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External Shocks, Financial Volatility and Reserve Requirements in an Open Economy

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External Shocks, Financial Volatility and Reserve Requirements in an Open Economy

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Abstract

The performance of a simple, countercyclical reserve requirement rule is studied in a dynamic stochastic model of a small open economy with financial frictions, imperfect capital mobility, a managed float regime, and sterilized foreign exchange market intervention. Bank funding sources, domestic and foreign, are imperfect substitutes. The model is calibrated and used to study the effects of a temporary drop in the world risk-free interest rate. Consistent with stylized facts, the shock triggers an expansion in domestic credit and activity, asset price pressures, and a real appreciation. An optimal, credit-based reserve requirement rule, based on minimizing a composite loss function, helps to mitigate both macroeconomic and financial volatility—with the latter defined both in terms of a narrow measure based on the credit-to-output ratio, the ratio of capital flows to output, and interest rate spreads, and a broader measure that includes real asset prices as well. Greater reliance on sterilization implies a less aggressive optimal reserve requirements rule, implying that the two instruments are partial substitutes.

JEL Classification Numbers: E32, E58, F41.

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1 Introduction

A key lesson of the global financial crisis is the importance of going beyond a microprudential approach, focused solely on the regulation of individual institutions, and adopt instead a macroprudential perspective for containing systemic risks and preserve financial and economic stability. At the same time, the greater focus on systemic risk has fostered a broad debate in academic and policy circles on how macroprudential regulation can prevent asset price pressures and unsustainable credit booms. Even though no consensus has yet emerged on what instruments are most appropriate and under which circumstances, some of them (such as countercyclical capital requirements, leverage and liquidity ratios) have already been made part of the Basel III regime for banking regulation (see Basel Committee on Banking Supervision (2011, 2013)). Indeed, a key instrument in the global framework for liquidity regulation introduced by Basel III is a minimum standard for managing liquidity risk: the liquidity coverage ratio (LCR), which requires each bank to hold a sufficient quantity of highly-liquid assets to survive a 30-day period of market stress.[1]

Among these instruments figures reserve requirements, which are often thought of as a liquidity management tool. However, in recent years they have been used extensively in middle-income countries (MICs) for a broader set of purposes. Both Brazil and Turkey, for instance, lowered required reserve ratios in response to the collapse of Lehman Brothers in 2008 and increased them again in the period of large capital inflows that occurred between 2010 to mid-2011. The Central Bank of Brazil also used average reserve requirements as a mechanism to prevent disruptions in the interbank market following the Lehman episode. Specifically, average reserve requirements imposed on large and liquid banks were lowered if they extended credit to small and illiquid banks.[2]

Other Latin American countries, such as Colombia and Peru, have also used this instrument aggressively (Vargas et al. (2010) and Tovar et al. (2012)). Prior to the global financial crisis the central banks of both countries managed reserve requirements

[1]Basel III also introduced another minimum standard for managing liquidity risk, the net stable funding ratio (NSFR), which is viewed as complementary to the LCR. The NSFR focuses on a one-year time horizon and establishes a minimum amount of stable funding each bank must obtain based on the liquidity characteristics of its assets and activities. See Dietrich et al. (2014) for a discussion.

[2]See Robitaille (2011), Tovar et al. (2012), Glocker and Towbin (2015), and Barroso et al. (2017) for Brazil, and Mimir et al. (2013) for Turkey. As discussed by Robitaille (2011), in Brazil, despite the country's high reserve ratios, reserve requirements continue to be seen as an important tool for managing liquidity risk.

as a prudential tool to contain pressures on credit growth emanating from large capital inflows. Both central banks raised marginal reserve requirements during those episodes. In addition, in the case of Peru, marginal reserve requirements were imposed on foreign-currency deposits. More generally, there is evidence showing that central banks in a broad group of MICs have often raised reserve requirements in response to capital inflows (Hoffmann and Löffler (2014)) and rapid credit growth (Federico et al. (2014), Cerutti et al. (2017), and Fendoglu (2017)).

This paper contributes to the debate on the role of reserve requirements on domestic-currency deposits in several ways. It extends the model in Agénor et al. (2014) to account for several important financial and policy features of MICs: a managed float; sterilized foreign exchange market intervention; and imperfect substitutability between deposits and central bank borrowing as sources of funding for commercial banks. The first two extensions are consistent with the evidence suggesting that many MICs operate a managed float regime, in which the central bank manipulates foreign reserves to mitigate exchange rate fluctuations, and the fact that sterilized intervention—rather than the policy interest rate—is the main instrument used by many emerging market and developing country central banks to affect the exchange rate. Indeed, as discussed by Chang (2008), Aizenman and Glick (2009), and Devereux and Yetman (2014), sterilization activity has played an important role in central bank policy responses to surges in capital inflows; its use has actually intensified in several countries since the global financial crisis. Even though the feasibility and effectiveness of sterilization remain a matter of debate (see for instance Daude et al. (2016)), this may well have been the consequence of greater concern with mitigating exchange rate volatility. In the model, we account not only for the fact that the central bank sterilizes the impact of its intervention on the money supply but also for the possibility that changes in official reserves may be driven by other considerations, namely, self-insurance motives.

The model accounts also for imperfect substitutability between deposits and central bank liquidity as sources of commercial bank funding. This is captured by assuming that the rate at which banks can borrow from the central bank incorporates a premium (above and beyond a base policy rate, determined through a Taylor rule), which depends on the ratio of existing borrowing to deposits. Because higher reserve requirements lower the deposit rate and hamper the ability of financial institutions to attract deposits, they also lead (all else equal) to an increase in the cost of central bank liquidity, which in turn affects the cost at which private agents can borrow. As it turns out, this is the key channel through which changes in reserve requirements may operate in countercyclical fashion.

Our key findings (based on a parameterization that replicates the main stylized facts associated with episodes of large capital inflows driven by external shocks) are twofold. First, in response to a drop in the world risk-free rate an optimal, a credit-based reserve requirement rule may help to mitigate both macroeconomic and financial volatility, with the latter defined either in terms of a narrow measure based on the credit-to-output ratio, the ratio of capital flows to output, and interest rate spreads, or in terms of a broader measure that includes also real asset prices. Second, if the quasi-fiscal costs of sterilization—which may be substantial in practice—are not accounted for in the central bank's loss function (or, equivalently, if macroeconomic and financial stability are the overwhelming considerations in setting policies) it is optimal to fully sterilize, even when an optimal countercyclical reserve requirements rule is in place. In that sense, the two instruments are complements. More importantly, greater reliance on sterilization implies a less aggressive optimal reserve requirements rule, which implies that the two instruments are partial substitutes at the margin.

The remainder of the paper is organized as follows. Section 2 provides a brief background on the use of reserve requirements in MICs. Section 3 provides an intuitive discussion of the key mechanism through which reserve requirements may operate in a countercyclical fashion, whereas Section 4 gives a formal description of the complete model. As in Agénor et al. (2014), the model features imperfect capital mobility and a two-level financial intermediation system, which accounts for bank borrowing abroad—an important feature of cross-border capital flows in recent years.[3] In addition, as noted earlier, several novel elements are introduced: exchange rate smoothing, self insurance, sterilized foreign exchange market intervention, and imperfect substitutability between bank borrowing from the central bank and deposits. The equilibrium and some key features of the steady state are discussed in Section 4, and an illustrative parameterization is presented in Section 5. The results of our main experiment, a temporary drop in the world safe interest rate, are described in Section 6. As documented in a number of

[3]See Hoggarth et al. (2010), Committee on International Economic Policy and Reform (2012), Herrmann and Mihaljek (2013), and Reinhardt and Riddiough (2014) for a discussion of the importance of cross-border bank flows—especially changes in the external liabilities of resident banks—in international capital movements during the run up to, and the immediate aftermath of, the global financial crisis.

studies, shocks to world interest rates are a key source of domestic macroeconomic fluctuations in middle-income countries (Agénor and Montiel (2015)). Sensitivity analysis, involving alternative assumptions about the rule used by the central bank to set the cost of bank borrowing, the degree of exchange rate smoothing, the intensity of sterilization, and endogenous reserve requirements (linked to credit growth and the credit-to-output ratio) are reported in Section 7. Optimal countercyclical reserve requirements are discussed in Section 8. The concluding section discusses the implications of the analysis for the design of macroprudential regimes in MICs and identifies some potentially fruitful directions for future research.

2 Related Literature

As noted by Gray (2011) reserve requirements usually serve three purposes, depending on circumstances: a microprudential function, a monetary control role (through market interest rates and monetary aggregates), and a liquidity management function (especially to sterilize excess reserves). The microprudential function relates to protection against liquidity and solvency risks; from that perspective, reserve requirements help to ensure that adequate liquidity is available in the event of funding outflows. This role is particularly important in countries where the lack of development of financial markets translates into an inadequate supply of effectively liquid assets.

Regarding the monetary control and liquidity management functions, the evidence suggests that in MICs reserve requirements have proved to be particularly useful during episodes of strong capital inflows associated with changes in world interest rates and risk perceptions.[4] As documented in a number of studies, these episodes have often been accompanied by an expansion in credit, an increase in aggregate demand, and in some cases (if the exchange rate pass-through associated with the initial appreciation is weak) heightened inflationary pressures. In such conditions, although interest rate hikes could dampen activity and restrain inflation, they may also attract more capital, which in turn can fuel further an excessive expansion in credit. By contrast, an increase in reserve requirements would induce banks to *lower* deposit rates. The mechanics are as follows. In response to large capital inflows, central banks often intervene to buy foreign

[4] Ahmed and Zlate (2014) provided evidence that interest rate differentials and global risk aversion are important determinants of net private capital inflows, especially (for portfolio flows) in the aftermath of the global financial crisis.

exchange and prevent an appreciation of the exchange rate. Concurrently, to avoid an expansion in the money supply and maintain price stability, they engage not only in open-market operations (sales of government bonds) but also in increases in reserve requirements.[5] In an open economy the incentive to do so is particularly strong if the use of open-market operations to sterilize capital flows is costly, due to large differentials between the interest rate on assets used for these operations and the interest earned on foreign reserves. Because reserve requirements represent a tax on bank intermediation, they drive a wedge between the rate that a bank pays its depositors and its cost of funding. If bank deposits offer special transaction and liquidity services to households, the cost of higher reserve requirements would normally be passed on in full to depositors in the form of lower deposit rates. A similar outcome, albeit with a less than complete pass through, would occur if banks can only partly substitute reservable liabilities with other funding sources as a result for instance of information frictions or a less than perfectly elastic supply of liquidity from the central bank. In either case, the policy may lead to an increase in bank intermediation spreads through lower deposit rates, higher lending rates, or both.

In an early contribution, Reinhart and Reinhart (1999) found indeed that increases in reserve requirements in developing countries tend to reduce deposit rates and to raise lending rates, whereas Gelos (2009) found that high reserve requirements are a key determinant of the comparatively high intermediation spreads observed in Latin America. In subsequent studies, Montoro and Moreno (2011), Tovar et al. (2012), Izquierdo et al. (2013), Armas et al. (2014), Cordella et al. (2014), Federico et al. (2014), and Glocker and Towbin (2015), all found that increases in reserve requirements tended to mitigate the expansion of credit in Latin America. In effect, during the recent global financial crisis, reserve requirements were used as a substitute to monetary policy, not only to curb lending growth but also to dampen inflationary pressures.[6]

More recent thinking on the use of reserve requirements has focused on their role as a systematic—as opposed to sporadic—countercyclical macroprudential instrument, aimed

[5] Higher reserve requirements on bank deposits have been used to sterilize the effects of capital inflows not just on the monetary base but also on the broader money supply, as was the case for instance in China, India, and Morocco, among others, in recent years. See for instance Ma et al. (2013) for a discussion of China's experience.

[6] Mora (2014) also found evidence that increases in reserve requirements were contractionary for Lebanon. See Agénor and Pereira da Silva (2016) for a detailed review of the literature and some country experiences.

at mitigating systemic risks to the financial system. By requiring banking institutions to hold a fraction of their deposits (in the form of cash earning no interest, or deposits at the monetary authority remunerated at below-market rates), mandatory reserves act as an implicit tax on financial intermediation; and by altering the cost of funding, they may be useful to reduce the volatility of credit. Increasing reserve requirements can restrain credit growth during expansions, while reducing them during downturns can provide additional resources to limit credit contractions. Thus, reserve requirements may have a significant impact on the financial and business cycles.[7]

Recent analytical contributions on the macroprudential role of reserve requirements, in both closed and open economies, include Prada (2008), Bianchi (2011), Montoro (2011), Glocker and Towbin (2012), Kashyap and Stein (2012), Mimir et al. (2013), Alper et al. (2014), Escudero et al. (2014), and Medina and Roldós (2014). In all of them, an increase in required reserves turns deposits into a more expensive source of funding, so that the interest rate on deposits falls. In Prada's model for instance, this fall leads not only to a drop in the demand for deposits but also a reduction in credit as well, because deposits and credit are complements. Thus, the policy is countercyclical. Bianchi (2011) showed that, for a generic bank balance sheet, capital and reserve requirements have similar effects and may therefore be thought of *ex ante* (although not *ex post*) as substitutes from a macroprudential perspective. Glocker and Towbin (2012) considered required reserves as an additional policy instrument and variations in loans as an additional target in an open-economy model with nominal rigidities and financial frictions. Their results imply that reserve requirements favor the price stability objective only if financial frictions are significant, and are more effective if there is a financial stability objective and debt is denominated in foreign currency. In their model, due to the endogeneity of monetary base, an increase in the reserve requirement rate increases loan-deposit spreads only if the remuneration of reserves is below the market rate. However, because they obtain opposite impact effects on consumption and investment, the overall effect on aggregate demand and inflation is ambiguous. Kashyap and Stein (2012) showed that the central bank can exploit a nonzero and time-varying scarcity value of reserves to tax the negative systemic externality from credit booms.

[7] In dollarized economies, differentiated reserve requirement rates are also used as instruments to mitigate the risks associated with financial dollarization, most notably by building foreign exchange liquidity buffers. See for instance Armas et al. (2014) for a discussion of the Peruvian case.

3 Countercyclical Reserve Requirements: Intuition

As discussed in more detail later, our analysis differs from existing contributions in significant ways. In contrast to the studies mentioned earlier, it accounts for imperfect capital mobility, a two-level financial intermediation system, exchange rate smoothing, and sterilized intervention—which are all important features to understand the transmission of external financial shocks and how policy responses can mitigate their domestic macroeconomic and financial effects. More important for the issue at stake, the effectiveness (or lack thereof) of reserve requirements as a countercyclical instrument, it provides a rationale that has not been clearly highlighted before.

In models where monetary policy targets a short-term interest rate, bank funding sources (deposits and central bank liquidity) are perfect substitutes, and there are no disincentives from accessing central bank facilities, an increase in reserve requirements has no impact on lending rates despite making deposits more expensive; banks simply borrow more from the central bank at the prevailing rate, while reducing the deposit rate. There is no direct effect on the loan rate. But without a change in the loan rate, it is difficult to generate a countercyclical role for reserve requirements; if anything, the opposite may occur—if intertemporal substitution effects are strong, the drop in the deposit rate tends to reduce savings and to *increase* current consumption—therefore generating a *procyclical* movement in aggregate demand (see for instance Evandro and Takeda (2013), Agénor and Pereira da Silva (2014), and Escudero et al. (2014)).

By contrast, a key feature of our analysis is that deposits and borrowing from the central bank are imperfect substitutes. Figure 1 provides a simplified description of the link between reserve requirements, policy rates, and market interest rates. Commercial banks have access to three sources of funding: deposits (which are determined by household optimization behavior), foreign borrowing, and central bank borrowing. Banks set market interest rates and lend for investment, with a perfectly elastic supply at the prevailing loan rate. For given amounts of deposits, foreign borrowing, and investment loans, central bank borrowing is thus determined residually from the bank's balance sheet, just as would be the case in a standing facility, with a perfectly elastic supply of liquidity at the prevailing cost of borrowing.

As shown in the figure, the required reserve ratio has no direct effect on the lending rate; it affects only the deposit rate, which is essentially a "mark-down" over the cost of borrowing from the central bank (also referred to in what follows as the refinance rate). For simplicity, required reserves are a fraction of deposits. Thus, an increase in the required reserve ratio may either raise or reduce the level of reserves, depending on the sensitivity of deposits to interest rates. Suppose then that this sensitivity is low, because the demand for deposits is essentially related to real transactions. All else equal, therefore, an increase in the required reserve ratio raises the level of reserves.

