Monetary Policy in Developing Economies: A Hybrid Model with Interventions in Forex Markets

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Abstract

The paper investigates the participation of an IT-central bank in the exchange rate market, as a supplemental tool for monetary policy. It presents a way of modeling a hybrid IT-regime with a managed float for a small open economy. The strategy followed, differs from most approaches that combine IT with partial control over the exchange rate, in that it uses the exchange rate as an operational target and interventions as instrument. The analysis is done in a general equilibrium setting, considering a financial system dominated by commercial banks, who solve an optimization problem giving rise to a premium in the UIP condition; Central bank's behavior is described by two rules: a policy rate in a Taylor-type rule and another one describing the accumulation of international reserves. The model suggests that, when shocks affecting the economy are supply shocks, intervention in forex market can render better results than just re-setting the policy rate, in the sense that it reduces volatility of inflation, keeping it closer to its long run-level. For other type of shocks, intervention exacerbates inflation volatility.

1 Introduction

Developing economies are different from their developed counterparts, however, are they different enough to require a different way to conduct monetary policy? There are some structural differences that, in principle, could restrict the available channels for transmission of monetary policy in developing economies. Differences like having less developed institutions, uncompetitive banking systems, being more exposed to international influences and having large informal sectors, may quite possibly require a different policy formulation and thus, call for separate models that allow policy makers to discern between competing policies.

An important question that arises when taking these differences into account is, what would be the optimal degree of exchange-rate flexibility for developing countries? In general, the recommendation for open economies is that optimal policy requires a flexible exchange rate. As Devereux and Engel (2003) report, the argument supporting this recommendation can be traced back to Friedman (1953), and it is based on the idea that the degree of flexibility between nominal prices and the exchange rate is different. Friedman argued that country-specific real shocks or demand shocks, require an adjustment in the relative price level between countries. This needed adjustment can be brought by a change either in the internal nominal prices or in the exchange rate, and since there is some evidence pointing to rigid nominal prices, the usual policy recommendation is to let the exchange rate move freely.

Despite the rooted acceptance of this policy recommendation, it relies on assumptions that are not necessarily observed in developing economies. For example, it assumes perfect capital mobility (to ensure an immediate adjustment of the exchange rate), but in developing economies with underdeveloped financial systems and limited supply of financial assets, this assumption might not be satisfied, at least in the short run. If the exchange rate is not subject to the same arbitrage pressures, the benefits attributed to a fully flexible exchange rate might be overstated, giving room for a better policy configuration; perhaps one that includes an active participation of the central bank in the exchange rate market.

Central banks in developing countries, have all along put more emphasis on the exchange rate than they have officially admitted, as documented by Calvo and Reinhart (2000). According to these authors, the fact that many emerging markets (and some developed) appear to be reluctant to let their currencies fluctuate stems from a common cause–*lack of credibility*, that hinders the anchorage of expectations. Nevertheless, since there is evidence of a positive correlation between the volatility of the nominal and the real exchange rate[1], avoiding large fluctuations in the nominal exchange rate, more than a *"fear to float"* due to a lack of credibility, it could be the optimal response for a central bank that implements its monetary policy in an environment plagued with internal and external distortions. For example, capital flows that are assumed to help smooth consumption in face of external shocks, could be exacerbating those shocks in developing countries, where boom-bust cycles are common; capital inflows and the associated currency appreciation had been followed by busts, featuring sudden stops, sharp depreciations and recessions. Intervention in the foreign exchange rate market in this context, could be a well justified policy measure, if intended to hamper down these vicious cycles.

Intervention in foreign exchange markets and the interest of central bankers on the exchange rate, has long been debated. Monetary policy evolved from targeting money aggregates in the 1980's towards targeting the exchange rate and using it as the nominal anchor. According to Batini (2006), in 1985 more than half of developed countries and 75% of developing countries, were engaged in some sort of fixed exchange rate regime, twenty years later, these proportions decreased to 5% and 55% respectively. Even today, some emerging countries seem to be targeting an undervalued real exchange rate level, as part of a development strategy, based on channeling investment to export industries, as proposed by Dooley, Folkerts-Landau, and Garber (2003). But in general, countries (developed and developing alike) have shifted towards a new preferred nominal anchor, *i.e.* inflation, under the so called Inflation Targeting -IT- regime. If we consider a small economy, open to international capital flows which is operating its monetary policy under this regime, the usual recommendation for the exchange rate policy, is again to adopt a flexible exchange rate regime and, there are two related arguments to support this recommendation: First, according to the Mundell-Fleming framework, countries that are integrated to the global capital markets cannot use the exchange rate as an additional tool for monetary policy, since these open economies are subject to the impossible trinity, *i.e.* they can achieve simultaneously, only

[1] As documented byMussa (1986), and many others afterwards.

two out of the following three policy goals: an independent monetary policy, financial integration and exchange rate stability, and second, since monetary policy represents only one instrument, according to Tinbergen (1952)it can only pursue one objective, therefore, if the central bank of a financially integrated economy chooses to control inflation, the exchange rate cannot be targeted simply because the lack of independent instruments.

Nevertheless, Aizenman, Hutchison and Noy (2011) show that even IT-central banks follow a mixed strategy, where both inflation and the real exchange rate are important determinants of the policy interest rate. The question is why? are these central banks just wasting resources, acting like a dog chasing its own tail? or is it possible, on the one hand, that the particularities of developing economies allows them to escape from the policy trilemma and, on the other hand, that the recent hoarding of international reserves provides some countries with an additional policy instrument to pursue simultaneously two objectives? At least we know that emerging countries indeed display a different configuration of the policy trilemma; according to Aizenman, Chinn, and Ito (2010) emerging market countries had move to a middle ground, where non of the three delimiting policy objectives of the trilemma dominates, contrasting with industrialized countries that had move markedly towards financial integration, and non-emerging market developing economies, that appear to be bias towards exchange rate stability.

For emerging economies, the more balanced configuration of the trilemma has been observed jointly with an increase in the reserves to GDP ratio, suggesting that it might be possible to target a desired combination of the three policies by accumulating international reserves. If reserves accumulation gives some slackness to the restrictions imposed by the trilemma, a bigger spectrum of feasible policies could be at the disposal of central banks. If so, we should ask again, what would be the best contribution of monetary policy in such economies? Should these countries devote monetary policy solely to restrain an internal distortion (*i.e.* the internal nominal price rigidity) and assume a passive role with respect to the exchange rate? or is it possible to use intervention in the foreign exchange rate market as an additional tool of monetary policy? Answering this question is especially important for developing countries who are implementing monetary policy under inflation targeting, since this policy regime can be destabilizing for a country subject to terms of trade volatility.

However, the analysis of such intervention practices are beyond the reach of standard modeling approaches. Monetary policy and concerns of central banks regarding the exchange rate are usually studied in the context of the New Keynesian -NK- model, which features only one instrument -a short term interest rate- used to target inflation and exchange rate behavior. This modeling approach is unfit for the practices of central banks in developing countries, where often, intervention in the forex market it is seen as another instrument in achieving central bank's objectives; frequently understood as a supplemental instrument, supporting the transmission role of the interest rate −the main instrument-, but also there are cases where interventions are used independently from the main instrument aimed to different objectives, and therefore, making the standard modeling approach (*i.e.* one featuring only a Taylor-type rule) too stylized to model these interactions.

Therefore, the aim of this paper is not to engage in the fixed vs. flexible exchange rates debate, but rather to consider the participation of an IT-central bank in the exchange rate market, as a supplemental tool for monetary policy. It presents a way of modeling a hybrid IT-regime with a managed float for a small open economy -SOE-. The strategy followed here, differs from most approaches that combine IT with partial control over the exchange rate, in that it uses the exchange rate as an operational target (and interventions as instrument), instead of studying concerns for the exchange rate in the context of a standard New Keynesian inflation targeting model with only one instrument -where interest rates that are used to target both, inflation and the exchange rate−. The main disadvantage of using this standard NK approach, is that it necessarily leaves the determination of interest rates to exogenous elements (usually the UIP condition) and fails to account for other possible transmission channels associated with achieving the exchange rate operational target through interventions in the foreign exchange market. Most of this literature, by ignoring the exchange rate management and its channels, it is not suitable for modeling the central bank behavior in developing countries and/or emerging markets.

The analysis is done in a general equilibrium setting, which allows the study of the financial stocks needed for capturing balance sheet effects of intervention. The model takes into account conditions under which monetary policy is conducted in developing countries, displaying two salient features. First, it considers a financial system dominated by commercial banks, who face limitations in their borrowing capacity from abroad. Banks are supposed to solve an optimization problem where they get to choose how much to borrow from abroad, and select how to divide its assets between loans and government securities. Their optimization problem is subject to an incentive compatibility constraint, that addresses the possibility of default and gives rise to a premium in the UIP condition that allows domestic interest rates to deviate from the international interest rate; it also introduces a wedge between the policy rate and the rate charged for loans. Second, Central bank's behavior is described by two rules: a policy rate in a Taylor rule and another one describing the accumulation of international reserves. In this first model, both rules will be used to target inflation, but in principle, both can pursue multiple targets. The rest of the paper is organized as follows. Section 2 describes the model. Section 3 describes the calibration of the model and the algorithm used to solve it. Section 4 describe model dynamics and Section 5 concludes.

2 The Model

The model takes into account the conditions under which monetary policy is conducted in developing countries, particularly, it includes a financial friction limiting the borrowing capacity of domestic banks from abroad, a preponderant role of banks within the financial system and, as in Ravenna and Walsh (2006), it introduces the cost of working capital into the production side of the model, by assuming that firms need to pay for labor before the proceeds from the sale of output are received. Considering these two frictions, is relevant since the dynamic and static interactions between frictions in both, the international and domestic financial markets, have important consequences for emerging market's performance as Caballero and Krishnamurthy (2001) -CK- have shown. Although the frictions that are considered here are different from the collateral constraints discussed in CK, it will be argued that these same interactions (between international and domestic financial frictions) might be relevant for the conduct of monetary policy in developing economies.

