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Abstract

This paper studies the effects of sterilized foreign exchange market intervention in an open-economy model with financial frictions and imperfect capital mobility. The central bank operates a managed float regime and issues sterilization bonds that are imperfect substitutes (as a result of economies of scope) to investment loans in bank portfolios. Sterilized intervention can be expansionary through a bank portfolio effect and may therefore raise financial stability risks. The model is parameterized and used to study the macroeconomic effects of, and policy responses to, capital inflows associated with a transitory shock to world interest rates. The results show that the optimal degree of exchange market intervention is more aggressive when the central bank can choose simultaneously the degree of sterilization; in that sense, the instruments are complements. At the same time, the presence of the bank portfolio effect implies that full sterilization is not optimal. By contrast, when the central bank's objective function depends on the cost of sterilization, in addition to household welfare, intervention and sterilization are (partial) substitutes—independently of whether exchange rate and financial stability considerations also matter.

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1 Introduction

Studies focusing on the evolution of exchange rate regimes during the past two decades have confirmed that managed floats remain the norm in middle-income countries—even among those that have adopted inflation targeting (IT) as their monetary policy framework. As documented by Frankel (2019) and Ilzetzki et al. (2019), for instance, in many of these countries central banks consistently react to foreign exchange market pressure not only with some degree of exchange rate flexibility but also with frequent intervention. Moreover, there is evidence that the *fear of floating*, and the decision to intervene, is increasingly driven by the goal of limiting exchange rate volatility, rather than concerns about competitiveness, the degree of exchange rate pass-through, currency and maturity mismatches, or the need to build foreign reserves for precautionary reasons. Adler and Tovar (2014), for instance, surveyed intervention motives in 15 economies in Latin America between 2004 and 2010. They found that, in addition to building reserves for self-insurance purposes, reducing excessive currency volatility is typically the main stated motive for foreign exchange market intervention—even though no specific level of the exchange rate is targeted. These results are confirmed in a more recent survey by the Bank for International Settlements, as discussed by Patel and Cavallino (2019), and the econometric analysis of Arslan and Cantú (2019).

One reason for greater concern with exchange rate volatility—beyond its adverse effect on price stability, in countries where openness to trade is high—is the existence of a financial channel, which may amplify the effect of currency fluctuations induced by external shocks.[1] For instance, by lowering the real cost of foreign borrowing (measured in domestic-currency terms) faced by local banks, an exchange rate appreciation may ease domestic credit conditions and lead to an expansion in aggregate demand, in addition to any positive wealth effect associated with downward pressure on domestic prices. If the financial channel is strong relative to the conventional (relative price) trade channel, domestic output may expand in response to a nominal appreciation. Thus, monetary policy may face a conflict between price and output stability. Moreover, if the expansion of domestic credit contributes to a build-up of vulnerabilities, which could put financial stability at risk if a sudden reversal in capital flows were to occur in the future, miti-

[1] For a more detailed discussion of the financial channel—sometimes also referred to as the risk-taking channel—see Shin (2015), Bruno and Shin (2015), Akinci and Queralto (2019), and Carstens (2019). Kearns and Patel (2016) and Georgiadis and Zhu (2019) provided some relevant empirical evidence.

gating exchange rate volatility through intervention becomes a key policy concern from a macroprudential perspective.

The evidence also suggests that, in practice, in both IT and non-IT countries, intervention has often been highly sterilized to avoid broader macroeconomic effects. For instance, when intervention takes place through spot operations and is unsterilized, a purchase of foreign exchange to prevent an appreciation translates into an expansion of the money supply. The opportunity cost of money (say, the government bond rate) must fall to raise demand and maintain market equilibrium. If prices are sticky, the real bond rate also falls, thereby inducing households to increase current consumption through intertemporal substitution. In turn, this expansionary effect will tend to raise prices over time.[2] In principle, sterilized intervention shuts down that channel, by neutralizing in the first place the expansion in liquidity and preventing changes in domestic interest rates.

There is substantial evidence to suggest that sterilized intervention through spot markets for foreign exchange has been fairly effective in terms of stabilizing the exchange rate, as documented by Aizenman and Glick (2009), Vujanovic (2011), Palma and Portugal (2014) for Brazil, Blanchard et al. (2015), Daude et al. (2016), Ghosh et al. (2017), Kuersteiner et al. (2018), and Fratzscher et al. (2019).[3] However, it is also well recognized that, even when sterilized, foreign exchange intervention can magnify macroeconomic fluctuations and (especially if foreign-currency risk is not fully hedged) adversely affect financial stability. The standard argument is that if domestic and foreign currency-denominated assets are imperfect substitutes, central bank intervention changes the relative supply of these assets. As a result, and even if sterilization succeeds in neutralizing the domestic monetary expansion associated with intervention, changes in portfolio compositions will affect domestic interest rates. Through this portfolio channel, and associated wealth and expenditure effects, sterilized intervention may affect not only the exchange rate but also credit flows, aggregate demand, and prices. In particular, through its effects on relative rates of return, sterilization may entail changes in the composition of bank portfolios; in turn, these changes may affect directly the supply of

[2]As can be inferred from our analysis, foreign exchange intervention itself may trigger more capital flows if it creates expectations of exchange rate appreciation. In turn, these capital flows can fuel credit growth and further stimulate spending.

[3]See also the summary by Villamizar-Villegas and Perez-Reyna (2017, Appendix B) and the discussion in Agénor and Pereira da Silva (2019).

loans and investment. Thus, even when fully sterilized, foreign exchange intervention may have broader macroeconomic consequences. The implication is that central banks may have another reason to be concerned when conducting foreign exchange sterilized interventions, besides their cost and their effectiveness (or lack thereof) in preventing nominal appreciation. Indeed, even if sterilized purchases are effective in preventing *nominal* exchange rate appreciation, they may stimulate credit and activity while raising inflation—thereby contribution to a *real* appreciation—with possible adverse effects on macroeconomic and financial stability.

Yet, the bank portfolio or financial sector balance sheet effects of foreign exchange intervention have received only limited attention in academic and policy discussions about financial stability and its interactions with macroeconomic stability.[4] Garcia (2012), for instance, argued that, in the presence of a credit channel, sterilized foreign exchange purchases may raise aggregate demand by creating an incentive for a further expansion of bank credit. Thus, sterilized intervention can be expansionary—even when it does not contribute to mitigating an exchange rate appreciation. In a more elaborate model, Vargas et al. (2013) reached similar conclusions. In a model where domestic banks are subject to occasionally binding collateral constraints, Chang (2019) also found that sterilized intervention can be expansionary—although this occurs because it contributes to weakening external debt limits, rather than through a direct portfolio allocation effect. However, none of these papers considers explicitly the implications of financial stability considerations for the joint optimal determination of foreign exchange market intervention and sterilization, in a context where the central bank may be explicitly concerned with exchange rate and financial stability.