If deposits and central bank borrowing are perfect substitutes, a change in the required reserve ratio would have (as noted earlier) no effect on the loan rate and investment; deposit rates fall, but all that happens is a switch in funding sources. However, suppose instead that they are imperfect substitutes. To capture this feature in a simple way, we assume that above and beyond a base policy rate (determined on the basis of standard macroeconomic objectives, inflation and the output gap) the central bank charges a penalty rate that increases with the ratio of actual borrowing to deposits. Put differently, even though the central bank operates a standing facility, its supply of liquidity is no longer perfectly elastic at the base policy rate.[8] Because the central bank borrowing-deposit ratio unambiguously increases (as noted earlier), the refinance rate rises following a hike in the required reserve ratio. While this increase mitigates the initial drop in the deposit rate, it also leads to a higher lending rate, which tends to lower investment.[9] All else equal, the output gap and inflation also fall.[10] Both effects contribute to a reduction in the base policy rate, which mitigates the contractionary effect associated with the increase in the penalty component of the refinance rate. Yet, if the effect on the penalty rate is sufficiently strong, the assumption of imperfect substitutability between deposits and central bank borrowing is capable of generating a countercyclical role for reserve requirements through their impact on investment—even if their effect on consumption can be procyclical. These effects are formally discussed

[8] A conceptually similar idea is developed in Alper et al. (2014), although in a very different setting. They also provide evidence for Turkey, which suggests that central bank liquidity and household deposits are imperfect substitutes.

[9] In the full model, the fall in investment tends to increase the collateral-loan ratio, which tends to increase (due to a stronger "skin in the game" effect) the probability that loans are repaid, whereas the drop in output (through a cyclical effect on cash flows) tends to lower that probability. Depending on the net effect on the repayment probability, this may either magnify or mitigate the change in the loan rate. These effects are shown in Figure 1 as dotted lines.

[10] Note that, as shown in the figure, there is a feedback effect of the refinance rate on bank foreign borrowing. This does not affect the thrust of the argument because in the model domestic and foreign funding are also imperfect substitutes, due to the fact that international capital markets impose a risk premium on all domestic borrowers—who in turn internalize this effect in their borrowing decisions.

and quantitatively evaluated in the next sections.

4 The Model

Consider a small open economy populated by seven categories of agents: a continuum of households with unit mass, a continuum of intermediate goods-producing (IG) firms, indexed by $j \in (0,1)$, a representative final good (FG) producer, a continuum of capital good (CG) producers with unit mass, a continuum of commercial banks, indexed by $i \in (0,1)$, the government, and the central bank. The country produces a continuum of intermediate goods, which are imperfect substitutes to a continuum of imported intermediate goods. Both categories of goods are aggregated to produce a homogeneous final good. In turn, the final good is consumed by households and the government, used for investment (subject to additional costs) by CG producers, or exported. Monopolistic competition prevails in the market for domestic intermediate goods and each intermediate good is produced or imported by a single firm.

4.1 Households

The representative household consumes the final good, demands housing services, supplies labor, and holds imperfectly substitutable domestic assets (cash, deposits, and government bonds) and foreign bonds. It owns all domestic firms and banks.[11] The household's objective is to maximize

$$U_t = \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s \left\{ \frac{C_{t+s}^{1-\varsigma^{-1}}}{1-\varsigma^{-1}} + \eta_N \ln(1 - N_{t+s}) + \eta_x \ln x_{t+s} + \eta_H \ln H_{t+s} \right\}, \tag{1}$$

where C_t is consumption, $N_t = \int_0^1 N_t^j dj$, the share of total time endowment (normalized to unity) spent working, with N_t^j denoting the number of hours of labor provided to IG producer j, x_t a composite index of real monetary assets, H_t the stock of housing, $\Lambda \in (0,1)$ the subjective discount factor, $\varsigma > 0$ the intertemporal elasticity of substitution in consumption, $\mathbb{E}_t$ the expectation operator conditional on the information available at the beginning of period t, and $\eta_N, \eta_x, \eta_H > 0$. Housing services are proportional to their stock.

[11] Cash and deposits are both accounted for because with capital being imperfectly mobile, the domestic bond rate is solved (as noted later) from the equilibrium condition of the money market.

The composite monetary asset is a geometric average of real cash balances, m_t^P, and real bank deposits, d_t, both of which provide liquidity services:

$$x_t = (m_t^P)^\nu d_t^{1-\nu}, \tag{2}$$

where $\nu \in (0,1)$. Both m_t^P and d_t are measured in terms of the price of goods sold on the domestic market, P_t^S.

The household's flow budget constraint is

$$\begin{aligned} & m_t^P + d_t + b_t^P + z_t B_t^{F,P} + p_t^H \Delta H_t \\ = w_t N_t - T_t - C_t + & \frac{m_{t-1}^P}{1+\pi_t^S} + (\frac{1+i_{t-1}^D}{1+\pi_t^S})d_{t-1} + (\frac{1+i_{t-1}^B}{1+\pi_t^S})b_{t-1}^P \\ & +(1+i_{t-1}^{F,P})z_t B_{t-1}^{F,P} + J_t^D + J_t^K + J_t^B, \end{aligned} \tag{3}$$

where $z_t = E_t/P_t^S$ is the real exchange rate (with E_t the nominal exchange rate), $p_t^H = P_t^H/P_t^S$ the real price of housing (with P_t^H the nominal price), $1+\pi_t^S = P_t^S/P_{t-1}^S$, H_t the stock of housing, b_t^P ($B_t^{F,P}$) real (foreign-currency) holdings of one-period, noncontingent domestic (foreign) government bonds, i_t^D the interest rate on bank deposits, i_t^B and $i_t^{F,P}$ interest rates on domestic and foreign government bonds, respectively, w_t the economy-wide real wage (measured in terms of the price of final goods sold domestically), T_t real lump-sum taxes, and J_t^D, J_t^K, and J_t^B end-of-period profits of the matched IG producer, CG producer, and commercial bank, respectively.[12] For simplicity, housing does not depreciate and domestic government bonds are held only at home.

The rate of return on foreign bonds is defined as

$$1 + i_t^{F,P} = (1 + i_t^W)(1 - \theta_t^{F,P}), \tag{4}$$

where i_t^W is the risk-free world interest rate and $\theta_t^{F,P}$ an endogenous spread, defined as

$$\theta_t^{F,P} = \frac{\theta_0^{F,P}}{2} B_t^{F,P}, \tag{5}$$

with $\theta_0^{F,P} > 0$. Thus, in contrast to models where the country's borrowing premium depends on *total* net foreign indebtedness (as for instance in Gertler et al. (2007)), the household internalizes the fact that its holdings of foreign bonds affect the premium that it faces on world capital markets.

[12] The definition of the real exchange rate assumes that the foreign-currency price of final goods sold on markets abroad is normalized to unity.

The household maximizes (1) with respect to C_t, N_t, m_{t+1}^P, d_{t+1}, b_{t+1}^P, $B_{t+1}^{F,P}$, and H_{t+1}, subject to (2) to (5), taking as given period-$t-1$ variables as well as w_t, T_t, and real profits. The first-order conditions are

$$\mathbb{E}_t(\frac{C_{t+1}}{C_t}) = \Lambda \mathbb{E}_t(\frac{1+i_t^B}{1+\pi_{t+1}^S})^{\varsigma}, \tag{6}$$

$$N_t = 1 - \frac{\eta_N C_t^{1/\varsigma}}{w_t}, \tag{7}$$

$$m_t^P = \frac{\eta_x \nu C_t^{1/\varsigma}(1+i_t^B)}{i_t^B}, \tag{8}$$

$$d_t = \frac{\eta_x (1-\nu) C_t^{1/\varsigma}(1+i_t^B)}{i_t^B - i_t^D}, \tag{9}$$

$$p_t^H H_t = \left\{1 - \mathbb{E}_t(\frac{1+\pi_{t+1}^H}{1+i_t^B})\right\}^{-1} \eta_H C_t^{1/\varsigma}, \tag{10}$$

$$1+i_t^B = (1-\theta_0^{F,P} B_t^{F,P})(1+i_t^W)\mathbb{E}_t(\frac{E_{t+1}}{E_t}), \tag{11}$$

where $1+\pi_{t+1}^H = P_{t+1}^H / P_t^H$ is the gross inflation rate in terms of nominal house prices.

Equation (6) is the Euler equation, whereas equations (7) to (9) define labor supply, the demand for cash, and the demand for deposits, respectively. Equation (10) defines the demand for housing services, whereas equation (11) equates the expected marginal rates of return on domestic and foreign assets under the assumption of imperfect world capital markets; it can be rearranged to give

$$B_t^{F,P} = \frac{(1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t) - (1+i_t^B)}{\theta_0^{F,P}(1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}. \tag{12}$$

which shows that the optimal level of household holdings of foreign bonds is a function of the difference between the expected, depreciation-adjusted world safe interest rate and the domestic bond rate.[13]

The risk-free world interest rate follows a first-order autoregressive process:

$$\frac{1+i_t^W}{1+\tilde{\imath}^W} = (\frac{1+i_{t-1}^W}{1+\tilde{\imath}^W})^{\rho_W} \exp(\xi_t^W),$$

where $\rho_W \in (0,1)$, $\xi_t^W \sim N(0, \sigma_{\xi^W})$, and a tilde is used to denote a steady-state value.

[13] Perfect capital mobility prevails when $\theta_0^{F,P} \to 0$, in which case $1+i_t^B = (1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)$, corresponding to the standard uncovered interest parity condition under risk neutrality. The specification used here follows Agénor (1997); see for instance Lartey (2012), Gabaix and Maggiori (2014), and Liu and Spiegel (2014) for alternative ways of modeling imperfect asset substitutability in an open economy.

4.2 Domestic Final Good

The FG producer imports a continuum of differentiated intermediate goods from the rest of the world and combines them with a similar continuum of domestically-produced intermediate goods to generate a domestic final good, in quantity Y_t, which is sold both domestically and abroad:

$$Y_t = [\Lambda_D (Y_t^D)^{(\eta-1)/\eta} + (1-\Lambda_D)(Y_t^F)^{(\eta-1)/\eta}]^{\eta/(\eta-1)}, \tag{13}$$

where $\Lambda_D \in (0,1)$, Y_t^D (Y_t^F) is a quantity index of domestic (imported) intermediate goods, and $\eta > 0$ is the elasticity of substitution between baskets of domestic and imported composite intermediate goods. These baskets are defined as

$$Y_t^k = \left\{ \int_0^1 [Y_{jt}^k]^{(\theta_k-1)/\theta_k} dj \right\}^{\theta_k/(\theta_k-1)}, \quad k = D, F \tag{14}$$

where $\theta_k > 1$ is the elasticity of substitution between intermediate domestic goods among themselves ($k = D$), and imported goods among themselves ($k = F$), and Y_{jt}^k is the quantity of intermediate good j of type k (domestic or imported), with $j \in (0,1)$.[14]

The FG producer sells its output at a perfectly competitive price. Let P_{jt}^D denote the price of domestic intermediate good j set by firm j, and P_{jt}^F the price of imported intermediate good j, in domestic currency. Cost minimization yields the demand functions for each variety of intermediate goods:

$$Y_{jt}^k = (\frac{P_{jt}^k}{P_t^k})^{-\theta_k} Y_t^k, \quad k = D, F \tag{15}$$

where P_t^D and P_t^F are price indices for domestic and imported intermediate goods, respectively, which are given from the zero-profit condition as

$$P_t^k = \left\{ \int_0^1 (P_{jt}^k)^{1-\theta_k} dj \right\}^{1/(1-\theta_k)}, \quad k = D, F \tag{16}$$

so that $P_t^k Y_t^k = \int_0^1 P_{jt}^k Y_{jt}^k dj$.

Aggregating across firms yields the allocation of total demand between domestic and foreign goods:

$$Y_t^D = \Lambda_D^\eta (\frac{P_t^D}{P_t})^{-\eta} Y_t, \quad Y_t^F = (1-\Lambda_D)^\eta (\frac{P_t^F}{P_t})^{-\eta} Y_t, \tag{17}$$

[14] For simplicity, the number of both domestic and imported intermediate goods is normalized to unity.

where P_t is the price of final output, given by

$$P_t = [\Lambda_D^{\eta}(P_t^D)^{1-\eta} + (1-\Lambda_D)^{\eta}(P_t^F)^{1-\eta}]^{1/(1-\eta)}. \tag{18}$$

Given our focus, imperfect exchange rate pass-through is accounted for in a simple manner. In the absence of transportation costs, the domestic-currency price of imports of intermediate good j is given by

$$P_{jt}^F = E_t^{\mu^F} E_{t-1}^{1-\mu^F} WP_{jt}^F, \tag{19}$$

where WP_{jt}^F is the foreign-currency price of imported good j and $\mu^F \in (0,1)$ measures the degree of exchange rate pass-through. Thus, $\mu^F = 1$ corresponds to instantaneous, complete pass-through (that is, local currency pricing).[15] Regardless of the value of μ^F, complete pass-through occurs in the long run.

The volume of goods sold abroad, Y_t^X, depends on the domestic-currency price of exports of the final good, P_t^X, relative to the price of goods sold on the domestic market:

$$Y_t^X = (\frac{P_t^X}{P_t^S})^{\varkappa}, \tag{20}$$

where $\varkappa > 0$ and P_t^X is defined as

$$P_t^X = E_t WP_t^X, \tag{21}$$

with WP_t^X denoting the foreign-currency price of exports.

Total output in volume terms is also given by

$$Y_t = Y_t^S + Y_t^X, \tag{22}$$

where Y_t^S denotes the volume of goods sold on the domestic market.

4.3 Domestic Intermediate Goods

Domestic IG firms, indexed by $j \in (0,1)$, produce intermediate goods by combining labor, N_{jt}, and capital, K_{jt}:

$$Y_{jt}^D = N_{jt}^{1-\alpha} K_{jt}^{\alpha}, \tag{23}$$

[15] See for instance Shi and Xu (2010) and Adolfson et al. (2014) for a full treatment with a monopolistically competitive import goods sector.

where $\alpha \in (0,1)$.[16]

Each IG producer rents capital from a randomly matched CG producer, at the rate r_t^K, and pays for it after the sale of output. However, a fraction $\kappa^W \in (0,1)$ of wages must be paid in advance. To do so firm j borrows from banks the amount $l_t^{W,j}$, given by

$$l_t^{W,j} = \kappa^W w_t N_{jt}. \tag{24}$$

Loans contracted for the purpose of financing working capital do not carry any risk, and are made at a rate that reflects only the marginal cost of borrowing from the central bank, i_t^C. Total costs of firm j in period t, TC_{jt}, are thus given by

$$TC_{jt} = (1 + i_t^C)\kappa^W w_t N_{jt} + r_t^K K_{jt}.$$

In standard fashion, cost minimization yields the capital-labor ratio and the unit real marginal cost, mc_t, as

$$\frac{K_{jt}}{N_{jt}} = (\frac{\alpha}{1-\alpha})[\frac{(1+\kappa^W i_t^C)w_t}{r_t^K}], \tag{25}$$

$$mc_t = (\frac{r_t^K}{\alpha})^{\alpha}[\frac{(1+\kappa^W i_t^C)w_t}{1-\alpha}]^{1-\alpha}. \tag{26}$$

Domestic IG producers incur a Rotemberg-type cost in adjusting prices, of the form $(\phi_D/2)[(P_{jt}^D/P_{jt-1}^D) - 1]^2 Y_t^D$, where $\phi_D \geq 0$.[17] Under monopolistically competitive markets, each firm j chooses a sequence of prices so as to maximize the discounted value of its current and future profits:[18]

$$\{P_{jt+s}^D\}_{s=0}^{\infty} = \arg\max \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s \lambda_{t+s} J_{jt+s}^D, \tag{27}$$

where J_{jt+s}^D denotes real profits at t, defined as

$$J_{jt}^D = (\frac{P_{jt}^D}{P_t^D})Y_{jt}^D - mc_t Y_{jt}^D - \frac{\phi_D}{2}(\frac{P_{jt}^D}{P_{jt-1}^D} - 1)^2 Y_t^D. \tag{28}$$

Taking $\{mc_{t+s}, P_{t+s}^D, Y_{t+s}^D\}_{s=0}^{\infty}$ as given, and using (15) with $k = D$, the first-order condition for this maximization problem is:

$$(1-\theta_D)(\frac{P_{jt}^D}{P_t^D})^{-\theta_D}\frac{1}{P_t^D} + \theta_D(\frac{P_{jt}^D}{P_t^D})^{-\theta_D - 1}\frac{mc_t}{P_t^D} \tag{29}$$

[16] The analysis could be extended to account for the fact that the production of domestic intermediates also requires the use of imported intermediate goods (say, oil imports, Y_t^O), by using a Leontief technology of the form $Y_{jt}^D = \min[N_{jt}^{1-\alpha}K_{jt}^{\alpha}/(1-\alpha_O), Y_t^O/\alpha_O]$, where $\alpha_O \in (0,1)$, or a generalized Cobb-Douglas function, as in Liu and Spiegel (2014) for instance.

[17] In this expression, the steady-state inflation rate in the price of goods sold domestically is assumed to be zero.