2.1 Banking Sector

The banking sector consists of a commercial bank and a central bank. The commercial bank seeks to maximize its cash flow and has access to a credit line from abroad. It will make loans to firms and will hold securities issued by the central bank. Therefore, its balance sheet has loans and central bank's securities on the assets side, and the credit line from abroad will be its sole liability (and source of funding). The balance sheet of the Central Bank will show international reserves in the assets side and self-issued securities on the liabilities side, these securities will be issued in order to finance the accumulation of reserves; as the commercial bank, the Central Bank will transfer its cash flow to households[2]. A detail description of the two financial agents follow.

2.1.1 Central Bank

The central bank will be allowed to hold a stock of foreign assets (international reserves) -IR_t- for which it collects a return -i_t^{rf}- by investing them abroad. In order to finance the acquisition of those reserves, it will issue securities -B_t^s- in the domestic market paying an interest rate -i_t-[3]. For the moment, fiat money will be ignored, implying that the accumulation of international reserves is done by sterilized interventions. The central bank will interact with commercial banks (in the local market) selling or buying securities when ever it wants to modify the stock of reserves; which is the usual way for central banks to acquire reserves in developing and emerging economies.

In this setting, the central bank will have two instruments at disposition: the interest rate to control inflation, and the level of reserves to influence the exchange rate. Therefore, its behavior will be characterized by two policy rules: a standard Taylor rule for the policy interest rate −as a function of inflation (π_t) and a random disturbance with zero mean ($\epsilon_{\pi,t}$)- which can be introduced without further explanation:

$$i_t = \omega_\pi \pi_t + \epsilon_{\pi,t} \tag{1}$$

and another rule describing the accumulation of international reserves, which deserves a short digression. In order to formulate a rule describing the accumulation of reserves, we should first clarify what are the motives for intervention. The objectives for intervention are particularly varied, according to the Bank of International Settlements (BIS), the reasons for intervention cited by central banks (that do not use the nominal exchange rate as the nominal anchor) include: to control inflation or maintain internal balance, to maintain external balance and prevent resource misallocation or preserve competitiveness and boost growth, and to prevent or deal with disorderly markets or crisis, among others. Since policies regarding intervention (ergo, the foreign exchange rate) can potentially target a wide range of objectives, in what follows, we will assume that the primary objective of monetary policy is to ensure low inflation as a sound

[2]From the point of view of a consolidated public sector, the distinction between government and central bank securities is unimportant since both represent official liabilities, monetary policy implemented with central bank issued securities will generate a quasi-fiscal deficit (or surplus), which will end up as a burden to tax-payers at some point. Since the central bank's cash flow will be transferred to households, this is a simple way of bypassing fiscal considerations, which are out of the scope of the present paper.

[3]Variables in capital letters denote nominal values.

basis for sustained economic growth, hence, the central bank will use both instruments to keep inflation close to its long run level.

Consequently, we assume that the central bank will have an operational target for the exchange rate $-\bar{S}_t-$, that is based on the state of the economy[4], and will adjust this target in order to stabilize inflation, according to:

$$\bar{S}_t = S_T - \gamma_s(\pi_t - \pi) \tag{2}$$

After setting a particular value for the operational target of the exchange rate, the central bank will accommodate the real value of its stock of international reserves, in order to move the exchange rate towards that particular target, according to:

$$\frac{S_t \cdot IR_t}{P_t} = \bar{IR} - \omega_s \left(e^{\left(S_t - \bar{S}_t\right)} - 1 \right) \tag{3}$$

where -$\bar{IR}$- is a long run value for the international reserves and S_t is the nominal exchange rate[5]. With this structure, the central bank will affect the exchange rate through systematic interventions, by varying the stock of international reserves and not through a re-setting of the interest rate.

Therefore, in every period the central bank will set the interest rate according to eq.(1) and will adjust the stock of reserves as specified by eq. (3). By issuing securities that pay an interest rate i_t, potentially different from the compensation -i_t^{rf}- coming from investing the international reserves at the international risk free interest rate, the central bank will generate a quasi-fiscal deficit (or surplus), which will be transferred to households; the transfer in domestic currency and nominal terms is given by,

$$CB_t^{NT} = (1 + i_{t-1}^{rf}) S_t IR_{t-1} - S_t IR_t + B_t^s - (1 + i_{t-1}) \, B_{t-1}^s$$

after imposing the budget identity $S_t IR_t = B_t$, this transfer can be expressed in real terms as follow[6]:

$$CB_t^T = \frac{b_{t-1}^s}{(1 + \pi_t)} \left[(1 + i_{t-1}^{rf}) \frac{S_t}{S_{t-1}} - (1 + i_{t-1}) \right] \tag{4}$$

2.1.2 Commercial banks

A representative bank, operating in a competitive industry, is assumed to determine optimal balance sheet quantities by taking all interest rates as predetermined. For simplicity, the liabilities side of the commercial bank's balance sheet, will only consist of credit lines coming from abroad $-F_t-$; the assets side will be comprised of the sum of loans $-L_t^s-$ supplied to firms, and securities $-B_t^d-$ purchased from the central bank in open market operations -OMO's-. Then, the commercial bank will seek to maximize its next period cash flow, at period t is given by,

[4] Many central banks will argue that their interventions aim to dampen exchange rate volatility rather than to meet a specific target for the level of the exchange rate, in this case we could introduce a rule for the stock of reserves as a function of the volatility of the exchange rate and define the operational target for the exchange rate in terms of its volatility.

[5] Defined as the amount of domestic currency needed to buy one unit of foreign currency, ergo, an increase in S_t implies a nominal depreciation; in the same way, an increase in $\bar{S}_t$ implies a depreciation of the central bank's exchange rate target.

[6] Lower case letters denote variables in real terms *e.g.* $x_t = X_t/P_t$, where P_t is the aggregate price level.

$$\Pi_t^{NB} = (1+j_{t-1})L_{t-1}^s - L_t^s + (1+i_{t-1})B_{t-1}^d - B_t^d + S_tF_t - (1+i_{t-1}^*)S_tF_{t-1} \tag{5}$$

after imposing the balance sheet identity: $S_tF_t = L_t^s + B_t^d$, the cash flow can be expressed in real terms:

$$\Pi_t^B = \frac{(1+j_{t-1})}{(1+\pi_t)}l_{t-1}^s + \frac{(1+i_{t-1})}{(1+\pi_t)}b_{t-1}^d - \frac{(1+i_{t-1}^*)}{(1+\pi_t)}(b_{t-1}^d + l_{t-1}^s)\frac{S_t}{S_{t-1}} \tag{6}$$

where i_t is the return on securities, i_t^* is the interest rate paid over loans coming from abroad, and j_t is the interest rate paid by firms over granted loans. Banks face an agency problem between them and the foreign creditors, since the commercial bank is simultaneously a lender and a borrower −it will borrow abroad in order to lend domestically-. We assume that commercial banks can default on their foreign debt and abscond with a fraction θ_t of repayments made by firms[7]. As in *Céspedes et. al.,* banks maximization problem will be subject to the following incentive compatibility constraint (in order to prevent absconding):

$$(1+i_{t-1})\,B_{t-1}^d + (1+j_{t-1})L_{t-1}^s - (1+i_{t-1}^*)S_tF_{t-1} \geq \theta_t\,(1+j_{t-1})\,L_{t-1}^s \quad \forall t$$

This constraint simply states that profits made by the bank (given the current interest rates) should be higher or equal than the fraction of repayments that they can abscond in case of default, it also implies that banks cannot steal the amount invested in central bank securities, since those funds can be reimbursed to the foreign lender by the central bank in case of default. We assume that this constraint always binds and, as in Geanakoplos (2010) and Bruno and Shin (2012), it addresses the possibility of default in a way that the actual probability of default is zero in the resulting contract.

In order to solve the maximization problem of commercial banks, we set eq. (6) one period forward, and solve:

$$\max_{\{l_t,b_t\}} \Pi_{t+1}^B = \frac{(1+j_t)}{(1+\pi_{t+1})}l_t^s + \frac{(1+i_t)}{(1+\pi_{t+1})}b_t^d - \frac{(1+i_t^*)}{(1+\pi_{t+1})}(b_t^d + l_t^s)\frac{S_{t+1}^e}{S_t}$$

s.t.

$$\frac{(1+i_t)}{1+\pi_{t+1}}b_t^d + \frac{(1+j_t)}{1+\pi_{t+1}}\,(1-\theta_t)\,l_t^s = (1+i_t^*)S_{t+1}^e f_t$$

and the balance sheet identity,

$$S_tf_t = b_t^d + l_t^s$$

From were we get the following first order conditions,

$$l_t^s : \qquad (1+j_t) = (1+i_t^*)\,\frac{S_{t+1}^e}{S_t}\left[\frac{1+\eta_t}{1+\eta_t\,(1-\theta_t)}\right] \tag{7}$$

[7]Throughout most of the paper, we shall take this fraction as constant, *i.e.*, $\theta_t = \theta$. This assumption can be relaxed and allow the fraction to depend upon the composition of the level of credit in the economy or the ratio between loans and securities hold by the banking system as a whole.

$$b_t^d: \qquad (1+i_t) = (1+i_t^*)\,\frac{S_{t+1}^e}{S_t} \tag{8}$$

Where η_t is the Lagrangian multiplier associated to the incentive compatibility constraint. The first equation represents a modified UIP condition, which includes a premium that differentiates domestic and foreign interest rates, a premium related to how stringent the contract with the foreign lender is (measured by θ). Also notice that, if η_t was equal to zero (*i.e.* access to international capital markets was frictionless), we would have the conventional uncovered parity for both interest rates (the policy and the market rate), where foreign and domestic interest rates are equated to each other, once you take into account the corresponding expected variation of the exchange rate (S_{t+1}^e/S_t).