This paper addresses these issues in an open-economy DSGE model with banking and imperfect capital mobility. In the model, the central bank operates a managed float regime and follows a simple foreign exchange intervention rule that relates changes in its stock of foreign reserves to exchange rate movements. It also conducts sterilization operations by issuing bonds held by commercial banks. Because of economies of scope in managing bank assets, these bonds exhibit cost complementarity with investment

[4] Some recent contributions have focused on the use of microeconomic data to study the effects of foreign exchange intervention. In a study of Colombia for instance, Hofmann et al. (2019) found that sterilized intervention aimed at mitigating exchange rate appreciation tends to *dampen* domestic credit growth. Our model can replicate this outcome if there are diseconomies of scope in banking—even though this assumption is not well supported by the evidence. As discussed later on, our focus is on the case where sterilized intervention creates risks to financial stability by inducing a credit expansion.

loans. The model is parameterized for a middle-income country and is used to study the impact of capital inflows associated with a transitory shock to the world risk-free interest rate. Most importantly, the analysis assumes that when setting foreign exchange market intervention and sterilization policies the central bank may be explicitly concerned not only with maximizing household welfare but also with the cost of sterilization—possibly because it affects perceptions of independence and credibility—and financial stability considerations.

Our main results can be summarized as follows. First, the balance sheet effects associated with sterilized foreign exchange intervention are more involved than previously considered in the literature. Whether sterilized intervention is expansionary or not depends on both the strength of the bank portfolio effect (which affects borrowing costs) and the stance of monetary policy. Second, the optimal degrees of exchange rate smoothing and sterilization depend on the central bank's objectives. When the central bank aims solely to maximize household welfare, sterilized intervention generates sizable gains—both relative to free floating and unsterilized intervention. Moreover, the optimal degree of exchange market intervention is significantly more aggressive when the central bank can choose simultaneously the degree of sterilization. In that sense, intervention and sterilization are complements. However, the presence of the bank portfolio effect implies that full sterilization is not optimal. Intuitively, the reason is that sterilized intervention can affect macroeconomic and financial volatility through two separate channels: the first, and more conventional one, operates through its impact on liquidity, bond rates, and intertemporal substitution in consumption, as described earlier. The second operates through changes in the composition of banks' assets and the possible expansionary effect associated with portfolio reallocation, when the degree of substitutability between bonds and loans is sufficiently strong. While the first channel helps to mitigate volatility, the latter tends to amplify it. The existence of this trade-off implies that full sterilization is not optimal—even when the central bank is also concerned (in addition to household welfare) with exchange rate or financial volatility explicitly. At the same time, the central banks intervenes more aggressively when it can choose simultaneously the degree of sterilization; in that sense, the instruments are complements. By contrast, when sterilization costs are also accounted for in the central bank's objective function—regardless of whether exchange rate and financial stability concerns are accounted for—the central bank intervenes less and sterilizes more aggressively. Full sterilization is in fact optimal when the objective function is defined in terms of household welfare only, or jointly with financial volatility. The reason is that for a given degree of sterilization, less aggressive intervention weakens the bank portfolio effect; as a result, the central bank can sterilize more aggressively. In that sense, there is *burden sharing* between instruments, and intervention and sterilization are (partial) substitutes.

The remainder of the paper is organized as follows. Section 2 describes the model. In line with some other analytical contributions, including Vargas et al. (2013), Benes et al. (2015), Chang et al. (2015), Montoro and Ortiz (2016), Alla et al. (2019), and consistent with what has become common practice in middle-income countries (see, for instance, Gadanecz et al. (2014))), we assume that the central bank issues its own interest-bearing liabilities for sterilization purposes. Unlike some of these models, however, these debt instruments are held by commercial banks only, and are imperfect substitutes to loans.[5] Sterilized intervention changes banks' relative holdings of central bank liabilities and therefore affects the exchange rate both directly and indirectly. Section 3 discusses the equilibrium conditions and steady-state solution of the model, whereas Section 4 outlines its parameterization. Section 5 considers briefly the impact of a drop in the world risk-free interest rate (viewed as a key driver of capital inflows) and discusses macroeconomic responses under sterilized and unsterilized intervention. Optimal policy (both in terms of the degree of exchange rate smoothing and the degree of sterilization) is studied in Section 6, under three specifications of the central bank's objective function: the benchmark case where it maximizes the welfare of the representative household, the case where it is also concerned with the cost of sterilization (because, as noted earlier, it affects its perceived degree of independence and credibility), and the case where financial stability considerations also matter. Section 6 considers alternative assumptions regarding the formation of exchange rate expectations. The concluding section discusses some possible extensions of the analysis.

[5] In practice, sterilization operations can be conducted with any type of public sector liabilities. Our focus on instruments issued directly by the central bank, and held only by commercial banks, allows us to consider separately the behavior of the rates of return on government bonds and sterilization bonds, and to provide a direct link between the portfolio channel and the balance sheet effects associated with sterilization.

2 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, which also operates as a financial regulator. For simplicity, each household is matched to an IG producer, a CG producer, and a bank, and receives profits (if any) from all of them. The country produces a continuum of intermediate goods, which are imperfect substitutes to a continuum of imported intermediate goods. Both categories of goods are combined to produce a homogeneous final good, which is used for either domestic consumption and investment, or exported. The central bank conducts monetary policy through a standing facility and operates a managed float regime. To stabilize the exchange rate it intervenes on the spot market for foreign exchange. Intervention can be either sterilized or unsterilized; in the former case, the central bank issues its own bonds, which are held by domestic commercial banks only. Importantly, these bonds are imperfect substitutes to loans.

In what follows we describe the behavior of households, commercial banks, and the central bank. The production structure is fairly standard, and so is the description of the government; accordingly, details for these sectors are provided in Appendix A.

2.1 Households

The objective of the representative household is to maximize

$$U_t = \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s \left\{ \frac{C_{t+s}^{1-\varsigma^{-1}}}{1-\varsigma^{-1}} - \int_0^1 \frac{\eta_N (N_{t+s}^j)^{1+\psi_N}}{1+\psi_N} dj + \ln x_{t+s}^{\eta_x} H_{t+s}^{\eta_H} \right\}, \tag{1}$$

where C_t is final good consumption, N_t^j time allocated to IG firm j, x_t a composite index of real monetary assets, H_t the stock of housing, which produces shelter services, $\Lambda \in (0,1)$ a discount factor, $\varsigma > 0$ the intertemporal elasticity of substitution in consumption, $\psi_N > 0$ the inverse of the Frisch elasticity of labor supply, $\mathbb{E}_t$ is the expectation operator conditional on the information available at the beginning of period t, and $\eta_N, \eta_x, \eta_H > 0$ preference parameters.

The composite monetary asset consists of real cash balances, m_t, and real bank deposits, d_t, both measured in terms of the price of final output, P_t:[6]

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

where $\nu \in (0,1)$.