[18] In standard fashion, IG firms (which are owned by households) are assumed to value future profits according to the representative household's intertemporal marginal rate of substitution in consumption.

$$-\phi_D \left\{ (\frac{P^D_{jt}}{P^D_{jt-1}} - 1)\frac{1}{P^D_{jt-1}} \right\} + \Lambda \phi_D \mathbb{E}_t \left\{ \frac{\lambda_{t+1}}{\lambda_t}(\frac{P^D_{jt+1}}{P^D_{jt}} - 1)\frac{P^D_{jt+1}}{(P^D_{jt})^2}\frac{Y^D_{t+1}}{Y^D_t} \right\} = 0,$$

which determines the adjustment process of the nominal price P^D_{jt}.

4.4 Capital Good

At the beginning of the period, the representative CG producer buys an amount I_t of the final good from the FG producer and combines it with the existing capital stock to produce new capital goods, K_{t+1}, which are rented in the next period to a randomly matched IG producer at the rate r^K_{t+1}. Capital accumulates as follows:

$$K_{t+1} = \left\{ \frac{I_t}{K_t} - \frac{\Theta_K}{2}(\frac{K_{t+1} - K_t}{K_t})^2 \right\} K_t + (1-\delta)K_t, \tag{30}$$

where $\delta \in (0,1)$ is a constant rate of depreciation, and $\Theta_K > 0$ is a parameter that measures the magnitude of adjustment costs.

Investment goods must be paid in advance; the representative CG producer must therefore borrow from banks, at the rate i^L_t, the amount

$$l^I_t = I_t. \tag{31}$$

The matched household makes its housing stock, $\bar{H}$, available at no direct charge (for simplicity) to the CG producer, who uses it as collateral against which it borrows from the bank. Repayment is uncertain and occurs with probability $q_t \in (0,1)$. Expected repayment is thus $q_t(1+i^L_t)I_t + (1-q_t)\kappa p^H_t \bar{H}$, where $\kappa = \int_0^1 \kappa^i di \leq 1$ and $\kappa^i \in (0,1)$ is the fraction of the housing stock pledged as collateral to each bank i.

Subject to (30) and (31), the representative CG producer chooses the level of capital K_{t+1} (taking the rental rate, the lending rate, and the existing capital stock as given) so as to maximize the value of the discounted stream of dividend payments to the matched household:

$$\{K_{t+s+1}\}^{\infty}_{s=0} = \arg\max \sum_{s=0}^{\infty} \Lambda^s \mathbb{E}_t(\lambda_{t+s} J^K_{t+s+1}), \tag{32}$$

where $\lambda_{t+s} = C^{-1/\varsigma}_{t+s}$ is the marginal utility value (in terms of consumption) of an additional currency unit of real profits at $t+s$ and J^K_{t+s+1} denotes real profits at the end of period $t+s$, defined as

$$J^K_{t+s+1} = r^K_{t+s}K_{t+s} - q_{t+s}(1+i^L_{t+s})I_{t+s} - (1-q_{t+s})\kappa p^H_{t+s}\bar{H}.$$

Using (6), the first-order condition for maximization can be written as

$$\mathbb{E}_t r^K_{t+1} = q_t(1+i^L_t)\mathbb{E}_t \left\{ \left[1 + \Theta_K(\frac{K_{t+1}}{K_t} - 1) \right] (\frac{1+i^B_t}{1+\pi^S_{t+1}}) \right\} \tag{33}$$

$$-\mathbb{E}_t \left\{ q_{t+1}(1+i^L_{t+1}) \left\{ 1 - \delta + \frac{\Theta_K}{2} \left[(\frac{K_{t+2}}{K_{t+1}})^2 - 1 \right] \right\} \right\},$$

which relates the expected rate of return on the capital stock to the expected marginal cost of investing. This cost depends, in particular, on the (current and expected) repayment probability and the loan rate.[19]

The amount borrowed by the representative CG producer is a Dixit-Stiglitz basket of differentiated loans, each supplied by a bank i, with a constant elasticity of substitution $\zeta^L > 1$:

$$l^I_t = [\int_0^1 (l^{I,i}_t)^{(\zeta^L - 1)/\zeta} di]^{\zeta^L/(\zeta^L - 1)}.$$

The demand for type-i loan, $l^{I,i}_t$, is thus given by the downward-sloping curve

$$l^{I,i}_t = (\frac{1+i^{L,i}_t}{1+i^L_t})^{-\zeta^L} l^I_t, \tag{34}$$

where $i^{L,i}_t$ is the interest rate on the loan extended by bank i and $i^L_t = [\int_0^1 (1 + i^{L,i}_t)^{1-\zeta^L} di]^{1/(1-\zeta^L)} - 1$ the aggregate loan rate.

4.5 Commercial Banks

Banks, indexed by $i \in (0,1)$, are monopolistically competitive. They collect differentiated deposits from households and extend differentiated loans to IG and CG producers. They also borrow on world capital markets and from the central bank. At the end of each period, each bank repays with interest household deposits and the liquidity borrowed from the central bank, and redeems in full its foreign debt. All profits are then distributed.

Bank i's balance sheet in real terms is

$$l^i_t + RR^i_t = d^i_t + z_t L^{F,B,i}_t + l^{C,B,i}_t, \tag{35}$$

where $l^i_t = l^{W,i}_t + l^{I,i}_t$, $L^{F,B,i}_t$ is foreign borrowing (in foreign-currency terms), $l^{C,B,i}_t$ borrowing from the central bank, and RR^i_t required reserves, which must be held at all

[19] With no borrowing in advance, and no adjustment costs, expression (33) boils down to the standard condition $1 + \mathbb{E}_t r^K_{t+1} = \mathbb{E}_t[(1+i^B_t)/(1+\pi^S_{t+1})] + \delta$.

times at the central bank and do not pay interest—a common practice, as documented by Gray (2011). They are set as a fraction $\mu_t^R \in (0,1)$ of deposit liabilities:[20]

$$RR_t^i = \mu_t^R d_t^i. \tag{36}$$

The aggregate supply of deposits by households is a basket of differentiated deposits, each supplied to a bank i, with a constant elasticity of substitution $\zeta^D > 1$ between different types of deposits:

$$d_t = [\int_0^1 (d_t^i)^{(1+\zeta^D)/\zeta^D} di]^{\zeta^D/(1+\zeta^D)}.$$

The supply of type-i deposit, d_t^i, is thus given by the upward-sloping curve

$$d_t^i = (\frac{1+i_t^{D,i}}{1+i_t^D})^{\zeta^D} d_t, \tag{37}$$

where $i_t^{D,i}$ is the deposit rate set by bank i and $i_t^D = [\int_0^1 (1+i_t^{D,i})^{1+\zeta^D} di]^{1/(1+\zeta^D)} - 1$ the aggregate deposit rate.

The bank's cost of borrowing on world capital markets, $i_t^{F,B}$, measured in foreign-currency terms, is defined as

$$1 + i_t^{F,B,i} = (1+i_t^W)(1+\theta_t^{F,B,i}), \tag{38}$$

where $\theta_t^{F,B,i}$ is a premium that increases with the amount borrowed:

$$\theta_t^{F,B,i} = \frac{\theta_0^{F,B}}{2} L_t^{F,B,i}. \quad \theta_0^{F,B} > 0 \tag{39}$$

Assuming that $\kappa^i p_t^H \bar{H} \leq (1+i_t^{L,i}) l_t^{I,i}$ to avoid a corner solution, bank i's expected profits at the end of period t (or beginning of $t+1$) are defined as

$$\mathbb{E}_t J_{t+1}^{B,i} = (1+i_t^C) l_t^{W,i} + q_t^i (1+i_t^{L,i}) l_t^{I,i} + (1-q_t^i)\kappa^i p_t^H \bar{H} \tag{40}$$

$$-(1+i_t^{D,i}) d_t^i - (1+i_t^C) l_t^{C,B,i} - (1+i_t^{F,B,i}) \mathbb{E}_t(\frac{E_{t+1}}{E_t}) z_t L_t^{F,B,i},$$

where $q_t^i(1+i_t^L)I_t + (1-q_t^i)\kappa p_t^H \bar{H}$ is expected repayment to bank i. The other terms are self explanatory.

[20] A marginal reserve requirement regime could be modeled as $RR_t^i = \mu_t^R d_t^i + \mu_t^{RR}(d_t^i - d_{t-1}^i)$, with $\mu_t^R \in (0,1)$ and $\mu_t^{RR} > 0$. This regime would be equivalent to (36) in the steady state. Note also that the bank holds no domestic bonds; as discussed in the next section, in the present setting it has no incentive to do so in equilibrium.

Each bank sets the gross deposit and lending rates and determines foreign borrowing so as to maximize expected profits:[21]

$$1+i_t^{D,i}, 1+i_t^{L,i}, L_t^{F,B,i} = \arg\max \mathbb{E}_t J_{t+1}^{B,i}. \tag{41}$$

Solving (41) subject to (34) and (35)-(40), and noting that from (39) $(1+i_t^{F,B,i})L_t^{F,B,i} = (1+i_t^W)(1+0.5\theta_0^{F,B}L_t^{F,B,i})L_t^{F,B,i}$, yields

$$-(\frac{1+i_t^{D,i}}{1+i_t^D})^{\zeta^D} d_t - [1+i_t^{D,i} - (1+i_t^C)(1-\mu_t^R)]\zeta^D(\frac{1+i_t^{D,i}}{1+i_t^D})^{\zeta^D-1}(\frac{d_t}{1+i_t^D}) = 0,$$

$$q_t^i(\frac{1+i_t^{L,i}}{1+i_t^L})^{-\zeta^L} l_t^{F,I} - q_t^i(1+i_t^{L,i})\zeta^L(\frac{1+i_t^{L,i}}{1+i_t^L})^{-\zeta^L-1}(\frac{l_t^{F,I}}{1+i_t^L})$$

$$+(1+i_t^C)\zeta^L(\frac{1+i_t^{L,i}}{1+i_t^L})^{-\zeta^L-1}(\frac{l_t^{F,I}}{1+i_t^L}) = 0,$$

$$(1+i_t^C)z_t - (1+i_t^W)\mathbb{E}_t(\frac{E_{t+1}}{E_t})z_t(1+\theta_0^{F,B}L_t^{F,B,i}) = 0,$$

so that, in a symmetric equilibrium,

$$i_t^D = \frac{\zeta^D}{1+\zeta^D}(1-\mu_t^R)(1+i_t^C) - 1, \tag{42}$$

$$i_t^L = \frac{\zeta^L}{q_t(\zeta^L-1)}(1+i_t^C) - 1, \tag{43}$$

$$L_t^{F,B} = \frac{1+i_t^C - (1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}{\theta_0^{F,B}(1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}. \tag{44}$$

Equation (42) shows that the equilibrium deposit rate is a markup over the refinance rate, adjusted (downward) for the implicit cost of holding reserve requirements. Equation (43) indicates that the lending rate depends negatively on the repayment probability and positively on the marginal cost of borrowing from the central bank. Equation (44) states that foreign borrowing is decreasing in the cost of borrowing abroad and increasing in the cost of domestic funding from the central bank.

As in Agénor et al. (2013, 2014), the repayment probability depends positively on the effective collateral-CG loan ratio and the cyclical position of the economy:

$$q_t = (\frac{\kappa p_t^H \bar{H}}{l_t^I})^{\varphi_1}(\frac{Y_t^S}{\tilde{Y}^S})^{\varphi_2}, \tag{45}$$

[21] Because deposits, loans, and borrowing (domestic and foreign) all mature at the end of each period, the maximization problem is static in nature.

with $\varphi_1, \varphi_2 > 0$ and $\tilde{Y}^S$ is the steady-state level of output sold domestically.[22]

Borrowing from the central bank is determined residually from the balance sheet constraint (35), together with (36):

$$l_t^{C,B} = l_t - z_t L_t^{F,B} - (1 - \mu_t^R) d_t. \tag{46}$$

4.6 Central Bank

The central bank supplies liquidity to commercial banks through a standing facility, but at a price that reflects both a base policy rate and a premium. It also engages in partial sterilization and reserve accumulation. Its balance sheet is given by

$$z_t R_t^F + b_t^C + l_t^{C,B} - nw_t = m_t + RR_t, \tag{47}$$

where $z_t R_t^F$ denotes international reserves, b_t^C holdings of government bonds, m_t the real supply of cash, and nw_t the central bank's net worth.

We consider a managed float regime, in which the central bank also has a target level of reserves, which depends on the degree of exchange rate smoothing and self-insurance motives—captured by a multiple $\phi_1^R > 1$ of the value of imports, $WP_t^F Y_t^F$, and a fraction $\phi_2^R \in (0,1)$ of the net foreign-currency liabilities of the private sector, $L_t^{F,B} - B_t^{F,P}$:

$$R_t^F = (\frac{E_t}{E_{t-1}})^{-\varphi_1^R} (R_{t-1}^F)^{\varphi_2^R} \left\{ (\phi_1^R W P_t^F Y_t^F)^{\varphi^R} [\phi_2^R (L_t^{F,B} - B_t^{F,P})]^{1-\varphi^R} \right\}^{1-\varphi_2^R}, \tag{48}$$

where $\varphi^R \in (0,1)$ measures the relative importance of the trade motive versus the financial motive, $\varphi_1^R \geq 0$ the degree to which the central bank leans against movements in the nominal exchange rate, and $\varphi_2^R \in (0,1)$ the degree of persistence.[23] Thus, as long as $\varphi_1^R > 0$, the central bank buys (sells) reserves to stabilize the exchange rate when it

[22] Agénor and Pereira da Silva (2017) derive an equation similar to (45) as part of the representative bank's optimization problem by assuming that monitoring costs are endogenous and that monitoring effort is related one-to-one with the probability of repayment. The collateral-loan ratio reflects a moral hazard effect, whereas the cyclical position of the economy reflects the fact that in boom times monitoring is less costly.

[23] Note that in (48) self-insurance against trade shocks is captured only through an import coverage ratio, as is often the case in practice. A more general measure would be the trade (or current account) balance, which would imply a positive relationship between external *deficits* and the level of reserves. At the same time, however, with a mercantilist motive instead of a self-insurance motive, the relationship could go in the opposite direction—the relationship between trade or current account *surpluses* and reserves could be positive.

appreciates (depreciates).[24] In the particular case where $\varphi_1^R = 0$ and $\varphi_2^R = 1$, the stock of reserves remains constant over time and the exchange rate is fully flexible.[25]

The central bank also adjusts its holdings of government bonds in order to sterilize the effects of its buying and selling of international reserves on money supply. Thus, its stock of bonds evolves according to

$$b_t^C - \frac{b_{t-1}^C}{1+\pi_t^S} = -\kappa^F z_t \Delta R_t^F, \tag{49}$$

where $\kappa^F \in (0,1)$ measures the degree of sterilization.

Because all income received by the central bank is transferred to the government (as discussed later), changes in the nominal value of the central bank's net worth are given by capital gains from exchange rate depreciation only ($\Delta NW_t = R_t^F \Delta E_t$). Using this result, taking first differences of (47) in nominal terms and substituting (49) in the resulting expression yields

$$m_t = \frac{m_{t-1}}{1+\pi_t^S} + (1-\kappa^F) z_t \Delta R_t^F + (l_t^{C,B} - \frac{l_{t-1}^{C,B}}{1+\pi_t^S}) - (RR_t - \frac{RR_{t-1}}{1+\pi_t^S}), \tag{50}$$

which shows that, with full sterilization ($\kappa^F = 1$), changes in the domestic-currency value of foreign-exchange reserves would not affect directly the supply of cash.[26]

The central bank sets its base policy rate, i_t^R, on the basis of a Taylor-type policy rule:

$$\frac{1+i_t^R}{1+\tilde{\imath}^R} = (\frac{1+i_{t-1}^R}{1+\tilde{\imath}^R})^\chi \left\{ (\frac{1+\pi_t^S}{1+\pi^{S,T}})^{\varepsilon_1} (\frac{Y_t^S}{\tilde{Y}^S})^{\varepsilon_2} \right\}^{1-\chi}, \tag{51}$$

where $\tilde{\imath}^R$ and $\tilde{Y}^S$ are the steady-state values of the policy rate and domestic sales of the final good, $\pi^{S,T} \geq 0$ the central bank's headline inflation target, $\chi \in (0,1)$ a coefficient measuring the degree of interest rate smoothing, and $\varepsilon_1, \varepsilon_2 > 0$.

[24] See for instance Palma and Portugal (2014) for evidence on exchange rate smoothing for Brazil, and Vujanovic (2011) and Fratzscher et al. (2015) for cross-country evidence. As documented in the literature, the reasons for the central bank wanting to smooth exchange rate movements may be related to fear of floating, concerns with competitiveness, and possibly financial stability, if foreign-currency risk is not fully hedge. At the same time, there may be a fear of losing reserves, which would militate in favor of less smoothing and induce instead the use of capital controls.

[25] We also experimented with the *expected* depreciation rate, $\mathbb{E}_t E_{t+1}/E_t$, in (48). The central bank therefore would now sell (buy) foreign reserves if it expects the one-period ahead exchange rate to depreciate (appreciate). The results were essentially the same, except that, compared to what is discussed later, the magnitude of the initial jump in reserves is smaller.