2.2 Households

Households solve a standard problem, they decide how to divide their time between work and leisure and how much to consume. In order to smooth consumption intertemporally, households only have access to a one-period bond -D_t- that pays the domestic market rate -j_t-; this implies they do not have access to the foreign source of funding nor to central bank securities (only through commercial banks which they own)[8].

The economy is inhabited by infinitely lived households, who obtain utility from consumption of a composite good $-C_t-$ and disutility from time spent working $-N_t^s-$. Households seek to maximize the expected value of their lifetime utility function: $\beta \sum_{t=0}^{\infty} U\left(C_t, N_t^s\right)$, where $\beta \in (0,1)$ is the usual subjective discount factor and $U\left(C_t, N_t^s\right)$ is utility in period t, given by:

$$U\left(C_t, N_t\right) = \frac{\mu_t C_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{s(1+\varphi)}}{1+\varphi} \tag{9}$$

where μ_t is a preference shock, and the composite consumption good is defined as,

$$C_t = \left[\int_0^1 c_{it}^{(\varepsilon-1)/\varepsilon} di\right]^{\varepsilon/(\varepsilon-1)} \tag{10}$$

The budget constraint in nominal terms takes the form:

$$\int_0^1 p_{it} c_{it} di + (1+j_{t-1})\, D_{t-1} = W_t N_t^s + D_t + \Pi_t^N \tag{11}$$

where p_{it} is the price of good i, W_t is the nominal wage, D_t are bonds purchased at time t, and Π_t^N are transfers coming from the central bank -CB^{NT}-, commercial banks -Π_t^{NB}- and firms -Π_t^{Nf}-, all of which are not internalized by the household, thus taken as given. By maximizing the the composite good for any given level of expenditure, we get the following set of demand equations,

$$c_{it} = \left(\frac{p_{it}}{P_t}\right)^{-\varepsilon} C_t \tag{12}$$

[8]The net supply of this one-period bonds is assumed to be zero in equilibrium, and households are subject to the usual no-ponzi scheme restriction *i.e.* $\underset{k\to\infty}{lim} \frac{D_{t+k}}{\prod_{s=0}^{j}(1+j_{t+s})} \leq 0$.

$\forall i \in [0,1]$, where $P_t \equiv \left[\int_0^1 p_{it}^{(1-\varepsilon)}\right]^{\frac{1}{1-\varepsilon}}$ is the aggregate price index. Conditional on eq.(12), it can be shown that $\int_0^1 p_{it}c_{it}di = P_t C_t$, substituting this result into the budget constraint eq. (11) and solving household's maximization problem, we get the usual equilibrium conditions:

$$U_{C_t}\left(C_t, N_t^s\right) = \beta U_{C_{t+1}}\left(C_t, N_t^s\right)\frac{(1+j_t)}{(1+\pi_{t+1})} \tag{13}$$

$$-\frac{U_{N_t^S}\left(C_t, N_t^s\right)}{U_{C_t}\left(C_t, N_t^s\right)} = \frac{W_t}{P_t} \tag{14}$$

$$C_t + \frac{(1+j_{t-1})}{(1+\pi_t)}d_{t-1} = \frac{W_t}{P_t}N_t^s + d_t + CB^T + \Pi_t^B + \Pi_t^f \tag{15}$$

2.3 Firms

Assume a continuum of firms indexed by $i \in [0,1]$. Each firm will produce a differentiated good using the same technology:

$$y_{it} = Z_t\left(N_{it}^d\right)^{1-\alpha} \tag{16}$$

where Z_t is a productivity factor, common across firms that evolves exogenously over time. All firms will face the same demand schedule, given by eq. (12) and all of them will take as given the aggregate price level P_t and the composite consumption good C_t. It is also assumed that the firm must borrow an amount W_tN_t from commercial banks to pay for labor services, making the nominal cost of labor equal to: $(1+j_t)W_tN_{it}^d$. Therefore, the standard cost minimization problem (given the production function eq. 16) will render the following first order condition, which determines firm's real marginal cost,

$$\varphi_{it} = \frac{(1+j_t)^{W_t}/_{P_t}}{(1-\alpha)Z_t\left(N_{it}^d\right)^{-\alpha}} \tag{17}$$

assuming a small price dispersion, the average real marginal cost will be,

$$\varphi_t = \frac{(1+j_t)^{W_t}/_{P_t}}{(1-\alpha)Z_t\left(N_t^d\right)^{-\alpha}} \tag{18}$$

Following Calvo (1983), we assume that each firm can reset its price only with probability $(1-\omega)$, in any given period, therefore, firm's pricing decision becomes a dynamic one, that involves choosing p_{it} to maximize,

$$E_t\sum_{j=0}^{\infty}(1-\omega)\omega^j\Delta_{t+j}\left[\left(\frac{p_{it}}{P_{t+j}}\right)c_{it+j} - \varphi_{t+j}c_{it+j}\right]$$

were $\Delta_{t+j} = \frac{\beta^j U_{C_{t+j}}(C_{t+j}, h_{t+j})}{U_{C_t}(C_t,, h_t)}$ is the appropriate discount factor and c_{it+j} is given by eq. (12). Let p_t^* be the optimal price chosen by all firms adjusting at time t. The first-order condition for this optimal price is given by,

$$p_t^* = \frac{\varepsilon}{\varepsilon-1}\frac{E_t\sum_{j=0}^{\infty}\omega^j\Delta_{t+j}\cdot C_{t+j}\cdot\varphi_{t+j}\cdot P_{t+j}^{\varepsilon}}{E_t\sum_{j=0}^{\infty}\omega^j\Delta_{t+j}\cdot C_{t+j}\cdot P_{t+j}^{\varepsilon-1}}$$

dividing both sides by $1/P_t$,

$$\frac{p_t^*}{P_t} = \frac{\varepsilon}{\varepsilon-1}\frac{E_t\sum_{j=0}^{\infty}\omega^j\Delta_{t+j}\cdot C_{t+j}\cdot\varphi_{t+j}\left(\frac{P_{t+j}}{P_t}\right)^{\varepsilon}}{E_t\sum_{j=0}^{\infty}\omega^j\Delta_{t+j}\cdot C_{t+j}\left(\frac{P_{t+j}}{P_t}\right)^{\varepsilon-1}}$$

which can be rewritten as,

$$\frac{p_t^*}{P_t} = \frac{\varepsilon}{\varepsilon-1}E_t\left(\frac{\Theta_t}{\Psi_t}\right) \tag{19}$$

where,

$$\Theta_t = \Delta_t\varphi_t C_t + \omega E_t\left[(1+\pi_{t+1})^{\varepsilon}\,\Theta_{t+1}\right], \tag{20}$$

$$\Psi_t = \Delta_t C_t + \omega E_t\left[(1+\pi_{t+1})^{\varepsilon-1}\,\Psi_{t+1}\right] \tag{21}$$

The remaining fraction -ω- of firms that do not get the signal to re-optimize, will set their price according to the rule,

$$P_t^{rule} = P_{t-1}(1+\pi_{t-1})$$

where prices are set taking into account the average price level of the previous period and last period inflation. With this indexation rule, the appropriate price average in period t satisfies:

$$P_t^{1-\varepsilon} = (1-\omega)p_t^{*(1-\varepsilon)} + \omega P_t^{rule(1-\varepsilon)}$$

implying the aggregate price dynamics:

$$(1+\pi_t)^{1-\varepsilon} = (1-\omega)\left(\frac{\varepsilon}{\varepsilon-1}\cdot E_t\frac{\Theta_t}{\Psi_t}\cdot(1+\pi_t)\right)^{1-\varepsilon} + \omega\,(1+\pi_{t-1})^{1-\varepsilon} \tag{22}$$

Firm profits in real terms are,

$$\Pi_t^f = C_t\,(1-\varphi_t)$$

2.4 Closing the small open economy

In order to close the model, it is necessary to impose an exogenous steady state level for foreign indebtedness -f_t-, without it, foreign liabilities may not be stationary, complicating the analysis of local dynamics. Given the structure of the model, imposing this steady state level is enough to ensure a unique solution, without resorting to other common ways of closing a small open economy[9].

[9] See Schmitt-Grohé and Uribe (2003).

Additionally, a country borrowing premium is introduced, defining the interest rate at which commercial banks can borrow from abroad -i_t^*-, as a function of foreign indebtedness:

$$i_t^* = (1+\iota)i_t^{rf} + \psi(e^{\zeta(f_t - f)} - 1) + \chi_t \tag{23}$$

where -χ_t- is an AR(1) process with zero mean.

It is usual to assume that sovereign borrowers face, up to a certain limit, an upward sloping supply curve of foreign funds. This upward-sloping portion of the supply curve reflects the fact that, as the level of the debt increases, the perceived probability of default also rises. In this model, the country risk premium is not included because it is needed to make foreign indebtedness revert to trend (as aforementioned, a long run value for -f- suffices and the incentive compatibility constraint deals with default), but rather it is included for two important reasons: First, it makes possible to take into account the social cost of holding reserves, captured by the last term of eq.(28), which depends on the spread between the private sector's cost of borrowing abroad -i_t^*- and the yield that the Central Bank earns on its liquid foreign assets -i_t^{rf}-, the appropriate social cost, as suggested by Rodrik (2006)[10]. Second, introducing a country borrowing premium is a simple way to model sudden capital outflows or changes in the external cost of funding, represented by shocks to -χ_t- in eq.(23).