The household's flow budget constraint is

$$m_t + d_t + b_t + z_t B_t^F + p_t^H \Delta H_t \tag{3}$$

$$= \omega_t N_t - T_t - C_t + \frac{m_{t-1}}{1+\pi_t} + (\frac{1+i_{t-1}^D}{1+\pi_t})d_{t-1} + (\frac{1+i_{t-1}^B}{1+\pi_t})b_{t-1}$$

$$+(1+i_{t-1}^{FB})z_t B_{t-1}^F + J_t^D + J_t^K + J_t^B,$$

where $z_t = E_t/P_t$ is the real exchange rate (with E_t denoting the nominal exchange rate), $p_t^H = P_t^H/P_t$ the real price of housing, $1+\pi_t = P_t/P_{t-1}$, b_t (B_t^F) 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^{FB} interest rates on domestic and foreign government bonds, respectively, ω_t the real wage, T_t real lump-sum taxes, $J_t^D = \int_0^1 (P_{jt}^D J_{jt}^D/P_t)dj$, J_t^K, and J_t^B end-of-period profits (if any) of the matched IG producer, CG producer, and commercial bank, respectively. Housing does not depreciate and domestic government bonds are held only at home.

The gross rate of return on foreign bonds is defined as

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

where i_t^W is the risk-free world interest rate and θ_t^{FB} a financial intermediation cost (which may also reflect official restrictions on cross-border financial restrictions), defined as

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

with $\theta_0^{FB} > 0$. Thus, the cost of acquiring foreign bonds is increasing in the amount of bonds held.[7]

The representative household chooses sequences of consumption, $\{C_{t+s}\}_{s=0}^{\infty}$, labor, $\{N_{t+s}^j\}_{s=0}^{\infty}$, $j \in (0,1)$, cash, $\{m_{t+s}\}_{s=0}^{\infty}$, deposits, $\{d_{t+s}\}_{s=0}^{\infty}$, domestic and foreign bonds,

[6] Both deposits and cash are accounted for because in this model the domestic bond rate is solved from the equilibrium condition of the market for cash.

[7] Gabaix and Maggiori (2015) and Cavallino (2019) developed more elaborate micro-founded models of the foreign exchange market in the presence of financial frictions. In these models, intermediaries are credit constrained, as creditors recognize the possibility that financiers may divert funds.

$\{b_{t+s}, B^F_{t+s}\}^{\infty}_{s=0}$, and housing services, $\{H_{t+s}\}^{\infty}_{s=0}$, so as to maximize (1) subject to (2) to (5), taking the path of domestic interest rates (i^B_t and i^D_t), the world risk-free rate (i^W_t), wages, prices, and inflation (ω_t, p^H_t, and π_t) and all lump-sum transfers and taxes (J^B_t, J^I_t, J^K_t, and T_t), as given. The first-order conditions are

$$C_t^{-1/\varsigma} = \Lambda \mathbb{E}_t \left\{ C_{t+1}^{-1/\varsigma} (\frac{1+i^B_t}{1+\pi_{t+1}}) \right\}, \tag{6}$$

$$N^j_t = (\frac{\omega_t C_t^{-1/\varsigma}}{\eta_N})^{1/\psi_N}, \quad \forall j \in (0,1), \tag{7}$$

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

$$d_t = \frac{\eta_x (1-\nu) C_t^{1/\varsigma}(1+i^B_t)}{i^B_t - i^D_t}, \tag{9}$$

$$\frac{z^H_t}{C_t^{1/\varsigma}} = \frac{\eta_H}{H_t} + \Lambda \mathbb{E}_t (\frac{z^H_{t+1}}{C_{t+1}^{1/\varsigma}}), \tag{10}$$

$$B^{FP}_t \simeq \frac{(1+i^W_t)\mathbb{E}_t(E_{t+1}/E_t) - (1+i^B_t)}{\theta^{FP}_0 (1+i^W_t)\mathbb{E}_t(E_{t+1}/E_t)}. \tag{11}$$

Equation (6) is the Euler equation, whereas (7) to (9) define labor supply and the demand functions for cash and deposits. Equation (10) is the intertemporal condition for housing, whereas (11) yields uncovered interest parity when $\theta^{FB}_0 \to 0$.[8]

2.2 Commercial Banks

Banks lend to CG producers and hold reserves and central bank bonds as assets, whereas their liabilities consist of deposits, domestic borrowing, and (unhedged) foreign borrowing. Thus, bank i's balance sheet is

$$l^{K,i}_t + b^{CB,i}_t + RR^i_t = d^i_t + z_t L^{FB,i}_t + l^{B,i}_t, \tag{12}$$

where $l^{K,i}_t$ represents investment loans, $b^{CB,i}_t$ holdings of sterilization bonds issued by the central bank, $L^{FB,i}_t$ foreign borrowing (in foreign-currency terms), $l^{B,i}_t$ borrowing from the monetary authority, and RR^i_t required reserves, which do not pay interest and are set as a fraction $\mu \in (0,1)$ of deposits:

$$RR^i_t = \mu d^i_t. \tag{13}$$

[8] In deriving equation (11), covariance terms are ignored for simplicity. This equation is therefore only an approximation.

The market for deposits is competitive, and deposits and central bank liquidity are perfect substitutes. This ensures therefore that, $\forall i$, the following no-arbitrage condition holds:

$$i_t^{D,i} = (1-\mu)i_t^R. \tag{14}$$

By contrast, monopolistic competition prevails in the loan market. As discussed in Appendix A, the amount borrowed by the representative capital good producer, l_t^K, is a Dixit-Stiglitz basket of differentiated loans, each supplied by a bank i, with an elasticity of substitution $\zeta^L > 1$:

$$l_t^K = [\int_0^1 (l_t^{K,i})^{(\zeta^L-1)/\zeta} di]^{\zeta^L/(\zeta^L-1)}.$$

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

$$l_t^{K,i} = (\frac{1+i_t^{L,i}}{1+i_t^L})^{-\zeta^L} l_t^K, \tag{15}$$

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

Bank i's cost of borrowing on world capital markets, $i_t^{FC,i}$, is defined as

$$1 + i_t^{FC,i} = (1+i_t^W)(1+\theta_t^{FC,i}), \tag{16}$$

where $\theta_t^{FC,i}$ is a premium that increases with the foreign-currency value of the amount borrowed:

$$\theta_t^{FC,i} = \frac{\theta_0^{FC}}{2} L_t^{FC,i}, \tag{17}$$

where $\theta_0^{FC} > 0$.