[26] This is complete sterilization in a broad sense, as opposed to a narrow sense where the supply of cash remains constant. Indeed, in the present case, changes in foreign reserves could affect the supply of cash—and therefore interest rates and aggregate demand—*indirectly*, through changes in $l_t^{C,B}$ and RR_t.

The actual cost of borrowing from the central bank (or, again, the refinance rate), in addition to the base policy rate, a penalty rate, $\theta_t^{C,B}$:

$$1 + i_t^C = (1 + i_t^R)(1 + \theta_t^{C,B}). \tag{52}$$

In turn, the penalty rate is positively related to the ratio of central bank borrowing to deposits:

$$\theta_t^{C,B} = \theta_0^{C,B}(\frac{l_t^{C,B}}{d_t}), \tag{53}$$

where $\theta_0^{C,B} > 0$. Thus, the central bank charges a penalty that increases with the amount borrowed. In addition, this amount is scaled by deposits. This helps to capture the fact that, from the perspective of the central bank, the *composition* of bank liabilities matters when setting borrowing terms. Indeed, in normal times central banks prefer commercial banks to raise deposits to fund their operations rather than borrow from them, so when the ratio $l_t^{C,B}/d_t$ is too high they raise the cost of refinancing to discourage further borrowing and induce commercial banks to raise deposit rates, thereby improving incentives for households to increase their deposit holdings. In a sense, an $l_t^{C,B}/d_t$ ratio that is too high creates a *stigma effect*, which raises funding costs either directly on borrowing from the central bank, as is modeled here, or indirectly through borrowing on the interbank market, as may be the case in practice (see Armantier et al. (2013) and Ennis and Weinberg (2013)).

4.7 Government

The government purchases the final good and issues nominal riskless one-period bonds to finance its deficit; it does not borrow abroad. In addition to lump-sum taxes, it also receives the interest income collected by the central bank on its foreign reserves and its loans to commercial banks. It pays interest on the share of government debt held by the private sector. Its budget constraint is given by

$$b_t - \frac{b_{t-1}}{1 + \pi_t^S} = G_t - T_t + \frac{i_{t-1}^B b_{t-1}^P}{1 + \pi_t^S} - (\frac{i_{t-1}^C l_{t-1}^{C,B}}{1 + \pi_t^S} + z_t i_{t-1}^W R_{t-1}^F), \tag{54}$$

where $b_t = b_t^C + b_t^P$ is the stock of government bonds and G_t government spending. In what follows the government is assumed to keep its real stock of debt constant ($b_t = b$, for all t) and to balance its budget by adjusting lump-sum taxes. The composition of the public debt therefore varies as a result of the open-market operations associated with the sterilized interventions (as described by (49)) conducted by the central bank.

Government purchases represent a fraction $\psi \in (0,1)$ of domestic sales of the final good:

$$G_t = \psi Y_t^S. \tag{55}$$

The production structure and main real and financial flows between agents are summarized in Figure 2.

5 Equilibrium and Steady State

In a symmetric equilibrium, $K_{jt} = K_t$, $N_{jt} = N_t$, $Y_{jt} = Y_t$, $P_{jt}^i = P_t^i$, for all $j \in (0,1)$ and $i = D, F$. All IG firms produce the same output, and prices are the same across firms.

Equilibrium in the goods market requires that sales on the domestic market be equal to domestic absorption, inclusive of price adjustment costs:

$$Y_t^S = C_t + G_t + I_t + \frac{\phi_D}{2}(\frac{P_t^D}{P_{t-1}^D} - 1)^2(\frac{P_t^D}{P_t^S})Y_t^D, \tag{56}$$

with the price of sales on the domestic market, P_t^S, determined through the identity

$$P_t Y_t = P_t^S Y_t^S + P_t^X Y_t^X. \tag{57}$$

Bank loans to IG firms and the capital producer are made in the form of cash. The equilibrium condition of the market for cash is thus given by

$$m_t = m_t^P + l_t, \tag{58}$$

where m_t (the supply of cash) is defined in (50).

The equilibrium condition of the housing market is

$$\bar{H} = H_t, \tag{59}$$

which can be solved, using (10), to determine the dynamics of house prices.

Finally, the external budget constraint is given by

$$WP_t^X Y_t^X - WP_t^F Y_t^F + i_{t-1}^W F_{t-1} + \theta_{t-1}^{F,P} B_{t-1}^{F,P} - \theta_{t-1}^{F,B} L_{t-1}^{F,B} - \Delta F_t = 0, \tag{60}$$

where $F_t = R_t^F + B_t^{F,P} - L_t^{F,B}$ is the economy's net foreign asset position.

The steady-state solution of the model is derived in Appendix B. Several of its key features are similar to those described in Agénor et al. (2013, 2014), so we refer to those papers for a more detailed discussion. In brief, with a headline inflation target $\pi^{S,T}$ equal to zero, the steady-state inflation rate $\tilde{\pi}^S$ is also zero. In addition to standard results (the steady-state value of the marginal cost, for instance, is given by $(\theta_D - 1)/\theta_D$ and the bond rate by $\tilde{\imath}^B = \Lambda^{-1} - 1$), the steady-state value of the repayment probability is $\tilde{q} = (\kappa\tilde{p}^H\bar{H}/\tilde{l}^I)^{\varphi_1}$, whereas $\tilde{\imath}^C = \tilde{\imath}^B$ (ensuring therefore that banks have no incentives to borrow from the central bank to purchase bonds), $1+\tilde{\imath}^D = [\zeta^D/(1+\zeta^D)](1-\tilde{\mu}^R)\Lambda^{-1}$, and $1 + \tilde{\imath}^L = \zeta^L\Lambda^{-1}/(\zeta^L - 1)\tilde{q}$. The base policy rate is thus $1 + \tilde{\imath}^R = \Lambda^{-1}/(1 + \tilde{\theta}^{C,B})$. These equations imply that $1 + \tilde{\imath}^D < 1 + \tilde{\imath}^C$ and, because $\zeta^L > 1$, $\tilde{q}(1 + \tilde{\imath}^L) > 1 + \tilde{\imath}^C$, which ensures that, given the risk of default, banks have an incentive to borrow from the central bank to lend.

From (12), the steady-state value of the stock of foreign bonds held by the representative household is

$$\tilde{B}^{F,P} = \frac{i^W - (\Lambda^{-1} - 1)}{\theta_0^{F,P}(1 + i^W)},$$

which is positive as long as the world risk-free interest rate exceeds the domestic bond rate. The greater the degree of imperfections on the world capital markets is (the higher $\theta_0^{F,P}$ is), the lower are household holdings of foreign bonds. From (48), the stock of reserves is equal to its target level:

$$\tilde{R}^F = \frac{(\phi_1^R W P^F \tilde{Y}^F)^{\varphi^R}}{[\phi_2^R(\tilde{L}^{F,B} - \tilde{B}^{F,P})]^{\varphi^R - 1}}.$$

To analyze the response of the economy to external shocks, we log-linearize the model around a nonstochastic, zero-inflation steady state. The log-linearized equations are summarized in Appendix C.

6 Parameterization

To calibrate the model we dwell partly on Agénor et al. (2013, 2014), who themselves rely on a variety of data and sources to characterize a "typical" middle-income country. We also provide here further supporting evidence from the literature for most of our parameter choices. In addition, for some of the parameters that are deemed critical for this study, sensitivity analysis is reported in the next section. This is the case, in particular, for the nature of the monetary policy rule, the degree of exchange rate smoothing, and the intensity of sterilization.

Parameter values are summarized in Table 1. The discount factor Λ is set at 0.985, which gives a steady-state annualized real interest rate of 6.1 percent—a fairly common value for studies focusing on developing countries, where real returns tend to be significantly higher than in advanced economies. The intertemporal elasticity of substitution, ς, is 0.6, in line with estimates for middle-income countries (see Agénor and Montiel (2015, Chapter 2)). The preference parameter for leisure, η_N, is set at 10, to ensure that in the steady state households devote one third of their time endowment to market activity, consistent with data for Korea and Mexico for instance (see Gertler et al. (2007) and Boz et al. (2015)). A similar share is also a standard normalization for advanced economies (see for instance Christoffel and Schabert (2015)). The parameter for composite monetary assets, η_x, is set at a low value, 0.02, to capture the common assumption in the literature that their weight in household preferences is negligible (see for instance Coenen et al. (2009) and Christoffel and Schabert (2015)). The same value is used for the housing preference parameter, η_H. The share parameter in the index of money holdings, ν, which corresponds to the relative share of cash in narrow money, is set at 0.35. This value is consistent with available data for many MICs, where the use of cash remains widespread. The sensitivity of the spread to household foreign bond holdings, $\theta_0^{F,P}$, is set at 0.5. This value is consistent with a wide range of estimates for developing countries (see for instance Ferrucci (2003, Table 4)), although most studies are based on sovereign or total external debt as a determinant of (sovereign) spreads. In our setting, it ensures that the steady-state domestic interest rate departs significantly from the (expected) rate of return on foreign assets, as implied by imperfect capital mobility.

The distribution parameter between domestic and imported intermediate goods in the production of the final good, Λ_D, is set at 0.7, to capture the case of a middle-income economy where imports are about a third of GDP, as in Tomura (2010) and Medina and Roldós (2014) for instance. The elasticity of substitution between baskets of domestic and imported composite intermediate goods, η, is set at 1.5, a fairly standard value used for instance by Cuadra and Nuguer (2014) for Mexico. This implies that these goods are substitutes in the production of the final good. The elasticities of substitution between intermediate domestic goods among themselves, θ_D, and imported goods among themselves, θ_F, are set to the same value, 10. This value is close to those used for instance by Medina and Soto (2007) for Chile and by Demirel (2010) and Quint and Rabanal

(2014); it gives a steady-state estimate of the markup rate, $\theta_D/(\theta_D-1)$, equal to 11.1 percent. The instantaneous pass-through coefficient is set at $\mu^F = 0.3$; this is line with the evidence suggesting a decline in the strength of the pass-through effect in recent years in both industrial and developing countries, possibly as a result of increased integration of global value chains (see Bussière et al. (2014), Devereux and Yetman (2014), and Ahmed et al. (2015)). The price elasticity of exports, $\varkappa$, is set equal to 0.9, which is close to the value of unity used by Gertler et al. (2007) for Korea and consistent with the lower range of estimates for developing countries reported by Imbs and Méjean (2017).

The share of capital in domestic output of intermediate goods, α, is set at 0.35, a fairly standard value. The adjustment cost parameter for prices of domestic intermediate goods, ϕ_D, is set at 74.5; this value implies a Calvo-type probability of not adjusting prices of approximately 0.71 percent per period, or equivalently an average period of price fixity of about 3.5 quarters. The latter figure is significantly higher than the numbers reported for Mexico and Turkey by Klenow and Malin (2011) and Özmen and Sevinç (2011) for instance, but it is consistent with the estimate of Carvalho et al. (2014, Table 2) for Brazil. The rate of depreciation of private capital, δ, is set equal to 0.02, a fairly standard value, which implies an annualized depreciation rate of 8.2 percent. In the absence of a well-established benchmark in the literature, the adjustment cost incurred by CG producers for transforming investment into capital, Θ_K, is set at 14 to generate an investment path in response to shocks that is of the order of 2 to 3 times more volatile than domestic output, as documented in studies of macroeconomic fluctuations in developing countries (see for instance Neumeyer and Perri (2005) and Agénor and Montiel (2015)). The share of labor costs financed in advance, κ^W, is set at a relatively high value, 0.8, in line with the evidence provided by Cabezon (2014) for instance on the rapid growth of working capital loans in major Latin American countries in recent years.

Regarding commercial banks, the effective collateral-loan ratio, κ, is set at 0.2—a significantly lower value than the one used by Cavalcanti (2010) for instance but which better captures in our view the difficulty of seizing collateral in most developing countries, due to weak legal systems and inefficient debt enforcement procedures (see Djankov et al. (2008) and Agénor and Pereira da Silva (2013, 2014)). For the elasticities of substitution ζ^D and ζ^L, there are no readily available model-based estimates for middle-income countries; accordingly, we set them to the values used by Dib (2010), 2.0 and

4.5 respectively. The elasticities of the repayment probability are set at $\varphi_1 = 0.1$ with respect to the effective collateral-loan ratio and at $\varphi_2 = 0.3$ with respect to deviations in output from its steady state. Parameter $\theta_0^{F,B}$, which determines how bank foreign borrowing responds to the differential in the cost of domestic and foreign borrowing, is set at 0.16; this value implies that bank foreign liabilities represent about 10 percent of their total liabilities in the initial steady state.

Regarding the central bank, the required reserve ratio μ^R is set at 0.1, consistent with the lower range of estimates reported by Montoro and Moreno (2011) for Latin America. Responses of the base policy rate to inflation and output deviations, ε_1 and ε_2, and the degree of persistence in the central bank's policy response, χ, are set at 2.0, 0.5, and 0.8, respectively. These values are consistent with estimates of Taylor-type rules for MICs, including those of Medina and Soto (2007) for Chile, Palma and Portugal (2014) for Brazil, Armas et al. (2014) for Peru, and Moura and Carvalho (2010) for a broad sample of Latin American countries. The sensitivity of the penalty rate to the bank borrowing-required reserve ratio, $\theta_0^{C,B}$, is set to 0.1 initially; sensitivity analysis is reported later on. The parameter characterizing the degree of exchange rate smoothing in the foreign reserves targeting rule, φ_1^R, is set at 0.5 initially, to reflect a high degree of exchange rate flexibility. The trade motive for self insurance (compared to the capital account motive) is assumed to be predominant and accordingly the parameter φ^R is set at 0.8, whereas the degree of persistence in the rule, φ_1^R, is set at 0.8. Given that the model is log-linearized and solved in terms of deviations from the steady state, parameters ϕ_1^R and ϕ_2^R (which relate the targeted stock of foreign reserves to imports and net private foreign-currency liabilities, respectively) are both normalized to unity. The degree of sterilization, κ^F, is set initially at a relatively low value, 0.2 and sensitivity analysis is also conducted later on.[27] The share of noninterest government spending in output, ψ, is set at 0.2, a value consistent with the evidence for a number of middle-income countries such as Brazil and South Africa for instance (see Carvalho et al. (2014) and Liu and Seeiso (2011)). Finally, the degree of persistence of the shock to the world risk-free rate, ρ_W, is set at 0.8, which implies a reasonably high degree of inertia.

[27] As documented by Aizenman and Glick (2009) and Agénor and Pereira da Silva (2013), the degree of sterilization (as measured by offset coefficients) remains imperfect, even though it has increased in recent years in many MICs.

7 Drop in the World Risk-Free Rate

To illustrate the impact of external shocks, consider a temporary drop in the world risk-free interest rate by 35 basis points at a quarterly rate, or about 141 basis points at an annual rate.[28] The magnitude of this shock is relatively large by historical standards but it helps to illustrate well the transmission mechanism.

The results of this experiment are summarized in Figure 3. On impact, the shock lowers both the return on foreign assets and the cost of bank borrowing abroad. Thus, households' holdings of foreign bonds decline, whereas bank foreign liabilities increase; these effects combine to generate an inflow of capital, which leads to a nominal appreciation. The domestic-currency price of imported intermediate goods falls as a result, thereby raising the demand for these goods; because both consumption and investment increase (as explained next), the production of final goods also rises. At the same time, the nominal appreciation lowers inflation (measured in terms of the price of domestic sales) initially, which would normally lead the central bank to reduce the base policy rate. The net effect, however, is an *increase* in that rate, given the need to mitigate the boom in domestic activity. The inflow of foreign borrowing leads to a *reduction* in the central bank borrowing-deposit ratio, which in turn lowers the penalty rate; this reduction is large enough to translate into an initial drop in the refinance rate. As a result the loan rate also falls, which further dampens inflation, through a (reverse) cost channel, and promotes investment.

The increase in net private foreign-currency liabilities, combined with higher imports, raise the central bank's desired and (to a smaller extent, given partial adjustment) actual stocks of foreign reserves. With partial sterilization, the accumulation of foreign reserves translates into an expansion of the monetary base. At the same time, because the increase in bank foreign borrowing reduces (at the initial level of investment loans) the amount borrowed from the central bank, the monetary base tends to contract. Given our base parameterization the former effect dominates and this translates into an increase in the supply of cash. Thus, at a given level of consumption, the nominal bond rate must fall to raise the demand for cash and restore market equilibrium. Because expected

[28] See for instance Edwards (2010), Byrne and Fiess (2016), Eichengreen and Gupta (2016), and Sarno et al. (2016) for the importance of global factors in explaining capital flows to middle-income countries. In analyzing the effects of this shock, we do not account for the fact that changes in foreign interest rates could affect foreign output, and thus domestic exports. Doing so allows us to isolate the pure financial effects of the shock.

future inflation increases, the *real* bond rate unambiguously falls as well. This induces households to reduce savings and increase consumption today.