2.5 Exogenous processes

The model includes three sources of uncertainty: a productivity shock, a demand (or taste) shock and a shock to the cost of foreign funding. All three shocks are assumed to follow an autoregressive process of order one:

$$Z_{t+1} = \rho_z Z_t + (1-\rho_z)\bar{Z} + \nu_{t+1}^Z; \qquad \nu_t^Z \sim N\left(0, \sigma_{\nu^Z}^2\right) \tag{24}$$

$$\mu_{t+1} = \rho_\mu \mu_t + (1-\rho_\mu)\bar{\mu} + \nu_{t+1}^\mu; \qquad \nu_t^\mu \sim N\left(0, \sigma_{\nu^\mu}^2\right) \tag{25}$$

$$\chi_{t+1} = \rho_\chi \chi_t + (1-\rho_\chi)\bar{\chi} + \nu_{t+1}^\chi; \qquad \nu_t^\chi \sim N\left(0, \sigma_{\nu^\chi}^2\right) \tag{26}$$

where $\rho_j \in (0,1)$ for $j = Z; \mu; \chi$.

2.6 Market Clearing

Market clearing requires that demand equals supply in all markets, *i.e.*

Clearing in the goods market requires,

[10] This cost differs from perhaps the most commonly found in the literature, *i.e.* the fiscal one, accounting for the difference between the interest rate of domestic government bonds and the yield on reserves, however, this is looking at the cost solely from the perspective of the public sector, but in a general equilibrium setting "...any difference between the interest costs of domestic government bonds and short-term foreign borrowing is tantamount to a transfer from the public to the private sector in the domestic economy (or vice versa), and needs to be netted out when calculating the cost from a national standpoint." D. Rodrik (2006). That is exactly what is happening in the model, the fiscal cost is netted out, remaining only the difference between i^* and i^{rf}.

$$y_{it} = c_{it} \qquad \forall i \in [0,1]\,; \forall t$$

From the labor supply equation we can obtain,

$$\int_0^1 N_{it}^d di = N_t^d = N_t^s = N_t$$

defining $N_t^d = \int_0^1 N_{it}^d di$, with the arrangements below,

$$N_t^d = \int_0^1 N_{it}^d di$$

$$N_t^d = \int_0^1 \left(\frac{y_{it}}{Z_t}\right)^{\frac{1}{1-\alpha}} di = \int_0^1 \left(\frac{c_{it}}{Z_t}\right)^{\frac{1}{1-\alpha}} di$$

$$N_t^d = \left(\frac{C_t}{Z_t}\right)^{\frac{1}{1-\alpha}} \int_0^1 \left(\frac{p_{it}}{P_t}\right)^{-\frac{\varepsilon}{1-\alpha}} di$$

Using Calvo insight,

$$\frac{Z_t N_t^{d(1-\alpha)}}{C_t} = \left[(1-\omega)\left(\frac{p_t^*}{P_t}\right)^{-\frac{\varepsilon}{1-\alpha}} + \omega\left(\frac{P_t^{rule}}{P_t}\right)^{-\frac{\varepsilon}{1-\alpha}}\right]^{1-\alpha}$$

$$\frac{Z_t N_t^{d(1-\alpha)}}{C_t} = \left[(1-\omega)\left(\frac{\varepsilon}{\varepsilon-1}\cdot E_t\frac{\Theta_t}{\Psi_t}\right)^{-\frac{\varepsilon}{1-\alpha}} + \omega\left(\frac{1+\pi_{t-1}}{1+\pi_t}\right)^{-\frac{\varepsilon}{1-\alpha}}\right]^{1-\alpha}$$

after imposing equilibrium in the labor market, we get the goods market equilibrium condition,

$$C_t = Z_t N_t^{(1-\alpha)}\left[(1-\omega)\left(\frac{\varepsilon}{\varepsilon-1}\cdot E_t\frac{\Theta_t}{\Psi_t}\right)^{-\frac{\varepsilon}{1-\alpha}} + \omega\left(\frac{1+\pi_{t-1}}{1+\pi_t}\right)^{-\frac{\varepsilon}{1-\alpha}}\right]^{\alpha-1} \tag{27}$$

Clearing Central Bank's securities market requires,

$$b_t^s = b_t^d = b_t \quad \forall t$$

The loan market equilibrium requires,

$$l_t^d = \frac{W_t}{P_t}N_t = l_t^s = l_t \quad \forall t$$

The real transfer to households is given by,

$$\Pi_t = CB_t^T + \Pi_t^f + \Pi_t^B$$

which after imposing equilibrium, can be written as:

$$\Pi_t = \frac{b_{t-1}S_t}{(1+\pi_t)S_{t-1}}\left[i^{rf}_{t-1} - i^*_{t-1}\right] + C_t\left(1-\varphi_t\right) + \frac{l_{t-1}}{(1+\pi_t)}\left[(1+j_{t-1}) - \left(1+i^*_{t-1}\right)\cdot\frac{S_t}{S_{t-1}}\right]$$

by substituting this real transfer into the households budget constraint eq. (15), we get the economy wide resource constraint:

$$C_t\varphi_t = l_t + \frac{l_{t-1}}{(1+\pi_t)}\left[(1+j_{t-1}) - \left(1+i^*_{t-1}\right)\cdot\frac{S_t}{S_{t-1}}\right] + \frac{b_{t-1}S_t}{(1+\pi_t)S_{t-1}}\left[i^{rf}_{t-1} - i^*_{t-1}\right] \tag{28}$$

This concludes the specification of the model. Appendix B contains the complete system of equations to solve.

3 Model parametrization and solution algorithm

3.1 Parametrization

The values assumed for the different parameters in the baseline calibration, are summarized in Table 1. Most of them are common in the literature (for a quarterly frequencies), and some are specific to this model and deserve some explanation.

Those parameters that are fairly standard, *e.g.* the discount rate $\beta = 0.93$, the inverse of the elasticity of labour supply $\varphi^{-1} = 1$ and the labor share in the production function $(1-\alpha) = 2/3$ were set in accordance with much of the recent business cycle literature. The relative utility weight on labour $\chi = 12.5$ was set to get a steady state share of working hours of roughly $1/3$. The parameter ε that determines the degree of competition in the differentiated goods market, is set to 6 in order to obtain a markup of 20%. The parameter that determines the degree of price stickiness $-\omega-$ is set to 0.75 in order to have prices changing every one year.

Now consider the the less common parameters, which are: the inflation coefficient -γ_s- on eq. (2) and the adjustment coefficient for international reserves -ω_s- in the intervention rule eq. (3). These are policy parameters, and thus, the monetary authority will choose a value for them according to its intentions; a central bank inclined to a more flexible exchange rate will choose a small value for ω_s, on the contrary, a central bank that views intervention as an effective policy instrument and who is willing to intervene heavily in the forex market, will choose a higher value for this parameter. In the same way, the policy makers will choose a high value for γ_s, when they believe intervention is an effective tool to achieve the central bank objective (defined in this model as to keep inflation close to its steady state value), and a low value otherwise. Therefore, for any particular set of believes or any particular information set, over which policy decision making is based on, there will be a different combination of these policy parameters. In order to assess what are the implications for model's dynamics, some sensitivity analysis is conducted on Appendix C, where a range of values of these parameters are considered in addition to their baseline settings, *i.e.* $\gamma_s = 1.2$ and ω_s =1.7.

Table 1: Parameters

Symbol	Value	Description:
φ^{-1}	1	Elasticity of labor supply
σ^{-1}	0.2	Elasticity of inter-temporal substitution
ε	6	Degree of competition in the differentiated goods market
θ	0.22	Fraction of repayments banks can abscond
ω_π	1.8	Inflation coefficient, Taylor rule
γ_s	1.2	Inflation coefficient, operational exchange rate target
S_T	1.2	Exchange rate consistent with fundamentals
ω_s	1.7	International reserves adjustment coefficient
i^{rf}	0.0073	Risk free interest rate
χ	12.5	Relative utility weight on labor
$1-\alpha$	2/3	Labor share in production function
ω	0.75	Probability of not adjusting prices
β	0.93	Subjective discount factor
f	0.56	Steady state foreign debt
ρ_Z	0.8	Autoregressive coefficient productivity process
ρ_μ	0.8	Autoregressive coefficient demand
ι	0.1	Coeff. determining steady state wedge between i^{rf} rate and $i*$
ρ_χ	0.71	Autoregressive coefficient of country premium process

3.2 Solution

In order to solve the model, the complete system of equations is transformed to express it in terms of logarithmic deviations from the steady state, *i.e.* I used transformed variables: $\hat{j}_t = log(\frac{j_t}{j_{ss}})$ for every variable j. Then, a first-order approximation is made using Taylor's expansion and the model is solved using the method of Klein (2000). By using this method, matrices P and F are obtained, which generate the dynamic solution by iterating on the following two linear equations:

$$x_t = Px_{t-1} + B\omega_t$$

$$k_t = Fx_t$$

where k is a vector composed by controls and co-state variables, x is a vector of endogenous and exogenous states, F characterizes the policy function (including the optimal dynamics of co-state variables) and P is a transition matrix for the states. B is a matrix that determines which variables can experience an exogenous shock and in what magnitude. ω_t is an innovation vector.

4 Intervention as a distinct form of monetary policy

It is common to define 'intervention' as official purchases or sales of foreign exchange undertaken with the objective of influencing the exchange rate. This definition is obscure with respect to whether the exchange rate is an intermediate target, an operational target or a policy goal in itself. An understanding of the motive for buying or selling foreign exchange is a necessary component of the definition of intervention. In the present model, sterilized intervention is the instrument used by the Central Bank to alter the supply of securities available in the domestic economy (held by commercial banks) in order to influence the exchange rate, with the final objective of keeping inflation close to its long run level.