Bank i's expected profits at end of period t (or beginning of $t+1$) are defined as

$$\mathbb{E}_t J_{t+1}^{B,i} = q_t^i(1+i_t^{L,i})l_t^{K,i} + (1-q_t^i)\kappa^i \mathbb{E}_t p_{t+1}^H H_t + (1+i_t^{CB})b_t^{CB,i} \tag{18}$$

$$+\mu d_t^i - (1+i_t^{D,i})d_t^i - (1+i_t^R)l_t^{B,i} - (1+i_t^{FB,i})\mathbb{E}_t(\frac{E_{t+1}}{E_t})z_t L_t^{FB,i} - \Gamma(l_t^{K,i}, b_t^{CB,i}),$$

where i_t^R is the marginal cost of borrowing from the central bank, or equivalently the refinance rate, and i_t^{CB} the interest rate on central bank bonds. Equation (18) defines expected profits as the difference between expected bank revenues, given by the sum of repayments on investment loans if there is no default, $q_t^i(1+i_t^{L,i})l_t^{K,i}$, the expected value of collateral seized in case of default, $(1-q_t^i)\left(\kappa^i \mathbb{E}_t p_{t+1}^H H_t\right)$, augmented by the income from holdings of central bank bonds and the value of reserves held at the central bank,

μd_t^i, and bank expenses, given by the sum of interest payments on deposits, $(1+i_t^{D,i})d_t^i$, central bank borrowing, $(1+i_t^R)l_t^{B,i}$, and foreign borrowing, $(1+i_t^{FB,i})\mathbb{E}_t(E_{t+1}/E_t)z_t L_t^{FB,i}$, with the latter accounting for expected depreciation.

The term $\Gamma(l_t^{K,i}, b_t^{CB,i})$ measures the nonseparable cost of managing loans and central bank bonds. Specifically, the function $\Gamma(l_t^{K,i}, b_t^{CB,i})$ is assumed to be strictly increasing and quasi-convex in its two arguments, so that $\Gamma_{l^K}, \Gamma_{b^{CB}} > 0$, $\Gamma_{l^K l^K}, \Gamma_{b^{CB} b^{CB}} \geq 0$; in addition, it is also assumed to be linearly homogeneous. By implication of linear homogeneity, $\Gamma_{l^K b^{CB}} \leq 0$, that is, higher holdings of central bank bonds lowers the cost of lending. There is therefore cost complementarity or economies of scope, that is, lower costs of managing assets than the sum of costs incurred when managing them individually.

In what follows, we will focus on the case where $\Gamma()$ can be represented by the Diewert cost function:

$$\Gamma(l_t^{K,i}, b_t^{CB,i}) = \gamma_B b_t^{CB,i} + \gamma_L l_t^{K,i} - 2\gamma\sqrt{b_t^{CB,i} l_t^{K,i}}, \tag{19}$$

where $\gamma_B, \gamma_L, \gamma > 0$.[9]

Each bank determines the lending rate, foreign borrowing, the intensity of monitoring, and holdings of central bank bonds, so as to maximize expected profits (18) subject to (12)-(17) and (19). Assuming that monitoring effort is related one-to-one with the repayment probability—a common specification in the banking literature, as, for instance, in Dell'Ariccia et al. (2014) and Cordella et al. (2018)—and that (unit) monitoring costs are countercyclical, the solution of the bank's optimization problem in a symmetric equilibrium is shown in Appendix B to be

$$1 + i_t^L = \frac{\zeta^L}{(\zeta^L - 1)q_t}\left\{1 + i_t^R + \gamma_L - \gamma(\frac{b_t^{CB}}{l_t^K})^{0.5}\right\}, \tag{20}$$

$$L_t^{FB} = \frac{(1+i_t^R) - (1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}{\theta_0^{FB}(1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}, \tag{21}$$

$$q_t = \varphi_0(\frac{\kappa \mathbb{E}_t p_{t+1}^H/\tilde{p}^H}{l_t^K/\tilde{l}^K})^{\varphi_1}(\frac{Y_t}{\tilde{Y}})^{\varphi_2}, \tag{22}$$

$$\frac{b_t^{CB}}{l_t^K} = \frac{\gamma^2}{(i_t^R + \gamma_B - i_t^{CB})^2}, \tag{23}$$

[9] See Vargas et al. (2013) and Agénor and Pereira da Silva (2017). An alternative specification, which has essentially the same properties as (19) and generalizes the functional form suggested by Edwards and Végh (1997, footnote 14), is $\Gamma(l_t^{K,i}, b_t^{CB,i}) = \sqrt{\gamma_B(b_t^{CB,i})^2 + \gamma_L(l_t^{K,i})^2}$, where $\gamma_B, \gamma_L > 0$.

where $\varphi_1, \varphi_2 > 0$ and $\tilde{Y}$ is the steady-state level of final output. Thus, the repayment probability depends positively on the expected value of collateral relative to the volume of loans and the cyclical position of the economy, whereas the ratio of central bank bonds over investment loans varies inversely with the differential between the refinance rate (augmented with the cost parameter γ_B) and the rate of return on these bonds.

Substituting equation (23) in (20) yields

$$1 + i_t^L = \frac{\zeta^L}{(\zeta^L - 1)q_t} \left\{ 1 + i_t^R + \gamma_L - \frac{\gamma^2}{i_t^R + \gamma_B - i_t^{CB}} \right\}, \tag{24}$$

which shows that an increase in the refinance rate has both a direct (cost) effect and an indirect (portfolio) effect on the loan rate. More importantly for the issue at stake, equations (20), (23) and (24) help to illustrate the partial equilibrium, bank portfolio channel associated with sterilized intervention. At the initial level of investment loans, an increase in holdings of central bank bonds by commercial banks raises the bond-loan ratio. All else equal, this tends to reduce the cost of managing loans (as implied by (20)) and to lower the loan rate, which is therefore expansionary. Alternatively, for banks to willingly hold the additional bonds issued by the central bank requires (as implied by (23)) an increase on their rate of return and (as implied by (24)) a lower rate of return on alternative assets—in the present case, loans to CG producers.

However, the general equilibrium effect of a lower loan rate is to increase investment, which tends now to *reduce* the bond-loan ratio and to mitigate the direct effect. In addition, policy responses also matter: if the increase in investment raises aggregate demand and inflationary pressures, the refinance rate will increase (as shown below in equation (31)), which may also dampen the initial downward effect on the loan rate. Whether the net effect on the loan rate is positive or not cannot be ascertained a priori. Put differently, as long as the cost function defined in (19) is not linear (that is, $\gamma > 0$), in general equilibrium the bank portfolio (or balance sheet) channel may be associated with either an expansionary or a contractionary effect on output. Which effect dominates is therefore an empirical matter. This issue is further explored numerically in the next sections.

2.3 Central Bank

As noted earlier, the central bank supplies liquidity to commercial banks through a standing facility. It also operates a managed float regime and engages in sterilized intervention. Its balance sheet is given by

$$z_t R_t^F + l_t^B = m_t^s + b_t^{CB} + RR_t + nw_t, \tag{25}$$

where R_t^F denotes international reserves (measured in foreign-currency terms), m_t^s the supply of cash, b_t^{CB} bond liabilities, and nw_t the central bank's net worth.