The fall in the real bond rate also leads to an increase in the demand for housing, which puts upward pressure on real estate prices and increases the value of the collateral that firms can pledge to secure investment loans. Nevertheless, the collateral-loan ratio *falls* initially, because the reduction in the cost of borrowing stimulates investment significantly. While the reduction in the collateral-loan ratio tends to reduce the repayment probability, the increase in cyclical output tends to increase it; in this experiment, the net effect is indeed positive, whereas the net effect on the loan rate is negative. Thus, as noted earlier, domestic spending increases unambiguously on impact. At the same time, the real appreciation translates into a reduction in exports, which allows domestic sales to increase.

During the transition, the increase in the capital stock (which mirrors the investment boom) tends to lower its rental rate and to raise the marginal product of labor. *Gross* wages tend therefore to increase. At the same time, because the marginal utility of leisure increases with the higher level of current consumption, households tend to reduce their supply of labor. The combination of lower supply of, and higher demand for, labor (associated with the expansion in output) translates into higher wages. Although the fall in the refinance rate (the rate at which intermediate goods producers borrow to finance labor costs) mitigates this initial pressure, the *effective* wage rate also increases on impact. Over time, the reduction in the rental rate of capital leads during a first phase to lower marginal costs, which magnifies the impact of the initial exchange rate appreciation on inflation, but these effects are eventually reversed.

The results of this experiment show that, consistent with the evidence, external shocks that lead to large inflows of capital (a "sudden flood," in the terminology of Agénor et al. (2014)) generate a domestic boom characterized by a credit expansion, asset price pressures, increases in aggregate demand, an expansion in output, and—over time only, given the initial appreciation—inflationary pressures. Although the boom in domestic activity tends to raise the base policy rate, the drop in inflation (associated with the exchange rate appreciation) tends to reduce it. Given the relative weights of inflation and output deviations in the calibrated Taylor rule, the net effect is an increase in the base policy rate. Nevertheless, the cost of commercial bank borrowing falls because the repayment probability increases (thereby reducing the premium imposed on domestic borrowers) and because the penalty rate imposed by the central bank falls. Essentially, because banks borrow more abroad, they borrow less domestically, which in turns reduces the penalty component of the refinance rate.

8 Sensitivity Analysis

To assess the sensitivity of the previous results we conduct several additional experiments, involving a stronger response of the penalty rate to the central bank borrowing-deposit ratio, more aggressive exchange rate smoothing, and full sterilization of foreign exchange market intervention. In addition, we also illustrate the performance of the model with a countercyclical reserve requirement rule, whose optimality is discussed in the next section.

8.1 Sensitivity of Penalty Rate

Consider the case where the parameter that characterizes the setting of the penalty rate, $\theta_0^{C,B}$ in (53), takes a value of zero compared to the baseline value of 0.1. In that case, deposits and central bank liquidity are perfect substitutes as sources of liquidity for banks and $i_t^R = i_t^C$.

The results are illustrated by the dotted lines in Figure 3. The behavior of most variables (except for the marginal cost) are qualitatively the same compared to the benchmark experiment, but there is a critical difference.

The reduction in the base policy rate (induced by the downward effect on inflation of the initial appreciation, as noted earlier) lowers the return on deposits, which leads to a drop in household demand for that category of assets. All else equal, this would normally induce banks to borrow more from other funding sources. However, as noted previously, banks borrow more abroad and less domestically; the central bank borrowing-deposits ratio falls (as before), and this tends to lower the penalty rate on impact. With $\theta_0^{C,B}$ positive, the drop in the penalty rate means that the cost of borrowing from the central bank (the refinance rate) falls by more than the drop in the base policy rate, whose behavior is determined by the Taylor rule. By contrast, with $\theta_0^{C,B} = 0$, the refinance rate and the policy rate fall initially by the same amount. The lending rate therefore drops by less, which implies a smaller increase in investment and aggregate demand, and a larger fall in inflation. In response, the base policy rate rises by less than before (it actually falls), but without altering the direction of these effects—even though it magnifies movements in marginal cost and inflation.[29] Thus, by and large, with a constant required reserve ratio the transmission mechanism of a shock to the world safe interest rate remains essentially the same under perfect and imperfect substitutability between deposits and central bank borrowing.

8.2 Exchange Rate Smoothing

Consider the case where the central bank engages in more aggressive exchange rate smoothing. This is illustrated by increasing the parameter φ_1^R in the reserve target rule (48) from an initial value of 0.5 to 15—a somewhat arbitrary value, but high enough to highlight possible differences in the transmission mechanism with respect to the benchmark case. The results are displayed in Figure 4. The key difference is that, to mitigate the appreciation, the central bank intervenes more heavily, and therefore accumulates more reserves; with partial sterilization, the money supply expands by more than in the benchmark case, implying that the bond rate must drop by a larger amount than before to restore equilibrium in the money market. However, the additional impact on consumption and the demand for land (and thus real house prices) remain fairly subdued, at least in the first stage of the transition.

Because intervention stabilizes exchange rate movements (both nominal and real), it also leads to a smoother path of inflation, and thus of the base policy rate, which further mitigates inflationary pressures during the initial phase of the transition through a reverse cost channel. In addition, the smoother (one-period ahead) path of the exchange rate triggers higher foreign bank borrowing today (as implied by (44)), implying a larger drop in the central bank borrowing-deposit ratio. This leads to a larger reduction in the penalty rate, which in turn translates into a more substantial drop in the refinance rate. Consequently, the fall in the loan rate is also larger, and investment expands by more than in the benchmark case. Thus, more aggressive exchange rate smoothing may actually be expansionary despite stabilizing the behavior of the currency.[30] As discussed later, this has implications for the degree of aggressiveness of a countercyclical reserve requirement rule.

[29] In fact, the larger drop in the policy rate is sufficient to offset the initial pressure on gross wages—implying that the effective wage rate now falls on impact and leads to a *reduction* in marginal cost.

[30] Although we do not report them here, similar results hold if the smoothing term in (48) is specified in terms of the *real* exchange rate, rather than the nominal value.

8.3 Full Sterilization

Consider the case now where the central bank engages in full sterilization of foreign exchange market intervention, which corresponds to $\kappa^F = 1$ in (50). Changes in the domestic-currency value of foreign-exchange reserves therefore have no direct effect on the supply of cash.

The results of this experiment are shown in Figure 5. Full sterilization mitigates volatility, first and foremost by smoothing the path of the nominal exchange rate. As a result, inflation and the base policy rate, and thus the refinance and loan rates, are less volatile, with all of these variables remaining below (above) their values in the benchmark case during the initial (later) phase of the adjustment process. However, the impact on the real side of the economy is negligible. These results therefore do not provide much support to some claims in the recent literature, according to which sterilized foreign exchange purchases under inflation targeting in an economy with an active credit channel may have expansionary consequences on aggregate demand through their negative impact on lending rates. Indeed, an argument often made is that even if sterilization succeeds in limiting domestic monetary expansion, it may not completely insulate an economy from the effects of capital inflows. If domestic interest-bearing assets are imperfect substitutes, then a capital inflow may be associated with a shift in the *composition* of demand for these assets, as well as with an increase in the total demand for them. In this case, unless the composition of domestic assets issued through sterilization operations matches that demanded by creditors, the structure of domestic asset returns would be altered. In turn, as argued by Garcia (2012), this could trigger a portfolio reallocation which, in the presence of wealth effects, may affect aggregate demand and prices. This is not the case in our simulations, in part because the degree of persistence in the reserve accumulation rule, as measured by φ_2^R, is quite large.[31]

8.4 Countercyclical Reserve Requirements

In the foregoing discussion it was assumed that the reserve requirement rate, μ_t^R, is kept constant. As noted earlier, in practice policymakers in MICs have often used reserve requirements as part of a countercyclical toolkit to mitigate credit fluctuations caused by capital inflows. Accordingly, we consider now the case where the central

[31] Note that our analysis abstracts from the fact that sterilized intervention entails quasi-fiscal costs, an issue we will return to later on.

bank implements a countercyclical reserve requirement rule that relates changes in μ_t^R endogenously to deviations in the ratio of investment loans to domestic output sales:

$$\frac{1+\mu_t^R}{1+\tilde{\mu}^R} = (\frac{1+\mu_{t-1}^R}{1+\tilde{\mu}^R})^{\chi_1^R} \left\{ (\frac{l_t^I/Y_t^S}{\tilde{l}^I/\tilde{Y}^S})^{\chi_2^R} \right\}^{1-\chi_1^R}, \tag{61}$$

where $\chi_1^R \in (0,1)$ and $\chi_2^R > 0$.[32]

At the outset, it is worth noting that in partial equilibrium there is a key difference in the model between an autonomous increase in the base policy rate and an autonomous increase in the reserve requirement rate. On impact, a higher μ_t^R lowers the deposit rate (and thus the supply of deposits); all else equal (that is, for a given level of foreign borrowing), the drop in deposits induces banks to borrow more from the central bank. Both effects combine to raise the $l_t^{C,B}/d_t$ ratio. This leads therefore to an increase in the penalty rate and in the cost of borrowing, i_t^C. Even though in principle $(1-\mu_t^R)i_t^C$ could either increase or fall, should it increase it will be by *less* than an increase in i_t^C induced by an autonomous rise in the base policy rate, i_t^R. In fact, if $(1-\mu_t^R)i_t^C$ falls, then i_t^D would also fall (see (42)), so an increase in the reserve requirement rate would not exacerbate capital flows that are sensitive to domestic deposit rates, in contrast to an increase in the base policy rate. However, in the model capital flows depend on the bond rate, and not the deposit rate. Thus, much depends also on the indirect effects of these two policies, that is, the general equilibrium effects that are captured by the model.

The properties of the model with and without the endogenous rule (61) are illustrated in Figure 6, in the base case where $\chi_1^R = 0.1$ and $\chi_2^R = 8$; thus, the case considered is that of a fairly aggressive policy with little inertia. On impact, the response of the reserve requirement rate to the initial expansion in credit leads indeed to a drop in bank deposits and to a slight increase in the central bank borrowing-deposit ratio; as a result, the penalty rate edges up, thereby mitigating the initial drop in the refinance rate and thus the lending rate. This dampens also the initial expansion in credit and investment. The supply of cash expands by less than in the benchmark case, requiring thereby a smaller drop in the bond rate—which in turn weakens incentives to consume today. As a result, aggregate demand also expands by less than in the benchmark case; the

[32] A forward-looking credit growth rule is discussed in Mimir et al. (2013) and Escudero et al. (2014), whereas Montoro (2011) uses a contemporaneous rule in terms of the *level* of credit. We report later on an experiment with a credit growth rule.

endogenous response of the reserve requirement rate is unambiguously countercyclical, in the sense that it mitigates the initial expansion in output, credit, and asset price pressures, even though the policy has more limited effects on inflation and the exchange rate. If anything, the exchange rate appreciates slightly more, because with the domestic bond rate increasing, there is a slight reduction in household holdings of foreign bonds. As a result, domestic inflation falls slightly more on impact—and so does the base policy rate.

To further illustrate how this policy operates, it is worth considering two scenarios: the case where (as discussed earlier) the parameter that characterizes the setting of the penalty rate, $\theta_0^{CB} = 0$ in (53), and the case where $\theta_0^{CB} = 0.15$, compared to the baseline value of 0.1. As noted earlier, the first case corresponds to a situation where deposits and central bank borrowing are perfect substitutes. In that case, the base policy rate and the refinance rate are one and the same ($i_t^R = i_t^C$); a change in the central bank borrowing-deposit ratio has no effect on the loan rate, and thus no effect on credit and investment. If foreign borrowing does not change, all that happens when deposits fall is that banks fully offset the drop in market funding by borrowing more from the central bank. Put differently, for the countercyclical reserve requirement policy to be effective, deposits and central bank borrowing must be imperfect substitutes, as discussed intuitively in Section 3 earlier.[33]

The second case is illustrated in Figure 7. The interest rate and aggregate demand effects described in Figure 6 are now magnified. In fact, and in contrast to what obtains in the benchmark case, with the higher value of θ_0^{CB} the refinance rate actually *increases* on impact, whereas the loan rate barely falls. Thus, the smaller the degree of substitutability between deposits and central bank borrowing, the stronger the countercyclical effect of reserve requirements. This result is well illustrated in Figure 8, which shows how the impact effect of the shock on domestic absorption falls with values of χ_2^R ranging from 0 to 10.

Finally, we also considered the case where the countercyclical reserve requirement rule is specified not in terms of the credit-to-domestic sales ratio, as in (61), but in

[33]If the shortfall in deposits is absorbed by increased bank borrowing abroad, the associated capital inflow would magnify the exchange rate appreciation, the reduction in inflation, and the expansion in economic activity. If the net effect is a higher base policy rate, the reserve requirement rule could be countercyclical—even if deposits and central bank liquidity are perfect substitutes.

terms of deviations in nominal credit growth, $(1+\pi_t^S)(l_t^I/l_{t-1}^I)$.[34] Figure 9 illustrates the results with the two rules, together with the benchmark case, for the same values of θ_0^{CB}, χ_1^R, and χ_2^R as in Figure 6. The figure shows that the results are qualitatively the same; the credit growth-based rule is also countercyclical, despite generating more volatility initially for some variables.

9 Optimal Simple Rules

In the foregoing analysis we have considered arbitrary values of the parameters characterizing the reserve requirement rule (61). We now consider the case where the central bank is concerned with two objectives, macroeconomic stability and financial stability. Extending the approach described in Agénor et al. (2014), we define macroeconomic (in)stability, V_t^M, in terms of a weighted average of the volatility of inflation deviations and output deviations, and financial (in)stability in terms of two composite measures: *a*) a narrow index, $V_t^{F,N}$, defined as a weighted average of the volatilities of the ratio of investment loans to domestic sales of the final good, l_t^I/Y_t^S; the ratio of net capital inflows to domestic sales, $(L_t^{F,B}-B_t^{F,P})/Y_t^S$; and the loan-refinance rate spread, $i_t^L-i_t^C$; and *b*) a broad index, $V_t^{F,B}$, which adds to the variables included in the narrow index the volatility of real asset prices, measured by the volatility of real house prices and the volatility of the real exchange rate. The focus on these variables is consistent with the large body of evidence suggesting that fluctuations in credit, capital flows, interest rate spreads, and asset prices have often been associated with financial instability and financial crises, both in developed and developing countries (see Agénor and Montiel (2015), Taylor (2015), and Caballero (2016)).

For the *macroeconomic stability index*, we use weights of 0.7 in inflation deviations and 0.3 for output deviations. These weights reflect relatively greater concern with price stability and are consistent with the evidence on central bank preferences in a flexible inflation targeting regime (see for instance Adolfson et al. (2011), Palma and Portugal (2014), Paez-Farrell (2015) and Carney (2017)). For the *narrow financial stability index*, the weights are 1/3 on each measure whereas for the *broad index* the weights are 0.3 each for the three variables included in the narrow index, and a weight of 0.05 on each asset price. In the latter case, the weighting ensures that financial variables continue

[34] We also experimented with *real* credit growth, by using l_t^I/l_{t-1}^I instead of $(1+\pi_t^S)l_t^I/l_{t-1}^I$ in (61); the results did not differ much from those reported here.

to dominate in the definition of financial stability. This also reflects the fact that the evidence on the behavior of asset prices prior to financial crises appears to be less robust than other variables, especially credit.[35]

In addition, we also specify a *composite index of economic stability*, V_t, defined with two sets of weights: first with equal weights of 0.5 attached to each stability objective, and second with a weight of 0.8 for macroeconomic stability and 0.2 for financial stability. Thus, in the first case the central bank shows equal concerns with the two objectives, whereas in the second macroeconomic stability dominates. Formally, the central bank's instantaneous policy loss function can be written as

$$V_t = [V_t^M(\sigma^2_{\pi^S}, \sigma^2_{Y^S},)]^{\zeta}[V_t^F]^{1-\zeta}, \tag{62}$$

with $\zeta = 0.5, 0.8$ and V_t^F equal to either $V_t^{F,N}$ or $V_t^{F,B}$, defined as[36]

$$V_t^{F,N} = V_t^{F,N}[\sigma^2_{l^I/Y^S}, \sigma^2_{(L^{F,B}-B^{F,P})Y^S}, \sigma^2_{i^L-i^D}], \quad V_t^{F,B} = V_t^{F,B}[V_t^{F,N}, \sigma^2_{p^H}, \sigma^2_z].$$

We next consider two cases, for a given value of the persistence parameter $\chi_1^R = 0.1$ in the countercyclical rule (61): *a*) the case where the goal of the central bank is to determine the optimal value of χ_2^R only so as to minimize the loss function (62); and *b*) the case where *both* χ_2^R and the degree of sterilization κ^F are solved for so as to minimize (62).[37] A grid step of 1 or 1.5 is used for χ_2^R and 0.1 for κ^F, as this is sufficient for our purpose.