Under this narrower definition for intervention, the current section analyzes the response of an IT-Central Bank to three basic shocks (productivity, demand, and the cost of foreign funding). A comparison is made between two central banks, both of which follow a Taylor-rule -eq. (1)− and have the same steady state level of international reserves -$\bar{IR}$-, but they differ in the way they manage the exchange rate. The first central bank, despite it has a stock of international reserves, it will allow the exchange rate to move freely *i.e.* it will set $\omega_s = 0$ in eq. (3) and on eq. (2) it will set: $S_T = S_t$ and $\gamma_s = 0$; this means that it will not use its reserves for policy purposes and it will not target any particular value for the exchange rate -S_t-, I will refer to this case as: No-Intervention. The other central bank will follow a hybrid regime, in which in addition to the conventional Taylor-rule, it will use international reserves to influence the exchange rate, trying to move it closer to the operational target -$\bar{S}_t$-, a target that will be aligned with the ultimate goal of keeping inflation close to its long run level, thus, in this case $\omega_s, \gamma_s > 0$ and S_T will be set by the monetary authority, I will refer to this case as: Intervention.

4.1 Model Dynamics

In order to examine the dynamics of the artificial economy, this section shows the impulse-response functions for three types of transitory shocks, and for both types of central banks. In all figures the solid line depicts the system dynamics when the Central Bank decide to intervene and the discontinuous line depicts the responses of the system when the Central Bank allows the exchange rate to move freely[11].

4.1.1 Shock to the country borrowing premium

We analyze an unanticipated increase in the country borrowing premium -χ_t- (see Figure 1)[12]. As foreign cost of funding rises, also does the market interest rate in the economy -j_t- (around 15%). As the interest rate increases, firms will take less loans, therefore labor and output will decrease (˜ 3% and ˜ 2% respectively). Lower output implies lower consumption, and a lower demand implies that prices will go down (inflation decreases), to which the central bank reacts by lowering the policy rate. These results are aligned with conventional wisdom or other conventional models. What is noteworthy or specific to the present model is the following.

[11] Bear in mind that even when the central bank is not intervening, the economy is still subject to the incentive compatibility constraint and firms still need to borrow from banks to pay for labor, therefore the economy will not necessarily behave as the standard NK model.

[12] Some selected variables are shown in Figure 1, for the complete set of variables see Appendix A.3

As foreign funding cost increases and resources fly away from the domestic economy, the exchange rate depreciates on impact (~ 1.1%) in both cases, No-Intervention and Intervention. In the case of Intervention, the central bank tries to counteract the depreciation by decreasing its holdings of foreign reserves (~ 1% in real value), being mildly successful in affecting the exchange rate (only between the 5^{th} and the 10^{th} quarter). What results interesting is that, by reducing its holdings of international reserves, the Central Bank is not only unable to affect substantially the exchange rate, but also the foreign resources that it is liberating are not been used to ease the contraction of the economy, they are flying away, increasing the loss of foreign resources in the domestic economy. The contraction in the supply of loans is greater in the case of Intervention because, as the Central Bank increases the policy rate and reduces the supply of securities by its sterilized intervention, it makes even more stringent the compatibility constraint that limits the ability of commercial banks to access foreign resources, therefore the reduction in the supply of loans to firms and the loss of foreign resources are both worse under Intervention. Additionally, these results suggest that pursuing a hybrid-policy with this type of shock, is also detrimental for the ultimate goal of the central bank[13]. By intervening in the forex market, the central bank is exacerbating the reduction in prices and apparently increasing inflation volatility, with respect to inflation dynamics observed under the No-Intervention policy[14].

[13] The one assumed for this model: to keep inflation close to its long run value.

[14] On Appendix C, it can be observed how sensitive are inflation dynamics to different values of the inflation coefficient $-\gamma_s-$ in the exchange rate rule.

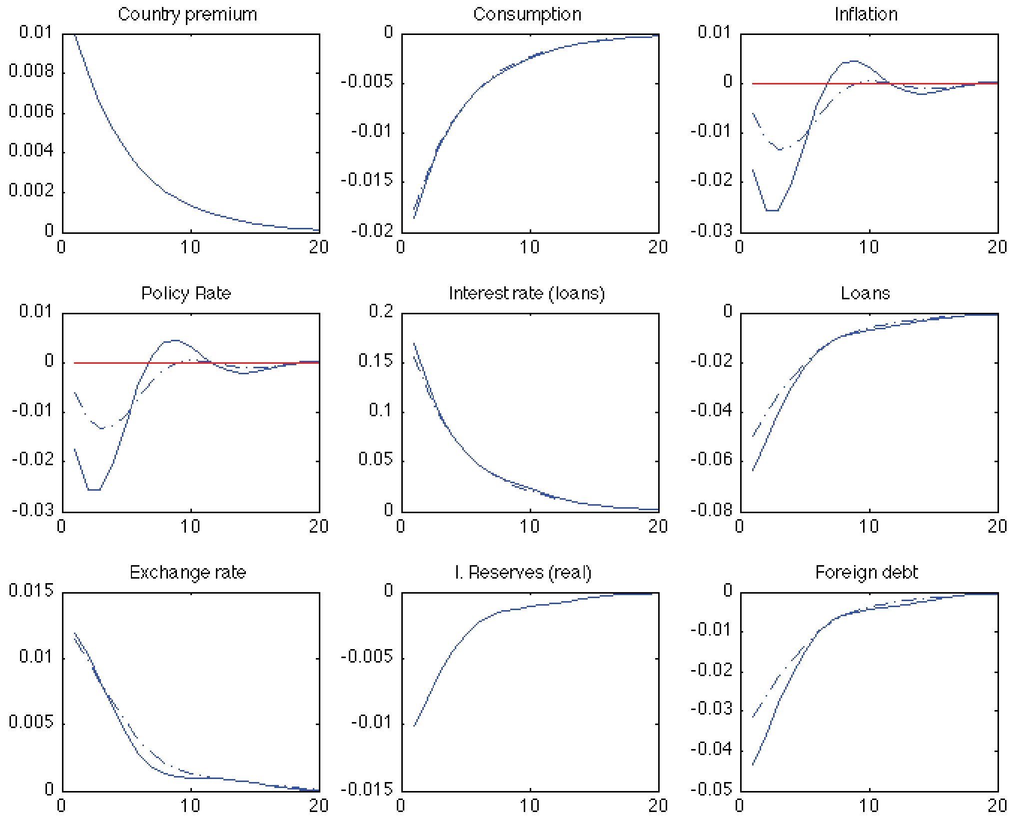

Figure 1: Transitory country premium shock. $- \cdot -$ No Intervention $-$ Intervention

4.1.2 Demand shock

Figure 2 shows the impulse-response functions for a demand shock -μ_t-. After a shift in preferences, households decide to consume more (~ 3%), nothing else has changed in the economy and therefore, in order to meet the higher demand, firms need to borrow more from banks, so demand for loans increases as well as the interest rate over those loans. In order to provide incentives to households to supply more labor, the real wage also increases (~ 2%) and as consequence (together with the increase in the interest rate), the real marginal cost also rises (~ 5%). Again, the model specific findings follow.

Commercial banks increase foreign borrowing in order to satisfy the higher domestic demand for loans. As foreign resources come into the economy, the exchange rate appreciates on impact (~ 1.2%). The Central Bank reacts by buying some of those resources, increasing both: its holdings of international reserves and the supply of securities when sterilizing. But again for this type of shock, Intervention seems to be pernicious. When the Central Bank increases the supply of securities it relaxes the constraint on foreign borrowing for commercial banks, and that is why foreign debt increases even more in the case of Intervention, which allows commercial banks to grant even more loans and again, worsening the outcome for inflation, which reaches higher levels under Intervention (again, with respect to No-Intervention).

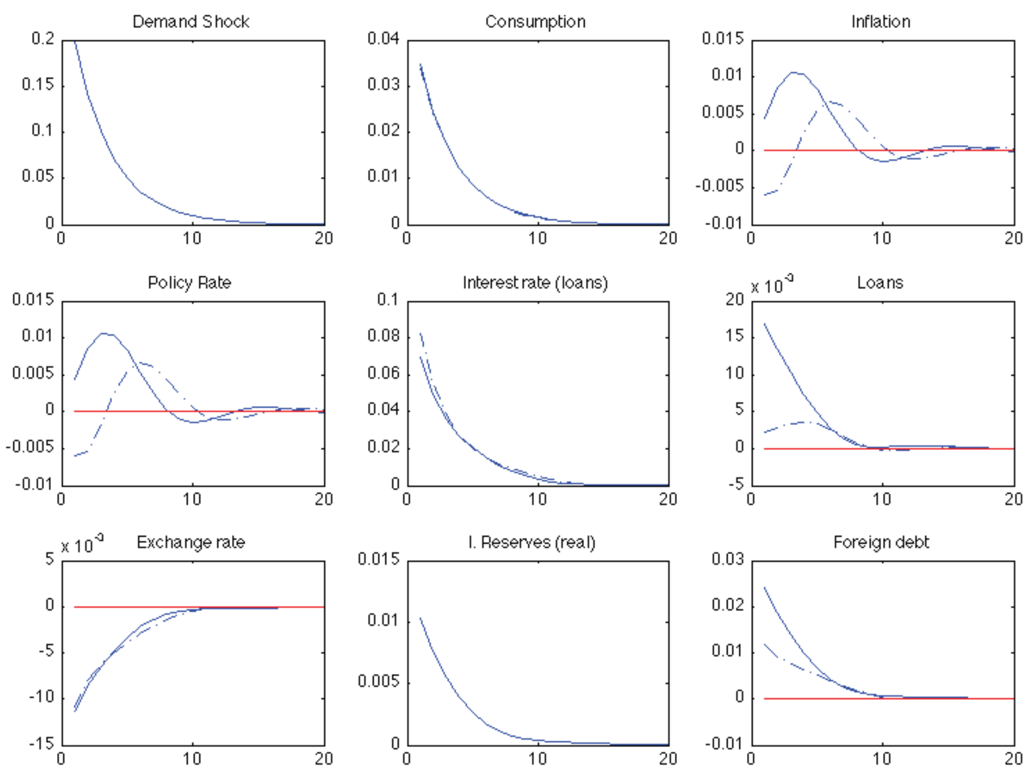

Figure 2: Transitory demand shock. $-\cdot-$ No Intervention $-$ Intervention

4.1.3 Productivity shock

An unanticipated increase in the total factor productivity -Z_t- is depicted in Figure 3. With this shock, the economy becomes essentially richer. The higher productivity allows a higher consumption of goods (~1.5%) and leisure (labor decreases ~15%). Since the economy can produce more efficiently, the real marginal cost decreases, firms use less labor and therefore demand for loans diminishes, as well as the market interest rate -j_t- . The higher productivity induces a depreciation of the exchange rate on impact, to allow for a gradual appreciation as long as total factor productivity remains above its steady state level. In order to counteract the initial depreciation, the Central Bank operating under the hybrid-regime will decrease its holdings of international reserves, which implies a reduction of securities' supply, and again, by reducing the supply of securities, the Central Bank is making tighter the collateral constraint, reducing the amount of resources that commercial banks can obtain abroad, therefore reducing further the amount of domestic loans granted to firms. The difference in this case, is that the effect of intervention over aggregate demand and prices, is one that helps to achieve Central Bank's objective.