Changes in foreign reserves are given by the symmetric rule

$$R_t^F = (R_{t-1}^F)^{\varphi_1^R}[R_m^F(\frac{E_t}{E_t^T})^{-\varphi_2^R}]^{1-\varphi_1^R}, \tag{26}$$

where $R_m^F > 0$ is an exogenous lower bound on official reserves, $\varphi_1^R \in (0,1)$ is the degree of persistence and $\varphi_2^R \geq 0$ the degree of exchange rate smoothing with respect to the target exchange rate, E_t^T, which is defined as

$$E_t^T = E_{t-1}^{\varphi^E}\tilde{E}^{1-\varphi^E}, \tag{27}$$

where $\varphi^E \in (0,1) > 0$ and $\tilde{E}$ is the steady-state value of the nominal exchange rate, which is determined (as discussed later) so as to ensure a zero current account balance. Thus, as discussed by Chutasripanich and Yetman (2015), for instance, the intervention rule combines two motives that are common in practice: leaning against exchange rate misalignment (given that in our calibration the steady-state exchange rate ensures current account equilibrium), and *leaning against the wind*. With $\varphi^E = 1$, rule (26) is similar to the rule specified in Devereux and Yetman (2014) and Benes et al. (2015), for instance. It is consistent with the evidence (referred to earlier) that MICs tend to intervene frequently and systematically in the foreign exchange market to stabilize currency fluctuations—even under an inflation targeting regime, where in principle the exchange rate should be allowed to float freely to avoid calling into question the preeminence and credibility of the inflation target. A current nominal depreciation, for instance, for a given target exchange rate, induces the central bank to sell foreign currency in the market for foreign exchange to strengthen the domestic currency. As a result, its stock of reserves falls. In the particular case where $\varphi_1^R = 1$, the stock of reserves remains constant over time and the exchange rate is fully flexible.

The central bank has no access to lump-sum taxes and adjusts its stock of bonds to sterilize the effects of its foreign exchange operations on the supply of cash:

$$b_t^{CB} - \frac{b_{t-1}^{CB}}{1+\pi_t} = \kappa^F z_t \Delta R_t^F, \tag{28}$$

where $\kappa^F \in (0,1)$ measures the degree of sterilization.[10]

[10]Unsterilized intervention corresponds therefore to $\kappa^F = 0$.

The interest income earned by the central bank is transferred in its entirety to the government. Thus, changes in the nominal value of the central bank's net worth, NW_t, depend only on capital gains associated with exchange rate depreciation only ($\Delta NW_t = \Delta E_t R_t^F$). Using this result, taking first differences of (25) expressed in nominal terms and substituting (28) in the resulting expression yields[11]

$$m_t^s = \frac{m_{t-1}^s}{1+\pi_t} + (1-\kappa^F)z_t \Delta R_t^F + (l_t^B - \frac{l_{t-1}^B}{1+\pi_t}) - (RR_t - \frac{RR_{t-1}}{1+\pi_t}), \tag{29}$$

which shows that, with full sterilization ($\kappa^F = 1$), changes in the domestic-currency value of foreign-exchange reserves have no direct effect on the supply of cash.

Note also that because sterilization involves issuing high-yielding domestic liabilities while the foreign reserves that are accumulated as a counterpart earn typically a lower yield (the world risk-free interest rate), the central bank incurs a quasi-fiscal cost when it engages in sterilized operations.[12] Measured in domestic-currency terms per unit, this cost can be written as $1 + i_t^{CB} - (1 + i_t^W)\mathbb{E}_t(E_{t+1}/E_t)$ in gross terms. Alternatively, in net terms, the total cost of sterilization, SC_t, can be defined at the beginning of period t as[13]

$$SC_t = i_{t-1}^{CB} \frac{b_{t-1}^{CB}}{1+\pi_t} - [\frac{(1+i_{t-1}^W)E_t}{E_{t-1}} - 1]z_t R_{t-1}^F. \tag{30}$$

If, as discussed subsequently, the central bank's policy objective accounts not only for welfare of the representative household but also the cost of sterilization, as defined in (30), the optimal degree of exchange rate smoothing and the optimal degree of sterilization may both be affected.

[11] In nominal domestic-currency terms, equation (25) can be written as $E_t R_t^F + L_t^B = M_t^s + B_t^{CB} + NW_t$. Taking first differences of this expression gives $\Delta E_t R_t^F + E_t \Delta R_t^F + \Delta L_t^B = \Delta M_t^s + \Delta B_t^{CB} + \Delta NW_t$. Setting $\Delta NW_t = \Delta E_t R_t^F$, and diviving by P_t yields $z_t \Delta R_t^F + \Delta L_t^B / P_t^D = (\Delta M_t^s + \Delta B_t^{CB})/P_t$. Using (28), $P_{t-1}/P_t = 1/(1+\pi_t)$, and $\Delta X_t\ /P_t = x_t - (X_{t-1}/P_t) = x_t - x_{t-1}/(1+\pi_t)$, for $X = L^B, M^s$, yields equation (29).

[12] In Brazil, for instance, the quasi-fiscal cost of foreign reserves amounted to 2.7 percent of GDP during 2010-11 (see Garcia (2012, p. 3)). As estimated by Adler and Mano (2016), for a group of 73 countries over the period 2002-13, the total cost of sustaining foreign exchange positions (through an expansion of central bank balance sheets) was in the range of 0.2-0.7 percent of GDP per year for countries that intervened sporadically and 0.3-1.2 percent of GDP per year for countries that intervened heavily. Note that these costs are "quasi" fiscal because they are calculated *ex post*, in the absence of default. In the model, we use an expected measure.

[13] Note that, as noted earlier, valuations gains or losses associated with intervention (that is, changes in official reserves) affect the central bank's net worth and are not part of sterilization costs. Cukierman (2019) argued that the cost of sterilization should be measured in *foreign*-currency terms, but this made little differences to our results.

The refinance rate is set through a Taylor-type rule with inertia:

$$\frac{1+i_t^R}{1+\tilde{\imath}^R}=(\frac{1+i_{t-1}^R}{1+\tilde{\imath}^R})^{\chi}\left\{(\frac{1+\pi_t}{1+\pi^T})^{\varepsilon_1}(\frac{Y_t}{\tilde{Y}})^{\varepsilon_2}\right\}^{1-\chi}, \tag{31}$$

where $\tilde{\imath}^R$ is the steady-state value of the refinance rate, $\pi^T \geq 0$ the central bank's inflation target, $\chi \in (0,1)$ a persistence parameter, and $\varepsilon_1, \varepsilon_2 > 0$.