9.1 Reserve Requirements

A numerical solution to the first problem is illustrated in Figures 10 and 11, in the first case for $\zeta = 0.5$ and the second for $\zeta = 0.8$, and for both measures of financial stability. The figures show clearly that the relationship between the degree of aggressiveness of the countercyclical reserve rule and economic volatility follows a U-shape pattern. Intuitively, as the policy becomes more aggressive, volatility falls at first, because (as can be

[35] See again Agénor and Montiel (2015) and Taylor (2015). Changes in these weights have a limited impact on the results. Individual volatility measures are based on the asymptotic (unconditional) variances of the relevant variable.

[36] As discussed by Debortoli et al. (2017) for instance, the macro component of the loss function (62) may represent a parsimonious approximation to social welfare. More generally, function (62) is consistent with studies that take a second-order approximation of household utility in models with financial frictions and find that it differs from the standard case by including a measure of financial conditions. See Andrés et al. (2013) and De Paoli and Paustian (2017) for instance.

[37] In both cases, experiments with a higher value of $\chi_1^R = 0.8$ did not affect the results qualitatively.

inferred from Figures 7, 8 and 9) the policy stabilizes credit, investment and domestic absorption. However, the more aggressive the policy becomes, the more volatile interest rates and deposits become; the volatility in domestic interest rates induces also more volatility in capital flows, and therefore tends to increase financial volatility—so much so that it eventually dominates the gains in terms of reduced volatility in credit and aggregate demand. Thus, there exists an optimal value for χ_2^R, which is 6 in Figure 10 for both measures of financial stability, when the central bank attaches equal weights to macroeconomic stability and financial stability. By contrast, when the central bank attaches a higher weight to macroeconomic stability ($\zeta = 0.8$), Figure 11 shows that the optimal value of χ_2^R is substantially higher, at 11. The reason is that the countercyclical reserve rule is particularly effective at mitigating fluctuations in investment (which is fully financed by credit) and output.[38] This result can be seen as providing some support for the use of reserve requirements as a partial substitute for monetary policy in response to external shocks.

Table 2 reports the asymptotic standard deviations of some key variables. The second column of the table, which corresponds to the case $\zeta = 0.5$, shows that the optimal use of reserve requirements improves (compared to the benchmark case, whose results are reported in the first column) economic stability by reducing both financial volatility and macroeconomic volatility, although the gains are relatively small in both cases—and despite the fact that volatility in the credit-to-output ratio, investment, and the loan rate all drop by about one third and output volatility (which reflects in part fluctuations in investment) by about a quarter. The benefit of the optimal policy in terms of financial stability stems fundamentally from its stabilizing effect on the credit-to-output ratio; with a greater weight attached to that variable in the financial stability index, the gain associated with the optimal policy would of course be magnified.

To study the sensitivity of these results, Figure 12 considers the case where foreign exchange market intervention aimed at smoothing the exchange rate, as captured by φ_1^R, is stronger. Given the illustrative nature of this exercise, only the narrow measure of financial stability is used. The figure shows the results for the benchmark value of $\varphi_1^R = 0.5$ and an alternative value of 1.5. They indicate that the stronger the exchange rate smoothing intervention, the more aggressive should also be the optimal response

[38] As can be inferred from Figure 6, the volatility of inflation marginally increases in the presence of the rule. However, this effect is dominated by the reduction in output volatility.

of the reserve requirement rate to credit; the optimal value of χ_2^R is now 8.5, instead of 6. Intuitively, more aggressive smoothing means a smaller real appreciation over the entire adjustment path. Although (as can be inferred from Figure 4) inflation may drop by more initially, given its forward-looking nature, it also follows a smoother path subsequently. As a result, the increase in the base policy rate is smaller, implying a larger drop in the loan rate and magnifying the increase in investment and output (see again Figure 4). To counter these effects, the optimal reserve requirement rule must therefore be more aggressive.

9.2 Reserve Requirements and Sterilization

Consider now the case where *both* χ_2^R and κ^F are solved for optimally. The results of the grid search show that, either in isolation or when combined with reserve requirements, the optimal degree of sterilization is unity. The transmission mechanism when $\kappa^F = 1$ was discussed earlier (see subsection 8.3); to understand why full sterilization is optimal consider the asymptotic variances and minimized loss functions reported in the last two columns of Table 2, which again correspond to the case where $\zeta = 0.5$ (similar results are obtained for $\zeta = 0.8$). The figures presented in the table show indeed that full sterilization is effective in terms of enhancing overall economic stability. By helping to insulate the money supply from the behavior of foreign reserves, used by itself it helps to stabilize movements in policy interest rates and asset prices and, by implication, market interest rates and capital flows. This generates benefits in terms of financial stability and, to a lesser extent, macroeconomic stability. When combined with an optimal use of reserve requirements, the benefits are magnified. Thus, the combination of policy instruments is preferable to the use of a single macroprudential tool; in that sense, the instruments are complements. In terms of our overall index of financial stability, the benefit of optimal (full) sterilization results solely from its effect on reducing private capital flow volatility. This implies that the marginal contribution of sterilization is higher in terms of macroeconomic stability than it is with respect to financial stability. Moreover, when the degree of sterilization κ^F increases from its initial value of 0.2 to its optimal value of 1.0, the countercyclical reserve requirement rule becomes less aggressive; χ_2^R falls from 6 to 4.5, implying that the two instruments are partial substitutes at the margin.

10 Concluding Remarks

Central banks in middle-income countries are often confronted with the dilemma of achieving several competing objectives with limited policy instruments. In particular, in response to large capital inflows, they may want to target a stable exchange rate and low inflation, as well as curb credit growth. However, although by raising the policy interest rate to tighten monetary policy the price stability objective may be met, the interest rate increase may attract additional capital inflows and magnify the appreciation of the domestic currency. As a result, central banks have often used reserve requirements as a substitute to monetary policy. Before the global financial crisis, the use of reserve requirements was indeed often motivated by monetary policy or microprudential objectives. More recently there has been a formal recognition that reserve requirements can also help to address concerns arising from the procyclicality of the financial system. Accordingly, there has been renewed thinking about the role of reserve requirements as a macroprudential instrument.

In this paper, the performance of a countercyclical reserve requirement rule was studied in a dynamic stochastic model of a small open economy with financial frictions, imperfect capital mobility, a managed float regime, and sterilized foreign exchange market intervention. Deposits and central bank liquidity were also assumed to be imperfect substitutes as sources of bank funding. This was captured by assuming that the rate at which banks can borrow from the monetary authority incorporates a premium (above and beyond a base policy rate), which depends on the ratio of central bank borrowing to deposits.[39] The model was calibrated and used to study the effects of a temporary drop in the world risk-free interest rate. Consistent with the stylized facts, the simulations showed that this shock triggers an expansion in domestic credit and activity, asset price pressures, and a real appreciation. We also showed that a credit-based reserve requirement rule helps to mitigate both macroeconomic and financial volatility, with the latter defined in terms of a narrow measure based on the credit-to-output ratio, the ratio of capital flows to output, and interest rate spreads, as well as a broader measure that includes also real asset prices. An optimal rule, based on minimizing a composite measure of *economic* volatility (a loss function combining measures of both macroeconomic and financial volatility), was also derived. Unlike other studies, such as

[39] Agénor and Pereira da Silva (2017) discuss another potential channel through which reserve requirements can be countercyclical, through their impact on production costs in banking.

Glocker and Towbin (2012), the relationship between the degree of aggressiveness of the countercyclical reserve rule and economic volatility was shown to be nonmonotonic. At first, as the policy becomes more aggressive, volatility falls because it stabilizes credit, investment and domestic absorption. As the policy becomes more aggressive, it magnifies volatility in interest rates and bank deposits; in turn, higher volatility in domestic interest rates induces more volatility in capital flows, and therefore tends to increase financial volatility—so much so that it eventually dominates the gains in terms of reduced volatility in credit growth and aggregate demand.

Sensitivity analysis was also performed, both in terms of the transmission process and the optimal rule. Among other results, it was shown that the stronger the intensity of exchange rate smoothing, the stronger should be the optimal response to credit growth in the countercyclical reserve rule. We also showed that if the quasi-fiscal costs of sterilization are abstracted from it is optimal to fully sterilize, even when a countercyclical reserve requirements rule is in place. In that sense, the two instruments are complements. In addition, greater reliance on sterilization implies a less aggressive optimal reserve requirements rule, which implies that the two instruments are partial substitutes at the margin.

The foregoing analysis can be extended in a number of directions. First, the use of central bank bonds (held by commercial banks) for sterilization purposes could be added, to capture a common practice in some middle-income countries (see for instance Vargas et al. (2010, 2013)). Second, the model could be extended to account for the fact that reserve requirements represent a tax on banking activity, which may have an adverse effect on the financial condition and credit of depository institutions relative to that of other financial institutions.[40] The bank's optimization problem could thus be generalized to account for the fact that financial institutions have an incentive to reduce the tax-like impact of (unremunerated) reserve requirements by evading them.[41] Moreover, if changes in reserve requirements lead to disintermediation away from the banking sector and toward less-regulated channels, the consequence may be to distort markets and weaken financial stability. This may entail long-run costs, which may exceed

[40] Robitaille (2011) discussed how reserve requirement policy in Brazil taxed large banks in order to subsidize small banks that were exempt, but that over time banks shifted from demand deposits with a high reserve requirement to other funding sources, such as certificates of deposits, with a lower requirement.

[41] If banks hold excess reserves, reserve requirements are generally non-binding and the incentive to mitigate their impact would of course be weaker.

the short-run stabilization benefits that the policy may generate.

Finally, it is important to keep in mind that the foregoing analysis has abstracted from the quasi-fiscal costs associated with sterilization. These costs are associated with the fact that the central bank typically exchanges high-yielding domestic assets (government bonds in this setting) for low-yielding foreign reserves; the magnitude of these costs will be greater the higher the degree of capital mobility and the larger the gap between (expected) gross domestic and foreign rates of return. These costs may be substantial in practice and may lead to departures from full sterilization. Indeed, as shown by Kletzer and Spiegel (2004) in a simple model, if sterilization costs are high, an optimizing central bank may choose to rely less on sterilization and more on nominal exchange rate flexibility. In the present setting, extending the central bank's loss function to account not only for macroeconomic and financial stability but also for the quasi-fiscal costs of sterilization could indeed imply that the optimal policy involves partial sterilization—whether or not a countercyclical reserve requirements rule is in place.

Notwithstanding these various extensions, as it stands our analysis provides important lessons for policymakers in middle-income countries confronted with the dilemmas associated with external financial shocks. Our results support the view that to dampen the potentially destabilizing effects of large capital flows on asset prices and credit markets, countercyclical reserve requirements can be highly effective. Raising interest rates to contain aggregate demand pressures during episodes of sudden floods can be self-defeating, as this may induce more capital inflows; under such circumstances raising reserve requirements—an instrument with which central banks in MICs are very familiar with and can be deployed quickly—may help to contain not only aggregate demand but also credit growth, a key determinant of systemic financial risks. This is an important message in the context of the ongoing debate about the choice and implementation of macroprudential instruments.

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Table 1
Benchmark Parameterization: Key Parameter Values

Parameter	Value	Description
Household		
Λ	0.985	Discount factor
ς	0.6	Elasticity of intertemporal substitution
η_N	10.0	Preference parameter for leisure
η_x	0.02	Preference parameter for money holdings
η_H	0.02	Preference parameter for housing
ν	0.35	Share parameter in index of money holdings
$\theta_0^{F,P}$	0.5	Sensitivity of premium, household foreign bonds
Production		
Λ_D	0.7	distribution parameter, final good
η	1.5	Elasticity of substitution, baskets of intermediate goods
μ^F	0.3	Exchange rate pass-through, imported goods
$\varkappa$	0.9	Price elasticity of exports
θ_D, θ_F	10.0	Elasticity of demand, intermediate goods
α	0.35	Share of capital, domestic intermediate goods
ϕ_D	74.5	Adjustment cost parameter, domestic IG prices
δ	0.02	Depreciation rate of capital
Θ_K	14	Adjustment cost parameter, investment
κ^W	0.8	Share of labor costs financed in advance
Commercial banks		
κ	0.2	Effective collateral-loan ratio
φ_1	0.1	Elasticity of repayment probability, collateral
φ_2	0.3	Elasticity of repayment probability, cyclical output
ζ^D	2.0	Elasticity of substitution, deposits
ζ^L	4.5	Elasticity of substitution, loans to CG producers
$\theta_0^{F,B}$	0.16	Sensitivity of premium, bank foreign borrowing
Central bank		
μ^R	0.1	Reserve requirement rate
χ	0.8	Degree of interest rate smoothing
ε_1	2.0	Response of base policy rate to inflation deviations
ε_2	0.5	Response of base policy rate to output deviations
$\theta_0^{C,B}$	0.1	Sensitivity of penalty rate to borrowing-deposit ratio
φ_1^R	0.5	Exchange rate smoothing parameter, foreign reserves rule
φ_2^R	0.8	Persistence parameter, foreign reserves rule
φ^R	0.8	Relative weight on trade motive, foreign reserves rule
κ^F	0.2	Sterilization coefficient
χ_1^R	0.1	Persistence coefficient, reserve requirement rule
Government		
ψ	0.2	Share of government spending in domestic output sales
World interest rate		
ρ_W	0.8	Persistence parameter, shock to world risk-free rate

Table 2
Asymptotic Standard Deviations of Key Variables
and Central Bank Loss Function under Alternative Policy Regimes

	Core experiment	Optimal required Reserve ratio	Optimal degree of sterilization	Optimal combination
Real variables				
Domestic sales, final good	0.0029	0.0023	0.0028	0.0022
Employment	0.0024	0.0031	0.0024	0.0031
Investment	0.0064	0.0048	0.0063	0.0047
Consumption	0.0009	0.0009	0.0009	0.0009
Real exchange rate	0.0075	0.0079	0.0076	0.0079
Exports	0.0068	0.0071	0.0068	0.0071
Price inflation	0.0009	0.0010	0.0008	0.0009
Financial variables				
Base policy rate	0.0017	0.0017	0.0014	0.0014
Refinance rate	0.0006	0.0007	0.0005	0.0005
Loan rate	0.0009	0.0007	0.0008	0.0007
Loan-refinance rate spread	0.0004	0.0004	0.0004	0.0003
Government bond rate	0.0006	0.0007	0.0005	0.0006
Real house prices	0.0016	0.0015	0.0015	0.0014
Repayment probability	0.0004	0.0004	0.0004	0.0003
Loan-to-output ratio	0.0035	0.0026	0.0035	0.0026
Bank foreign borrowing	0.6084	0.6224	0.5980	0.6080
Private capital inflows	0.2922	0.2934	0.2877	0.2879
Official foreign reserves	0.0497	0.0497	0.0488	0.0488
Loss function				
Macro component	0.0015	0.0014	0.0014	0.0013
Financial component	0.0978	0.0977	0.0962	0.0960
Composite	0.0496	0.0495	0.0488	0.0487

Note: In the core experiment and the optimal reserve requirement experiment (columns 1 and 2) the sterilization coefficient is set equal to its benchmark value of $\kappa^F = 0.2$. In the last two experiments, $\kappa^F = 1$. In addition, in the third experiment, the required reserve ratio is set at its benchmark value of $\mu^R = 0.1$. The optimal value of χ_2^R is 6 in the second column and 4.5 in the fourth column. All results are based on equal weights for macroeconomic stability and financial stability in the composite loss function.