It can be observed in Figure 3, that inflation for the Central Bank pursuing the hybrid-regime is almost half of that one resulting from the No-Intervention case, and thus the needed increase in the policy rate is also consequently higher for the No-Intervention case. This result suggest that when shocks affecting the economy are coming from the supply side, following a hybrid-regime can render better results than simply relying on the policy interest rate.

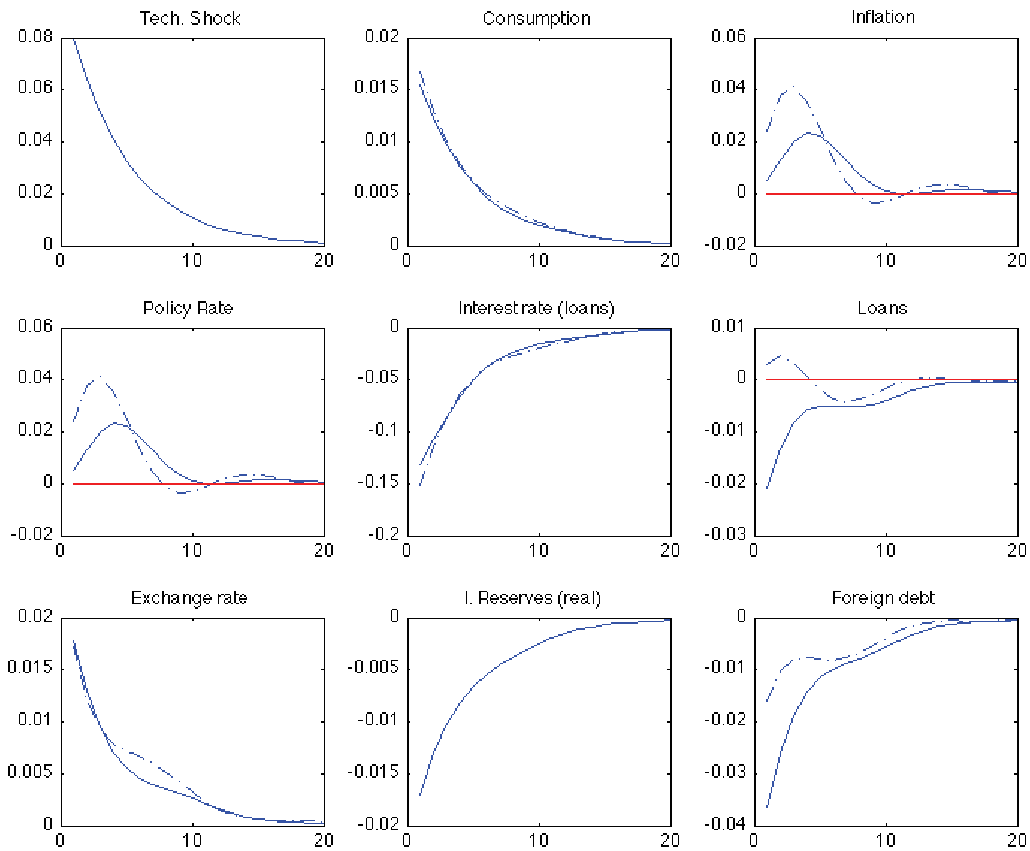

Figure 3: Transitory technology shock. $- \cdot -$ No Intervention $-$ Intervention

5 Concluding remarks

The model proposed in this paper, is related to the continuing efforts to integrate financial frictions into macroeconomic models, emphasizing the links between these financial frictions and relative prices, leverage, and aggregate outcomes. It is similar to Bernanke and Gertler (1989), Kiyotaki and Moore (1995a), and many others, in the sense that it includes a borrowing constraint (the incentive compatibility constraint in this case). The innovation here is that the borrowing constraint is related to international financial markets and it can be relaxed or tighten by actions of the central bank, specifically by interventions in the foreign exchange market. Modeling interventions explicitly is also an intended contribution of this paper, since most of the literature that explores policy concerns with respect to the exchange rate, does it through a re-setting of the interest rate, rather than through interventions as such.

An interesting result, is that the model can discern between situations in which intervention can be regarded as a beneficial supplemental policy, in the sense that it reduces the volatility of inflation, keeping it closer to its long run-level. Results suggest that, when shocks affecting the economy are supply shocks, intervening in the forex market can render better results than just re-setting the policy rate (see Figure 4). Although we can not formally address welfare implications of the model, since we are evaluating dynamics of the linearized version, it is still encouraging to find a combination of policies that can render a lower inflation volatility and also identify the type of shocks for which this hybrid-policy is effective in achieving the objective of an IT central bank. These results might be relevant for developing economies, which are subject to several supply shocks[15].

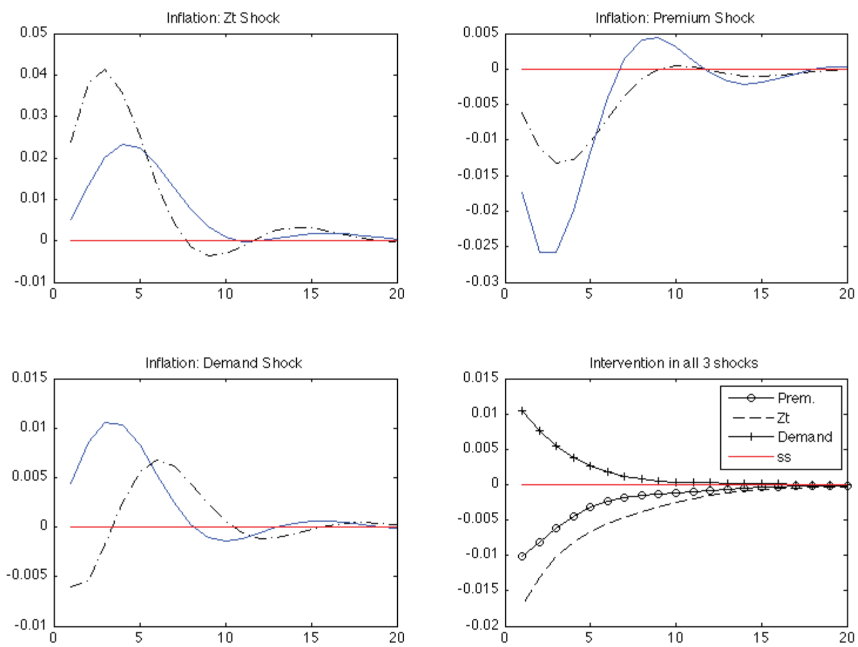

Figure 4: Inflation dynamics. Responses to all three shocks. – · – No Intervention – Intervention

The down side of accumulating reserves is that they are not free. According to Rodrik (2006), the costs "... amount to around 1 percentage point of GDP annually for developing nations taken as a whole". If reserves are able to reduces the probability of suffering a financial crisis, and all these nations are already paying this 'insurance premium', it is worthwhile to explore further whether these reserves can serve a better purpose than just being an expensive insurance.

[15]These results come from the dynamic responses of the model to a single realization of each exogenous shock. In order to see if the results hold for any realization of the random disturbance, a simulation of 2000 periods was conducted for each type of shock, reaching to the same conclusions. See Appendix B.