Finally, the risk-free world interest rate follows a first-order autoregressive process:

$$\frac{1+i_t^W}{1+\tilde{\imath}^W}=(\frac{1+i_{t-1}^W}{1+\tilde{\imath}^W})^{\rho_W}\exp(\xi_t^W), \tag{32}$$

where $\rho_W \in (0,1)$ and the serially uncorrelated innovation ξ_t^W is normally distributed with mean zero and standard deviation σ_{ξ^W}.

The production structure and the main real and financial flows between agents are summarized in Figure 1.

3 Equilibrium and Steady State

Market-clearing conditions under a symmetric equilibrium are stated in Appendix A. These conditions relate to the market for domestic sales of the final good, the market for cash, the labor market, the housing market, central bank liquidity, and the market for foreign exchange (or, equivalently, the balance of payments), which accounts for changes in the economy's net foreign asset position, defined as $F_t = R_t^F + B_t^{FP} - L_t^{FB}$. In particular, the demand for central bank liquidity by commercial banks is solved residually from (12), under the assumption that the supply of loans by the monetary authority is perfectly elastic at the prevailing refinance rate determined by the policy rule (31).

The steady-state solution of the model is described in Appendix C. Several of its key features are standard and similar to those described in Agénor et al. (2018), to which we refer for details. In particular, to ensure that banks have no incentive to borrow from the central bank to buy either government or sterilization bonds, the steady-state values of (real and nominal) interest rates on central bank borrowing, government bonds, and sterilization bonds must all be equal, that is, $\tilde{\imath}^R = \tilde{\imath}^B = \tilde{\imath}^{CB} = \Lambda^{-1} - 1$. The no-arbitrage condition (14) implies that the deposit rate must be less than the refinance rate. Official reserves are given by $\tilde{R}^F = R_m^F$, whereas the steady-state stock of foreign bonds held by households is $\tilde{B}^{FP} = (\tilde{\imath}^W - \tilde{\imath}^B)/\theta_0^{FP}(1+\tilde{\imath}^W)$, which is positive as long as the world risk-free interest rate exceeds the domestic bond rate. Similarly, borrowing by commercial banks is given by $\tilde{L}^{FB} = (\tilde{\imath}^R - \tilde{\imath}^W)/\theta_0^{FB}(1+\tilde{\imath}^W)$. The interest rate on sterilization bonds is determined by inverting the demand function for these bonds, so that $\tilde{\imath}^{CB} = \tilde{\imath}^B + \gamma_B - \gamma(\tilde{l}^K/\tilde{b}^{CB})^{0.5}$. In particular, an increase in the stock of sterilized bonds, if it is not matched by a concomitant rise in investment loans, must be accompanied by an increase in the rate of return on these bonds.

4 Parameterization

Our model is parameterized for a middle-income economy, using as a starting point the parameter values discussed in Agénor et al. (2018)—who themselves rely on a wide range of studies. While many of these values are fairly standard, we provide further supporting evidence for some of the parameters that we deem critical for this study. Some sensitivity analysis is also reported in the next section.

The discount factor Λ is set at 0.95, which gives a steady-state annualized interest rate (real and nominal, given zero steady-state inflation) of 5.3 percent—a fairly common value for studies focusing on developing countries. The intertemporal elasticity of substitution, ς, is set at 0.5, 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 25, to ensure that in the steady state households devote one third of their time endowment to market activity—also a common benchmark. The Frisch elasticity of labor supply is set at 0.71, which implies that $\psi_N = 1.4$; this value is within the range of values estimated by Dogan (2019), for instance. The parameter for composite monetary assets, η_x, is set at a low value, 0.001, to capture the view that the direct utility benefit of holding money is fairly small—a common assumption in the literature (see, for instance, Chang et al. (2015)). The housing preference parameter, η_H is also set at a low value, 0.02, for the same reason. 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. Thus, we consider an economy where the use of cash remains widespread. The sensitivity of the spread to household foreign bond holdings, θ_0^{FB}, is set at 0.2. In our setting, this parameter helps to ensure that the steady-state domestic bond 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_I, is set at 0.7, as in Hwang (2012), for instance, to capture the case of a country where imports are about a third of final output. The elasticity of substitution between baskets of domestic and imported composite intermediate goods, η, is set at 1.5, a fairly standard value, which implies that these goods are substitutes in the production of the final good (see Dogan (2019)). The elasticities of substitution between intermediate domestic goods among themselves, θ_I, and imported goods among themselves, θ_F, are set equal to the same value, 6, as in Demirel (2010), for instance. This gives a steady-state markup rate, $\theta_I/(\theta_I - 1)$, equal to 20 percent. The exchange rate pass-through to import prices is assumed instantaneous, so $\mu^F = 1.0$. By contrast, the degree of pass-through to export prices, μ^X, is set at 0.5. Thus, the current exchange rate and its equilibrium value have equal weights in measuring the domestic-currency price of exports. This assumption is consistent with the evidence which suggests that greater integration in global value chains has weakened, in the short run, the trade channel associated with the exchange rate.[14] The price elasticity of exports, $\varkappa_X$, is set equal to 0.9, which is close to the value used by Gertler et al. (2007) and consistent with the estimates obtained by Ahmed et al. (2015) for a broad sample of countries.

With respect to commercial banks, consistent with the evidence on the difficulty of seizing collateral in middle-income countries, the effective collateral-loan ratio, κ, is set at 0.2. The elasticity of substitution between differentiated loans, ζ^L, is set at 4.5, to obtain a spread between the refinance rate and the loan rate consistent with the evidence. The elasticities of the repayment probability with respect to the effective collateral-loan ratio, and deviations in output from its steady state, are set at $\varphi_1 = 0.05$ and $\varphi_2 = 0.4$, respectively. Parameter θ_0^{FC}, which determines the sensitivity of bank foreign borrowing to the differential in the cost of domestic and foreign loans, is set at 0.5, to obtain (as discussed later) a ratio of bank foreign liabilities to output in line with actual data. The parameters in the cost function, γ_B, γ_L, and γ, are set at 1, 0.1, and 0.1, respectively. The first two values ensure that, given the steady-state values of l^K and b^{CB} (as discussed next), marginal costs are positive, whereas the third ensures that the bank portfolio effect, as captured by γ, is relatively strong initially.

[14]See for instance Ollivaud et al. (2015) and Adler et al. (2019). Another factor, as documented by Boz et al. (2019), is the fact that much of international trade is invoiced in dominant currencies, especially the US dollar.

Regarding the central bank, the required reserve ratio μ is set at 0.2, consistent with the data reported by Cordella et al. (2014) for a group of large economies in Latin America. Responses of the refinance rate to inflation and output deviations, ε_1 and ε_2, and the degree of persistence in the central bank's policy rate, χ, are set at 2.0, 0.4, and 0.8, respectively. These values are consistent with estimates of Taylor-type rules for middle-income countries, including those of Moura and Carvalho (2010) for a broad sample of Latin American countries. The degree of persistence in the foreign exchange intervention rule, φ_1^R, is kept at 0.8. The weight of the lagged exchange rate in the target rate, φ^E, is set at 0.8, consistent with greater emphasis on *leaning against the wind*.

