policy rule using optimization to calculate the optimal monetary policy rule. Research should also be done to include more imperfections observed on the real economy, in order to better understand the movements in all variables.

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