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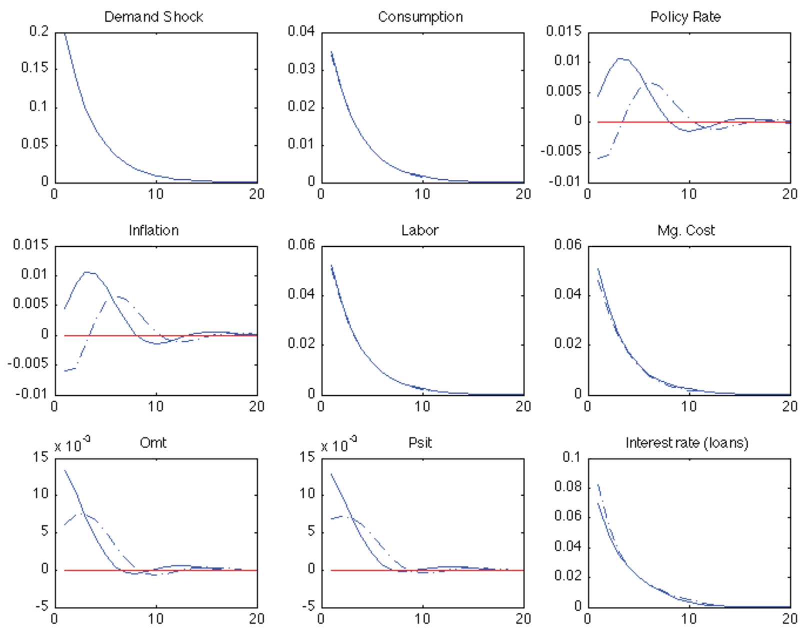
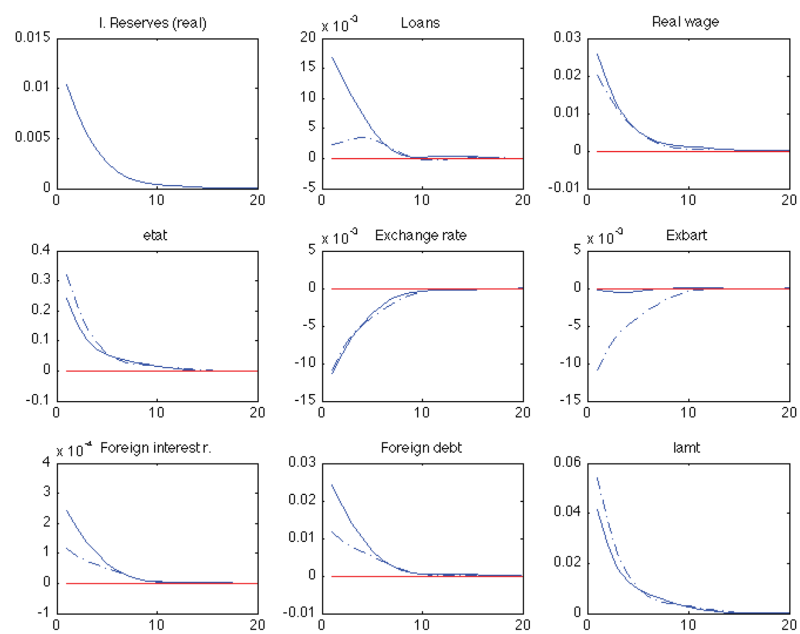
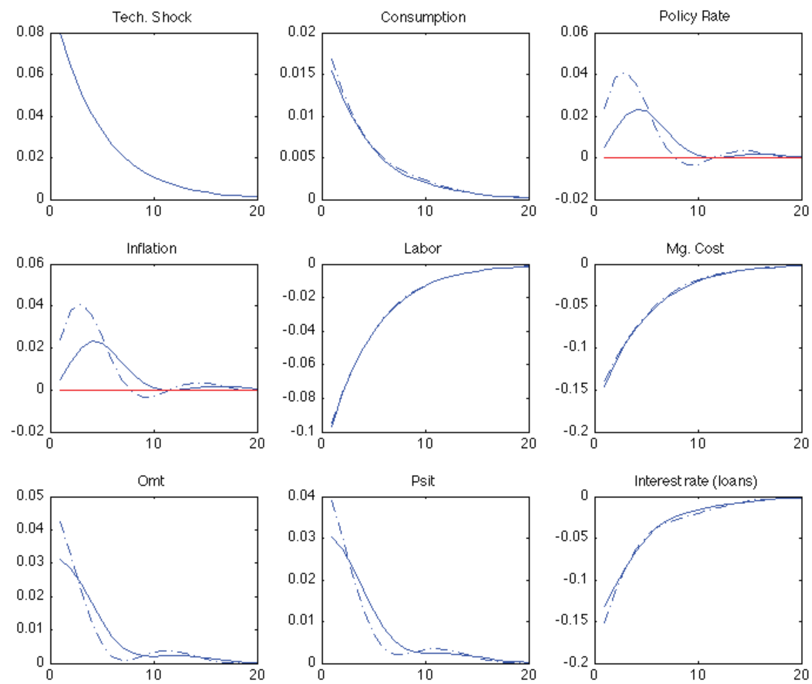
A Impulse responses for all variables

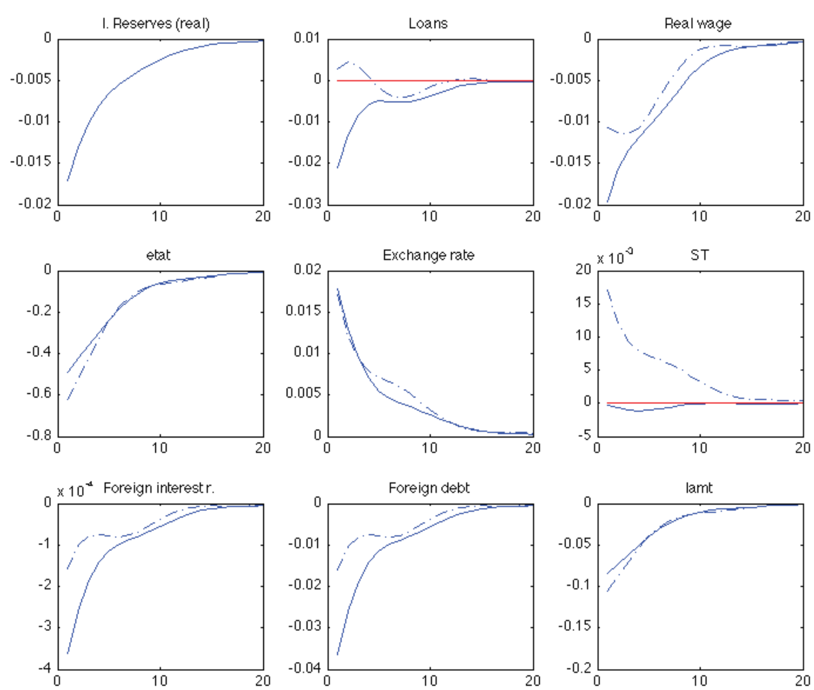
A.1 Demand shock



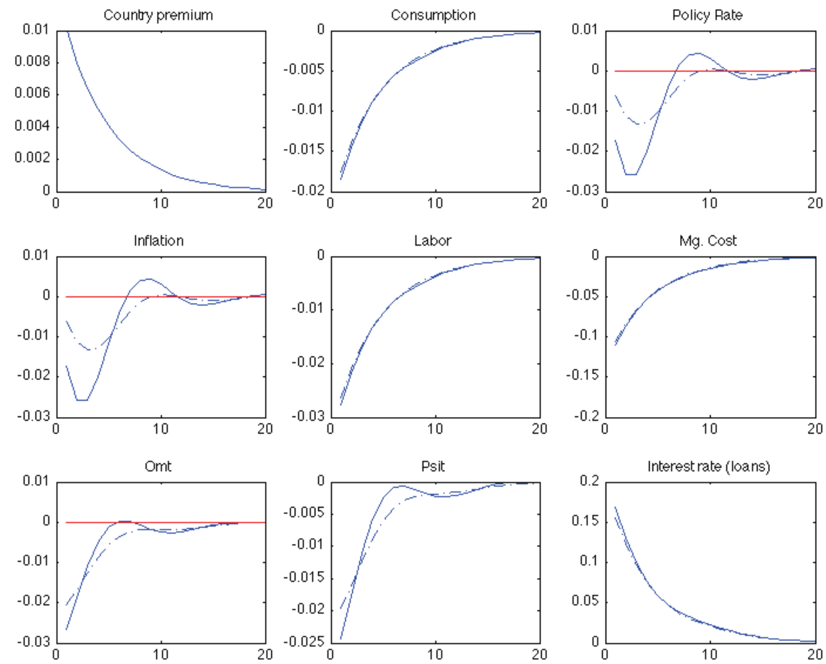


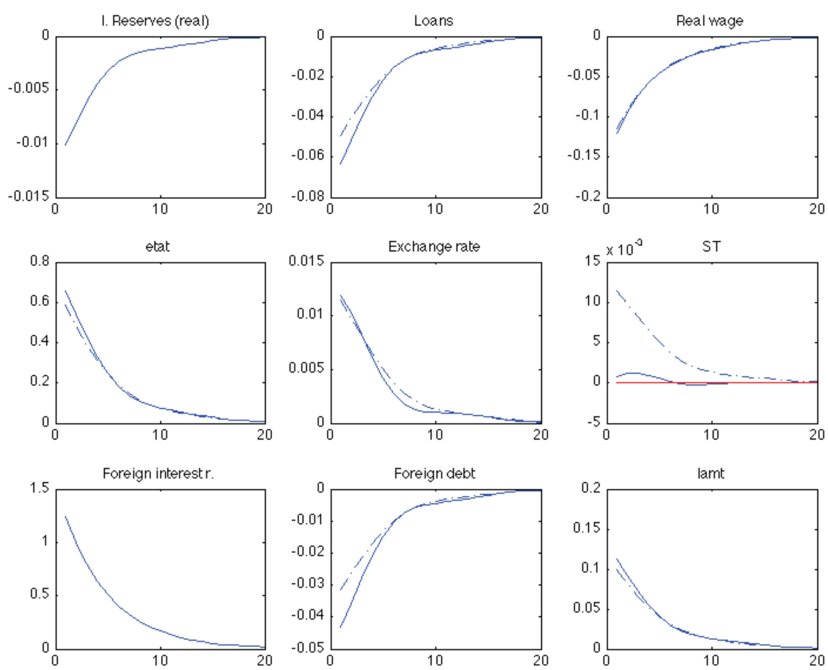
A.2 Productivity Shock





A.3 Country premium shock





B Simulation: Random disturbance in each period

So far, the dynamic responses analyzed were those coming from a single realization of the exogenous shocks. In order to see if the results hold for any realization of the random disturbance, a simulation involving a 2000-period run was conducted for each type of shock, reaching to the same conclusions: according to the model, central-bank intervention in the forex market can in principle be a highly effective tool for macroeconomic stabilization. In particular, it can be used to decrease inflation volatility at least when shocks affecting the economy are supply shocks.

The simulation exercise was done by generating artificial inflation series by hitting the economy in every period with a random disturbance for each of the three exogenous shocks (technology, demand and borrowing premium). After getting the simulated inflation series (generated by each of the exogenous shocks), the standard deviation was computed for the last 400 periods of each inflation series. On the top row of Figure B.1, it can be observed how the standard devation of inflation series its lower (about 35%) when the central bank follows a hybrid policy and intervenes in the forex market, than when it follows a pure IT-policy. The converse is true for the other two shocks; when the economy experiences demand shocks or shocks to the foreign borrowing premium, intervening in the forex market exacerbates inflation volatility.