The share of noninterest government spending in output, ψ_G, is set at 0.18, a value consistent with the evidence for a number of large middle-income countries (see, for instance, Carvalho and Castro (2016)). 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.

Parameter values are summarized in Table 1, whereas initial steady-state values are displayed in Table 2. Most of the aggregate ratios are broadly consistent with the data. Interest rates on central bank borrowing, government bonds, and sterilization bonds are all equal (as noted earlier) and given by $\tilde{\imath}^R = \tilde{\imath}^B = \tilde{\imath}^{CB} = 5.3$ percent. The deposit rate is $\tilde{\imath}^D = 4.2$ percent whereas the loan rate is $\tilde{\imath}^L = 9.5$ percent. Thus, these values satisfy the steady-state restrictions $\tilde{\imath}^L > \tilde{\imath}^R > \tilde{\imath}^D$.

The initial stock of sterilization bonds is set at a relatively small value, at $b^{CB} = 0.011$, implying a bank loans-sterilization bonds ratio of 10. With the world risk-free interest rate $\tilde{\imath}^W$ set equal to 1.0 percent, $\theta_0^{FB} = 0.2$, and the steady-state bond rate $\tilde{\imath}^B$ equal again to 5.3 percent, the steady-state value of the stock of foreign assets held by households is equal to $\tilde{B}^F = (\tilde{\imath}^W - \tilde{\imath}^B)/[\theta_0^{FB}(1 + \tilde{\imath}^W)] = -21.1$ percent of final output. Thus, households are net debtors in the initial steady state. With $\theta_0^{FC} = 0.5$, and with the same values of $\tilde{\imath}^W$ and $\tilde{\imath}^B$, the ratio of bank foreign debt to final output $\tilde{L}^{FB} = (\tilde{\imath}^B - \tilde{\imath}^W)/[\theta_0^{FC}(1 + \tilde{\imath}^W)]$ is 8.4 percent. By implication, with the initial level of foreign reserves $\tilde{R}^F = 0.06$ percent of output, the economy's net stock of foreign assets, $\tilde{F} = \tilde{R}^F + \tilde{B}^{FP} - \tilde{L}^{FB}$, is initially negative, at -23.5 percent of final output.

5 Capital Inflows and Sterilization

To illustrate the functioning of the model, we consider briefly the impulse response functions associated with a transitory, one-percentage point drop in the world risk-free interest rate. As documented in a number of studies, external financial shocks have been a key driver of capital flows to, and from, middle-income countries.[15] We consider the case where the central bank intervenes significantly to stabilize the exchange rate ($\varphi_2^R = 5$) and contrast two cases: no sterilization (or $\kappa^F = 0$) and full sterilization ($\kappa^F = 1.0$).

The results are shown in Figure 2.[16] 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. To stabilize the exchange rate, the central bank intervenes by buying foreign reserves. But because the smoothing effect is not perfect, the real exchange rate also appreciates, whereas the price of imported intermediate goods and the inflation rate fall.[17] The central bank therefore lowers the refinance rate, which leads to a reduction in the loan rate and an expansion in investment and aggregate demand. The increase in cyclical output raises the repayment probability, which further lowers the loan rate. In the absence of sterilization, the money supply increases *pari passu* with the increase in foreign reserves resulting from *leaning against the wind* of currency appreciation. To maintain equilibrium in the money market the nominal bond rate must therefore fall. And because this drop is larger than the reduction in inflation, the (expected) real bond rate also falls. Through intertemporal substitution, consumption expands, further increasing aggregate demand. The increase in demand for housing services leads to a rise in real house prices

[15]See, for instance, Friedrich and Guérin (2019) for a recent study of the determinants of episodes of large capital flows. See also Agénor and Pereira da Silva (2019), as well as the references therein.

[16]Because in our benchmark calibration the initial stocks of foreign reserves and central bank bonds are not zero, changes in both the real stock of of these bonds and the sterilization cost are not exactly zero under pure floating, due to valuation effects associated with inflation and (in the case of the sterilization cost) fluctuations in the world interest rate and the exchange rate. However, for clarity, these changes are not reported in the figures.

[17]As implied by equations (A5), the demand for domestic and foreign intermediate goods depends on both relative prices and final output. Although, as discussed next, aggregate demand increases (thereby raising demand for both types of goods), the real appreciation implies that while demand for foreign inputs definitely rises, demand for domestic intermediates may either increase or fall. Given our calibration, the net effect is negative, implying therefore input substitution in the production of the final good.

and collateral values, which contributes also to the increase in the repayment probability and magnifies the drop in the loan rate. Overall, therefore, the adjustment process to this shock is consistent with the well-established stylized facts associated with this type of global shocks—as documented by Agénor and Montiel (2015, Chapter 13), for instance—and their macroeconomic effects on middle-income countries: a capital inflow, a currency appreciation (both nominal and real), increased liquidity, an expansion in credit and aggregate demand (the latter occurring both through higher consumption and investment), and a current account deficit.

When intervention is sterilized, the central bank issues its own bonds to neutralize the effect on domestic liquidity of the build-up in foreign reserves that it buys to mitigate the currency appreciation. The qualitative features of the adjustment process are essentially the same as in the case of no sterilization, although there are some differences in terms of magnitudes. In particular, because intervention is (partly) sterilized, the drop in the nominal bond rate required to maintain equilibrium of the money market is smaller, which mitigates also the initial fall in the real bond rate and the expansion in consumption.[18] At the same time, however, for commercial banks to willingly hold the greater supply of sterilization bonds, the interest rate on these bonds must increase.[19] This therefore requires a larger drop in the loan rate—above and beyond the fall resulting from the increase in the repayment probability and the reduction in the refinance rate, as discussed earlier. The expansion in investment is therefore more pronounced. This latter effect dominates the weaker increase in consumption, implying therefore that aggregate demand expands by more than under unsterilized intervention. Put differently, and in line with some of the contributions discussed earlier, in this base calibration sterilized intervention magnifies the expansionary effect associated with capital inflows induced by external financial shocks.[20]

[18] The weaker expansion in consumption translates into a smaller increase in the demand for leisure and a smaller rise in real house prices as well. The increase in collateral values is therefore less significant than under unsterilized intervention, and so is the rise in the probability of repayment.

[19] As implied by (23), $i_t^{CB} = i_t^R + \gamma_B - \gamma(l_t^K/b_t^{CB})^{0.5}$. The increase in the stock of sterilization bonds held by commercial banks requires (at the initial level of loans) an increase in the premium embedded in their rate of return. This, therefore, captures the portfolio balance (or balance sheet) effect. At the same time, as implied by (20), the joint cost effect tends to lower the loan rate at the initial level of loans, which raises investment. Although both l_t^K and b_t^{CB} increase, the latter rises by more, implying that the ratio l_t^K/b_t^{CB} falls. This reduction is large enough to ensure that, despite the fall in the refinance rate i_t^R, the nominal rate of return on sterilized bonds increases.