Figure 1
Reserve Requirements, Refinance Rate, and Bank Interest Rates

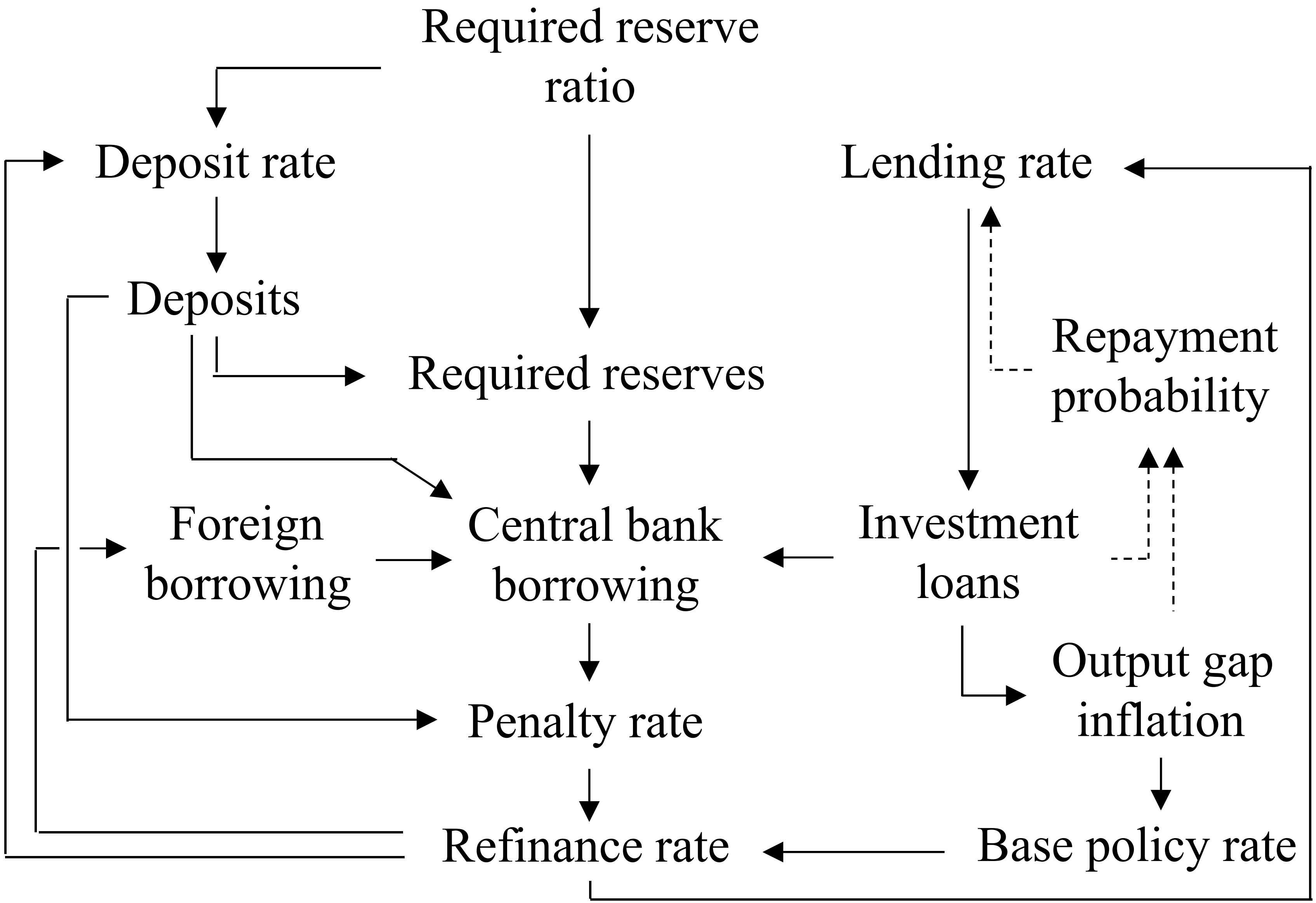


Figure 2
Model Structure

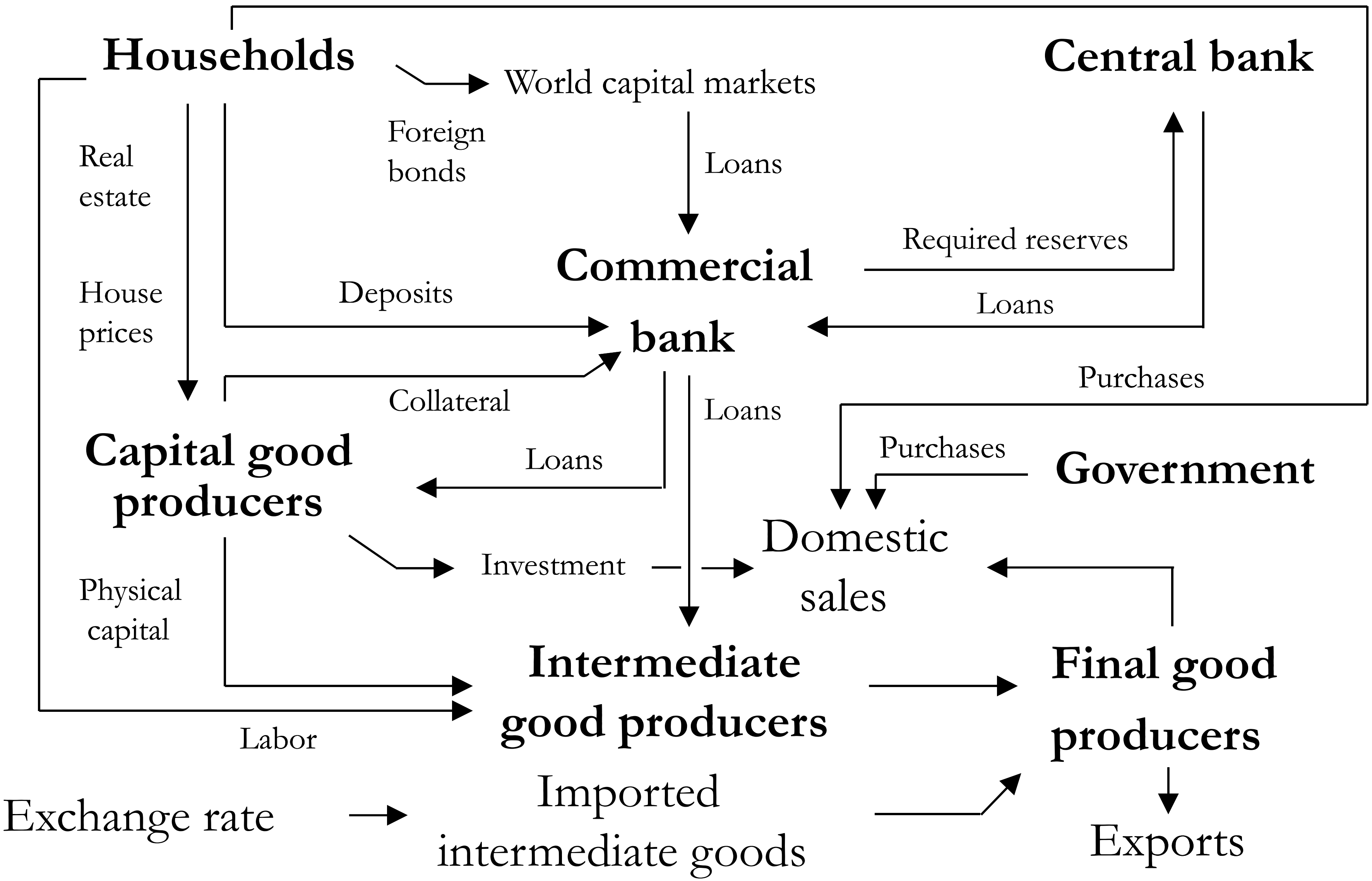
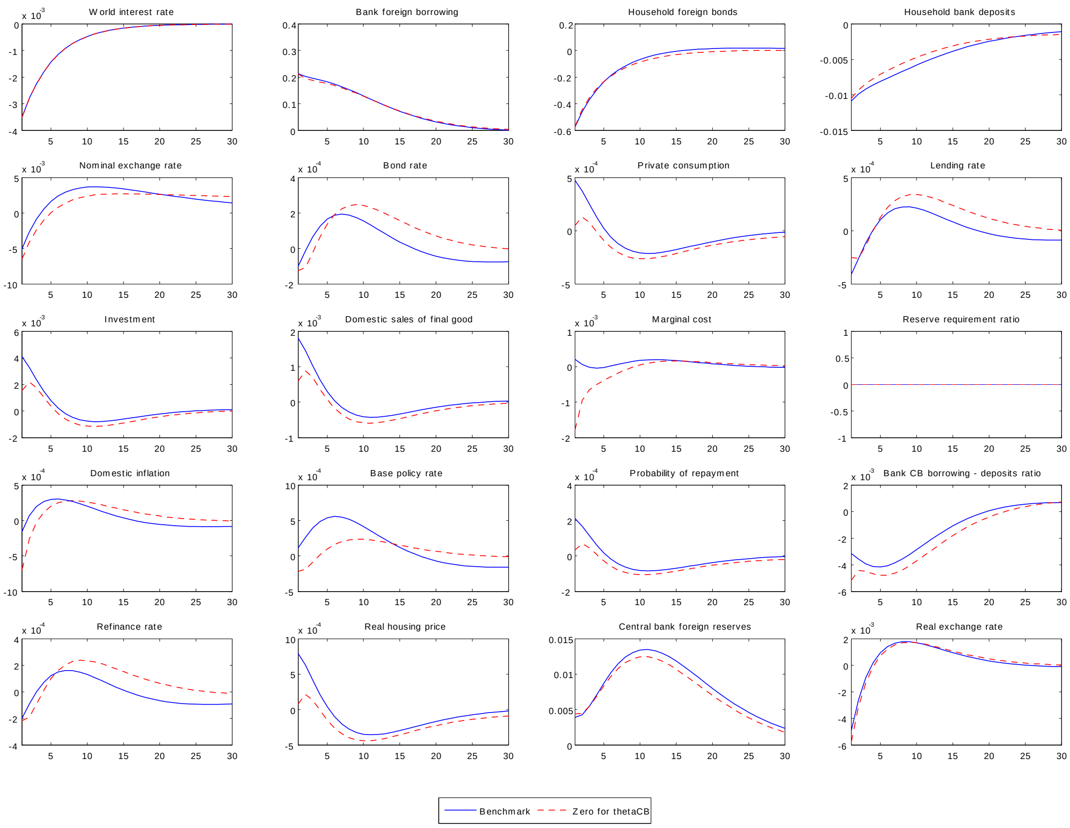


Figure 3

Experiment: Transitory Drop in the World Risk-Free interest Rate

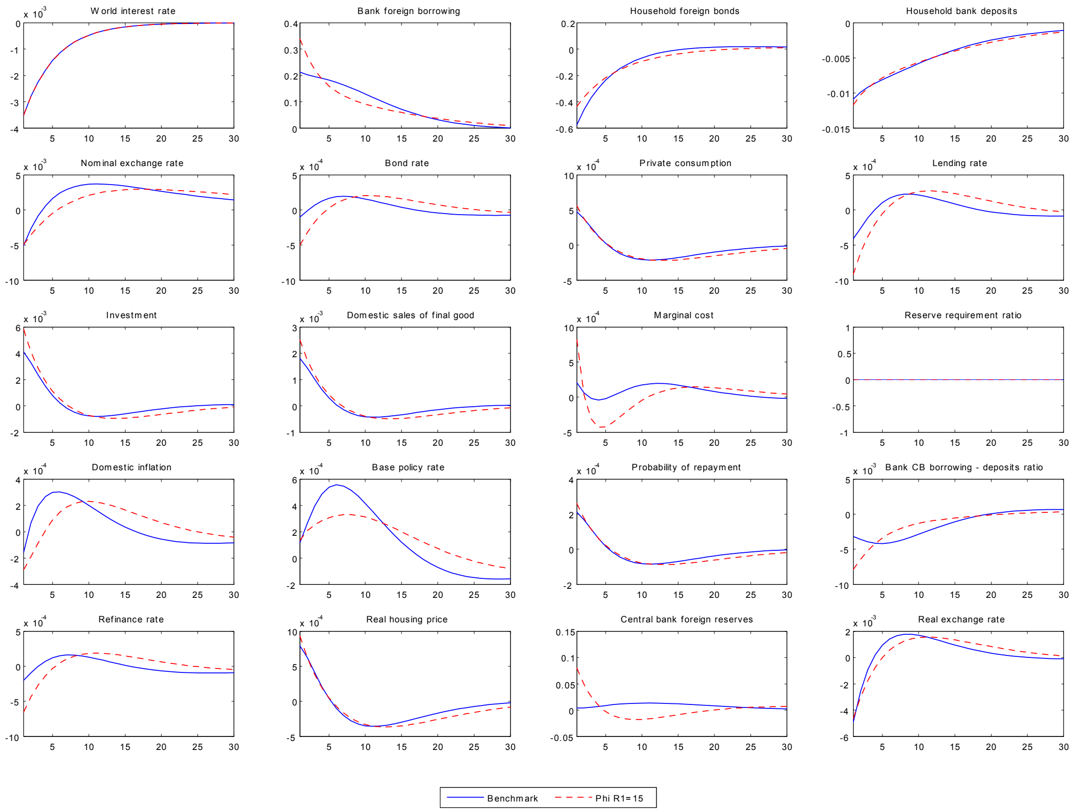
Benchmark Case and Case of Perfect Substitution between Bank Domestic Funding Sources

(Deviations from steady state)



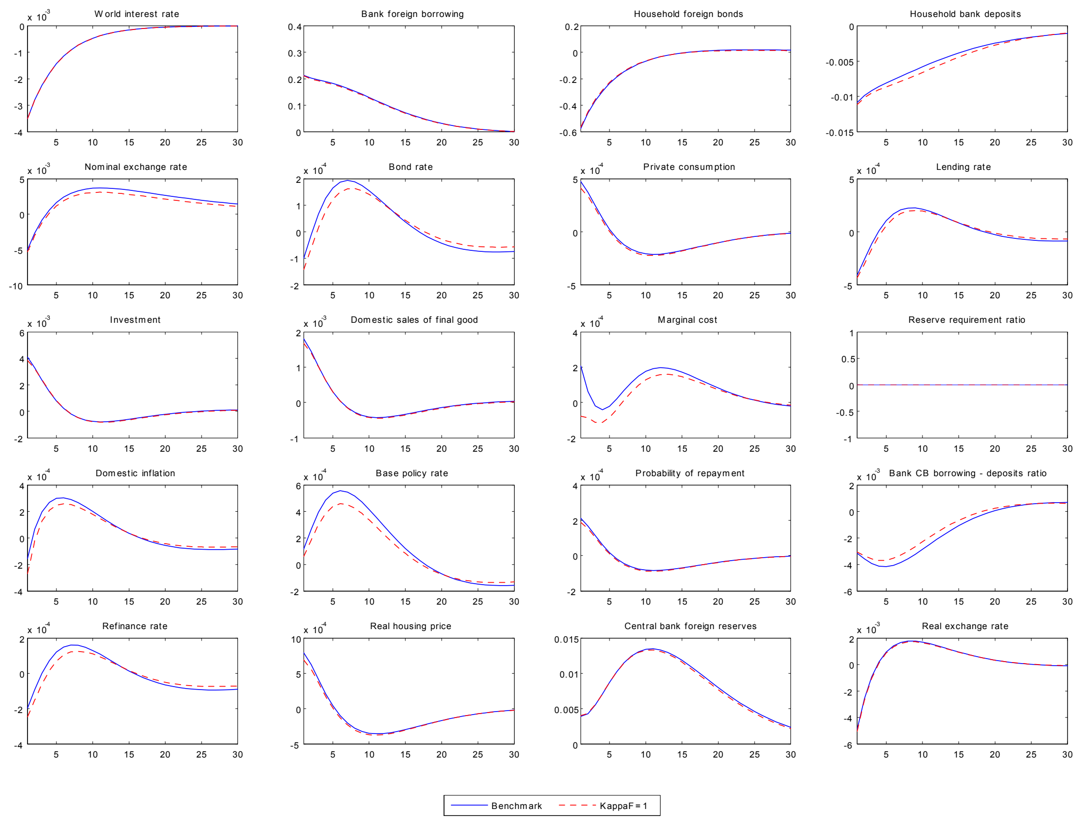
Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms. The real exchange rate is defined as the ratio of the nominal exchange rate divided by the price of domestically-produced final goods sold on the domestic market.

Figure 4
Experiment: Transitory Drop in the World Risk-Free interest Rate
Low and High Intensity of Nominal Exchange Rate Smoothing
(Deviations from steady state)



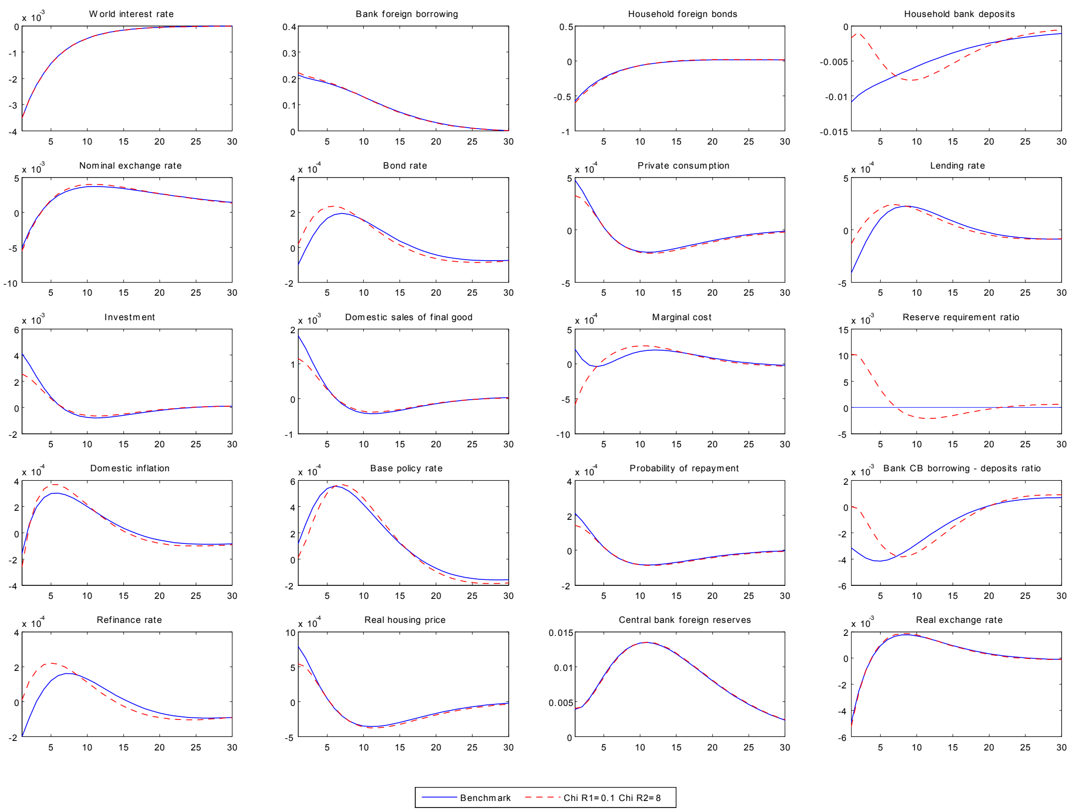
Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms. The real exchange rate is defined as the ratio of the nominal exchange rate divided by the price of domestically-produced final goods sold on the domestic market.