The bottom row of Figure 5 shows the simulated inflation series for both, the Intervention and No-Intervention policies. It can be observed that for supply shocks, the discontinuous line (inflation in the No-Intervention case) serves as an upper bound for the continuous one (inflation in the Intervention case). Again, the converse is true for the other two shocks, were deviations from steady-state inflation appear to be larger under the Intervention policy, and therefore the continuous line serves as the upper bound, enclosing the inflation series generated under the No-Intervention policy.

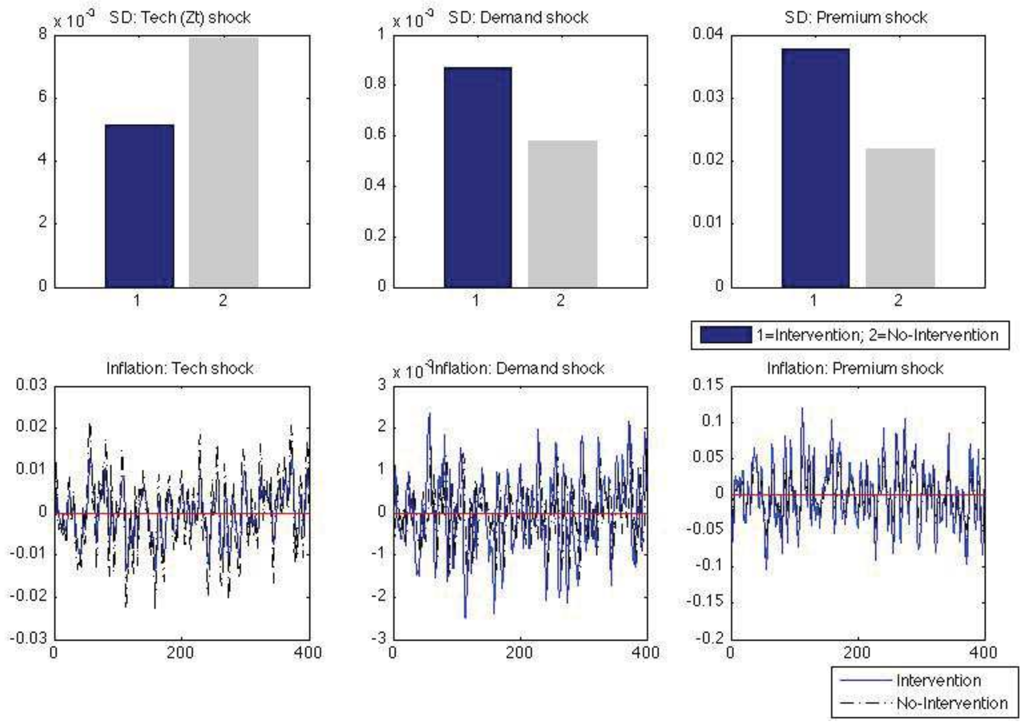


Figure 5: Inflation Volatility. Top row shows the standard deviation of inflation generated by each type of shock and bottom row, shows simulated inflation series for each type of shock for both: Intervention and No-Intervention cases.

C Sensitivity Analysis

C.1 Sensitivity to the International reserves adjustment coefficient, ω_s:

This parameter determines how aggressively the central bank will intervene in the forex market, when confronted with any given discrepancy between the market exchange rate and operational exchange rate target, (the exchange rate 'desired' by the central bank).

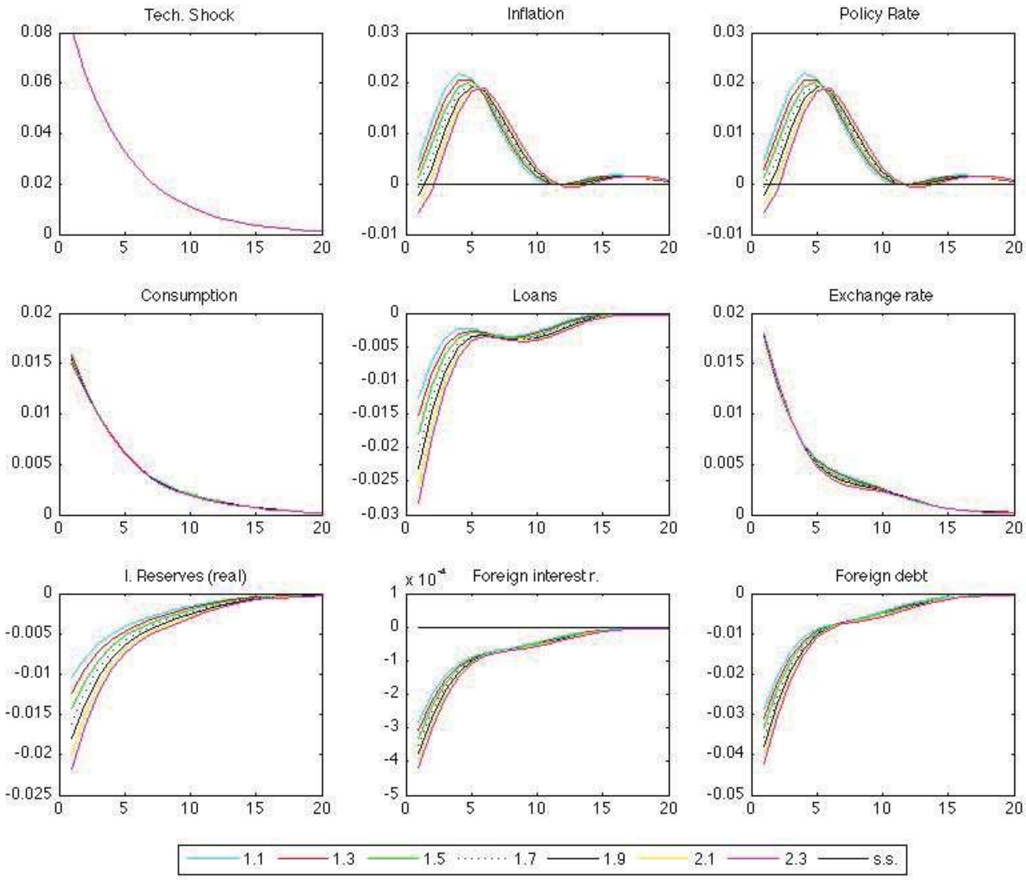


Figure 6: Model dynamics after a technology shock for different values of ω_s

C.2 Sensitivity to the Inflation coefficient in operational exchange rate target, γ_s:

The parameter γ_s links the operational target for the exchange rate $-\bar{S}_t-$ with the objective of central bank (inflation). The relationship is characterized by $\partial \bar{S}_t / \partial \pi_t = -\gamma_s$, ergo, the monetary authority confronted with a higher inflation, will desire a more appreciated level for the exchange rate, and therefore it will set a higher value for $\bar{S}_t$ through eq. (2). But whether this higher operational target translates into intervention, will still depend on the intervention rule (eq. (3) and parameter ω_s).

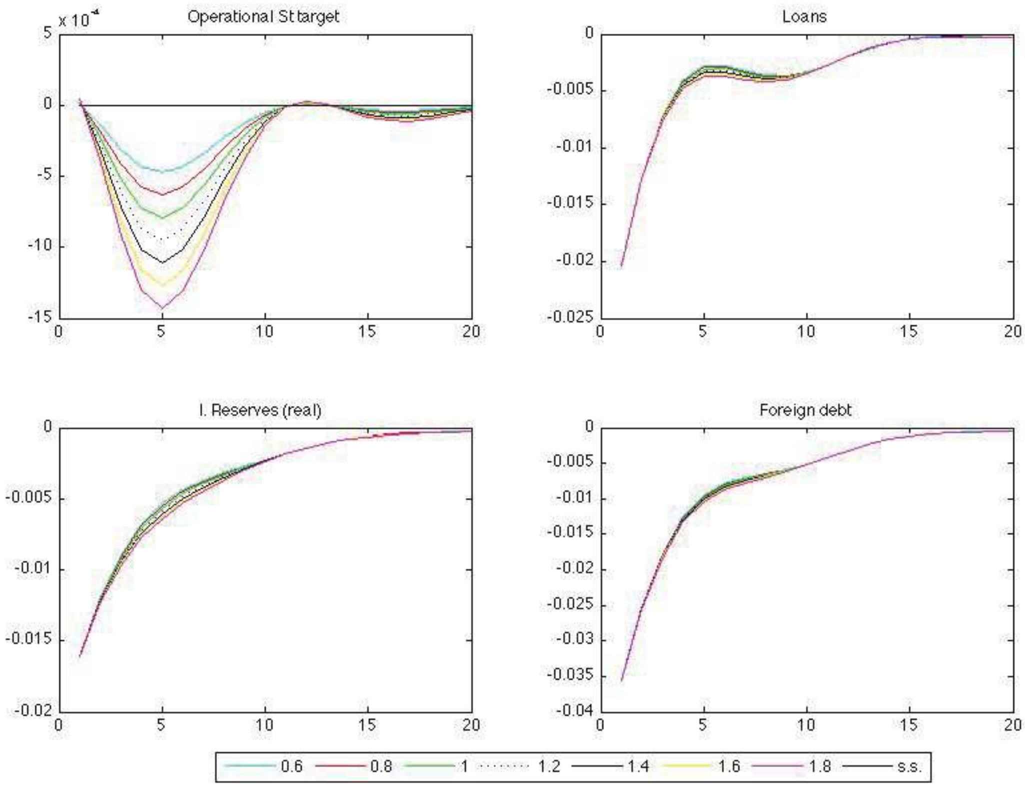


Figure 7: Model dynamics after a technology shock for different values of γ_s