Figure 5
Experiment: Transitory Drop in the World Risk-Free interest Rate
Partial and Full Sterilization of Foreign Exchange Intervention
(Deviations from steady state)



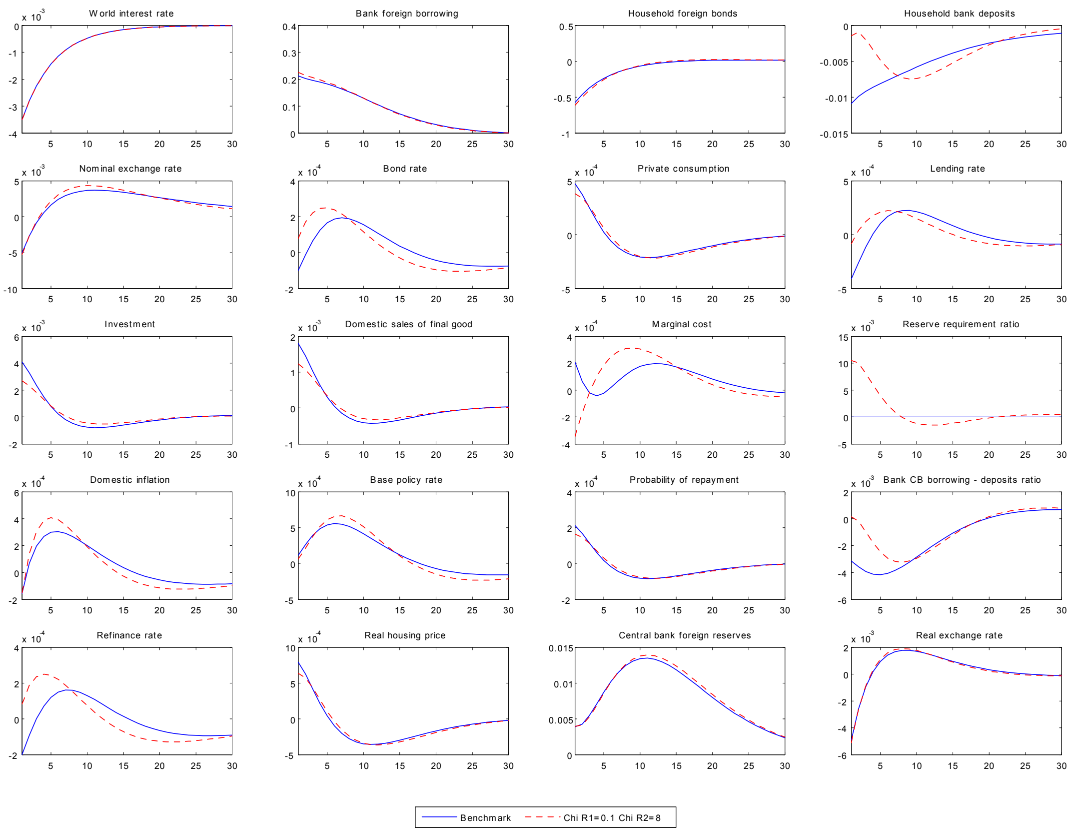
Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms. The real exchange rate is defined as the ratio of the nominal exchange rate divided by the price of domestically-produced final goods sold on the domestic market.

Figure 6
Experiment: Transitory Drop in the World Risk-Free interest Rate
Exogenous and Endogenous Countercyclical Reserve Requirement Rule,
$\chi_1^R = 0.1, \chi_2^R = 8, \theta_0^{CB} = 0.1$
(Deviations from steady state)



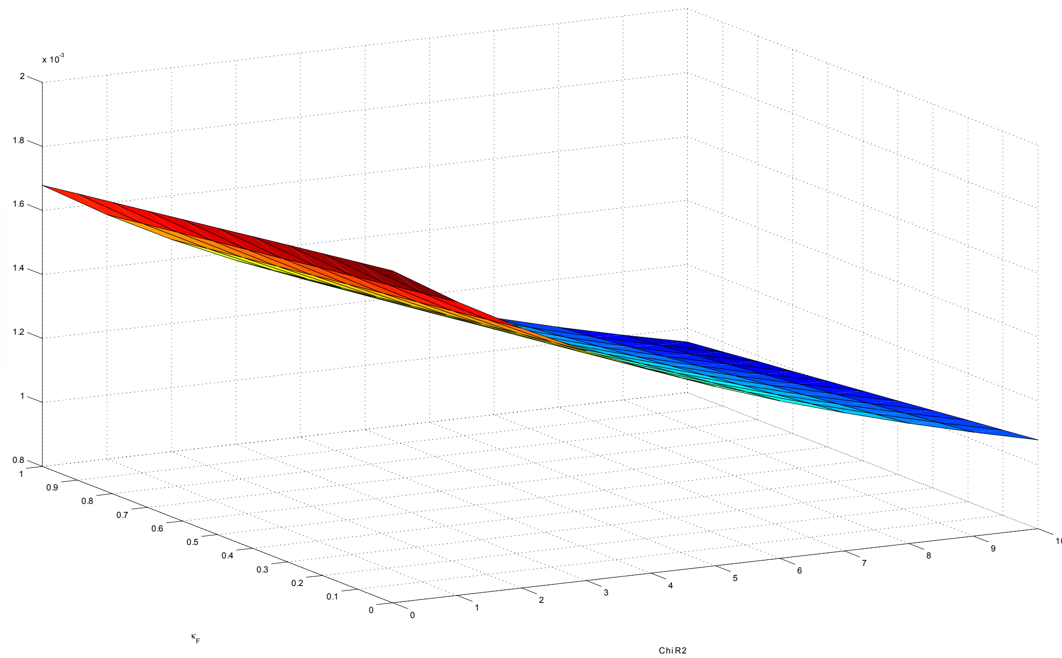
Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms. The real exchange rate is defined as the ratio of the nominal exchange rate divided by the price of domestically-produced final goods sold on the domestic market.

Figure 7
Experiment: Transitory Drop in the World Risk-Free interest Rate
Exogenous and Endogenous Countercyclical Reserve Requirement Rule,
$\chi_1^R = 0.1, \chi_2^R = 8, \theta_0^{CB} = 0.15$
(Deviations from steady state)



Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms. The real exchange rate is defined as the ratio of the nominal exchange rate divided by the price of domestically-produced final goods sold on the domestic market.

Figure 8
Experiment: Transitory Drop in the World Risk-Free Interest Rate Impact Response of Domestic Absorption for Diffferent Values of the Sterilization Coefficient and Aggressiveness of the Countercyclical Reserve Requirement Rule



Note: κ^F is the sterilization coefficient, which varies between 0 and 1, and χ_2^R is a positive parameter that measures the response to credit growth in the countercyclical reserve requirement rule. The vertical axis measures percentage deviations of the first period response of domestic absorption (defined as the sum of private consumption, investment, and government spending) from its steady-state value.

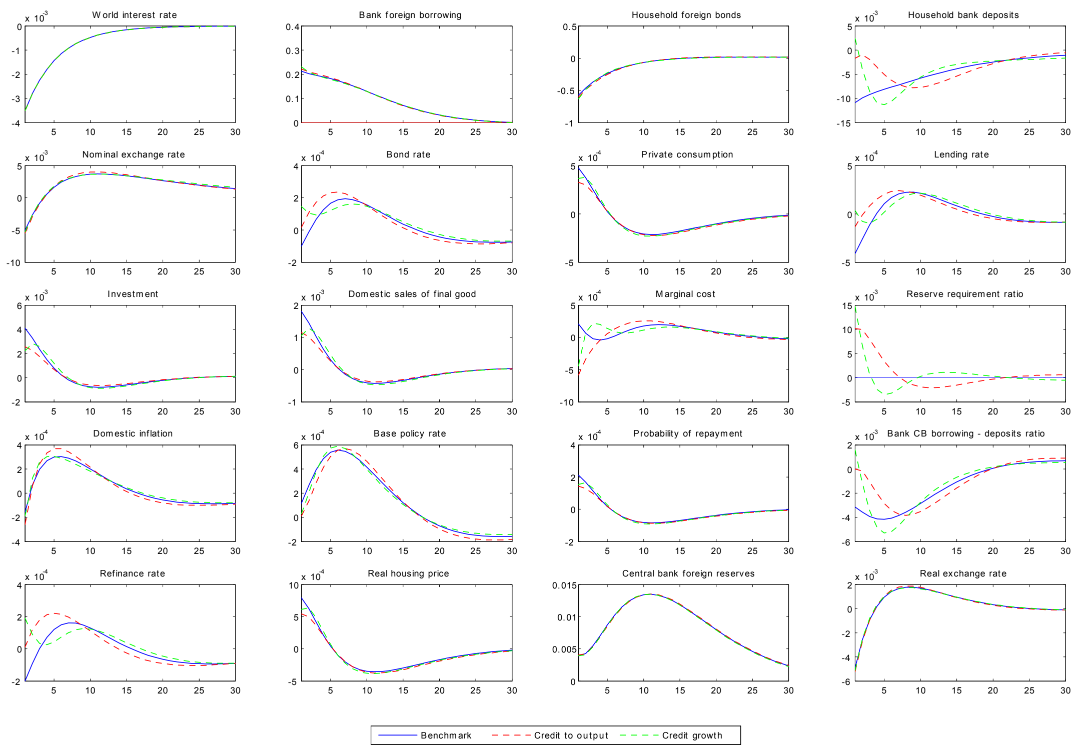
Figure 9

Experiment: Transitory Drop in the World Risk-Free interest Rate

Alternative Endogenous Countercyclical Reserve Requirement Rules,

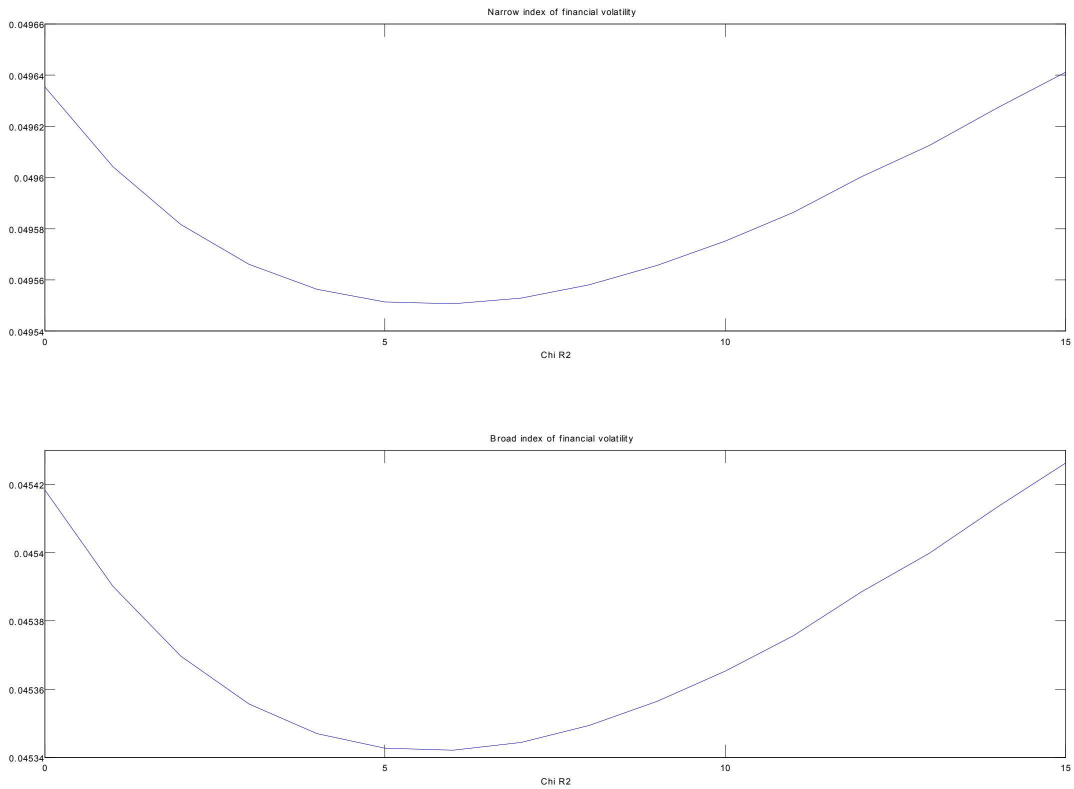
$\chi_1^R = 0.1, \chi_2^R = 8, \theta_0^{CB} = 0.1$

(Deviations from steady state)



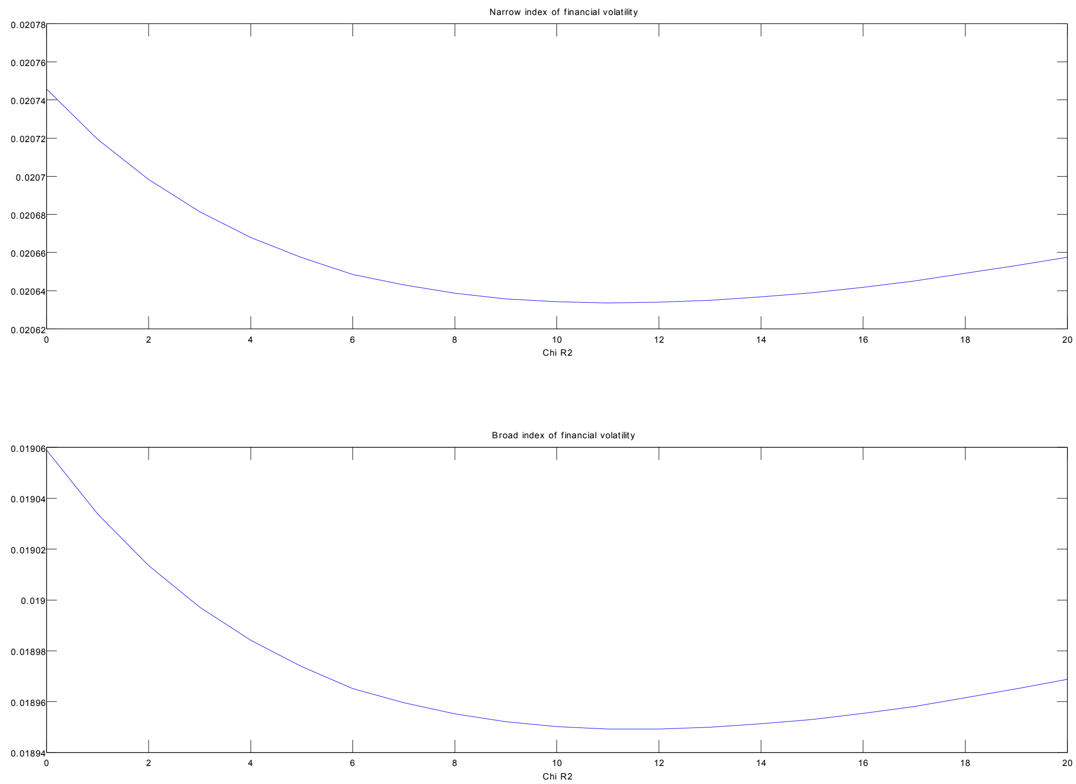
Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms. The real exchange rate is defined as the ratio of the nominal exchange rate divided by the price of domestically-produced final goods sold on the domestic market.

Figure 10
Index of Economic Volatility and Aggressiveness of the Countercyclical of the Reserve Requirement Rule Equal Weights of 0.5 to Macro and Financial Volatility



Note: χ_2^R is a positive parameter that measures the response to credit growth in the countercyclical reserve requirement rule. The vertical axis measures economic volatility, in terms of a composite index of macroeconomic volatility and a composite index of financial volatility, both narrow and broad, as defined in the text.

Figure 11
Index of Economic Volatility and Aggressiveness of the Countercyclical of the Reserve Requirement
Rule Weight of 0.8 to Macro, 0.2 to Financial Volatility



Note: χ_2^R is a positive parameter that measures the response to credit growth in the countercyclical reserve requirement rule. The vertical axis measures economic volatility, in terms of a composite index of macroeconomic volatility and a composite index of financial volatility, both narrow and broad, as defined in the text.

Figure 12
Index of Economic Stability (Equal Weights)
with Narrow index of Financial Stability
and for Alternative Values of Exchange Rate Smoothing