[20] As can be inferred from formula (30), the initial spike in the sterilization cost shown in Figure 2 is due to the fact that the nominal and the real exchange rates appreciate on impact, whereas the interest rates and the stock variables are predetermined.

To assess the role of the strength of the bank portfolio channel, Figure 3 shows the impulse responses under sterilized intervention, when the cost parameter γ is equal to 0.05 and 0.1, and for the same values for φ_2^R and κ^F as in Figure 2 (5 and 1.0, respectively). The figure shows, as expected, that the drop in the loan rate is less significant when economies of scope are weaker. As a result, the increase in investment is also weaker. Because cyclical output increases by less, the drop in the refinance rate is larger—and so is the drop in the bond rate. As a result consumption expands by more—although not enough to offset the smaller rise in investment. Consequently, the general equilibrium effect is indeed a smaller expansion in output; a weaker balance sheet effect mitigates the expansionary effect of sterilized intervention.

6 Optimal Policy

We now consider the welfare-maximizing policy under three regimes, all in response to the same world interest rate shock. In these regimes, the central bank sets optimally (A) the degree of exchange rate smoothing under unsterilized intervention ($\varphi_2^R \geq 0$, $\kappa^F = 0$); (B) the degree of sterilization, for the same degree of (optimal) exchange market intervention obtained under regime A ($\varphi_2^R = \varphi_2^R\big|_A$, $\kappa^F \geq 0$); and (C) the degree of exchange rate smoothing and the degree of sterilization simultaneously ($\varphi_2^R \geq 0$, $\kappa^F \geq 0$). Because indirect effects are internalized under regime C (the optimal combination policy), the optimal policy under that regime may differ significantly from what is obtained under regime B (conditional sterilized intervention).

We also consider separately three measures of the central bank's objective function: the standard case where it maximizes the welfare of the representative household, the case where it is also concerned with the cost of sterilization, and the case where financial stability considerations matter as well.

6.1 Welfare Maximization

Consider first the case where the objective of the central bank is to maximize solely the discounted present value of household utility, so that

$$W_t = \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s u(C_{t+s}, N_{t+s}, x_{t+s}), \tag{33}$$

where $u()$ is the period utility function, which is given from (1) as $u() \simeq (1-\varsigma^{-1})^{-1}C_t^{1-\varsigma^{-1}} - \eta_N(1+\psi_N)^{-1}N_t^{1+\psi_N} + \eta_x \ln x_t$.[21]

To calculate numerically the optimal policy, we solve for the conditional welfare-maximizing value of the reaction parameters φ_2^R in (26) and κ^F in (28), individually or jointly, based on a second-order approximation of both the model and the objective function (33), subject to the initial state of the economy ($t = 0$) being the deterministic steady state. As shown in Appendix D, the approximation of (33) gives

$$\mathcal{W}_t \simeq \frac{1}{1-\Lambda}\left\{\tilde{u} - \frac{\tilde{C}^{1-\varsigma^{-1}}}{2\varsigma}\text{Var}(\hat{C}_t) - \eta_N\psi_N\frac{\tilde{N}^{1+\psi_N}}{2}\text{Var}(\hat{N}_t) - \frac{\eta_x}{2}\text{Var}(\hat{x}_t)\right\}, \qquad (34)$$

where $\text{Var}(\hat{C}_t)$, $\text{Var}(\hat{N}_t)$, and $\text{Var}(\hat{x}_t)$ denote the conditional variances of (the log deviations of) consumption, employment, and real money balances, respectively, and $\tilde{u} = (1-\varsigma^{-1})^{-1}\tilde{C}^{1-\varsigma^{-1}} - \eta_N(1+\psi_N)^{-1}\tilde{N}^{1+\psi_N} - \eta_x \ln \tilde{x}$ is the steady-state level of period utility.

The welfare gain associated with each policy regime is assessed by calculating the percentage change in welfare, defined as welfare under activism divided by welfare under pure floating, minus unity. We calculate in a similar fashion the welfare gain associated with regimes B and C (both of which involving sterilized intervention) relative to regime A (unsterilized intervention). For all calculations, we use a step of 1.0 for φ_2^R and 0.01 for κ^F, when either one, or both, of these parameters are solved for explicitly. Again, under regime B, the value of φ_2^R is set at the optimal value obtained under regime A, as a natural benchmark.

Column (1) in Table 3 presents the results of the analysis in the benchmark case, with $\gamma = 0.1$ and 0.05. With unsterilized intervention (regime A), the optimal degree of exchange rate smoothing is $\varphi_2^R = 22$. Intuitively, the reason why an optimal intervention policy exists (under all policy regimes, and regardless of whether the cost of sterilization or financial stability concerns are accounted for) is because intervention has a nonlinear effect on volatility; as a result, welfare under activism follows an inverted U-shape. Initially, an increase in the degree of exchange rate smoothing mitigates exchange rate and price volatility, which translates into greater stability of interest rates—the policy rate first, given that it reacts fairly strongly to inflation, and market rates next—and therefore consumption and real money balances. This also stabilizes output and employ-

[21] In calculating welfare, we have ignored the stock of housing as this is constant in equilibrium—and so is its utility benefit.

ment. Thus, welfare tends to increase at first. However, as intervention becomes more aggressive, the expansion in domestic liquidity becomes more significant. This creates more volatility in the bond rate, which adjusts to clear the money market. As a result, consumption and real money balances become more volatile, and this translates into greater volatility in house prices and collateral values—thereby increasing volatility in the loan rate and investment, as well as output and employment. Eventually, the latter effect dominates, and this leads to a reduction in welfare. At the optimal value of the policy response, the welfare gain of unsterilized intervention relative to free floating is of the order of 3.1 percent when $\gamma = 0.1$.

When the degree of exchange rate smoothing is taken as given (at the optimal value of regime A) and intervention is sterilized (regime B), the results show that some degree of sterilization is always optimal ($\kappa^F = 0.47$). The reason is that the degree of sterilization also has a nonlinear effect on welfare. At first, a more active sterilization policy mitigates volatility and increases welfare because it neutralizes the effect of the expansion of liquidity associated with intervention on the bond rate, thereby mitigating volatility of consumption and real money balances. However, as the policy becomes more aggressive, the central bank must issue more bonds as a counterpart to accumulating reserves; as a result, this creates more volatility in interest rates, investment, consumption, real money balances, and eventually output and employment. At the optimal value of the sterilization coefficient (the point at which these positive and negative effects on welfare tend to offset each other), the welfare gain relative to free floating is a lot larger, of the order of 23.5 percent. The gain relative to (optimal) unsterilized intervention, of the order of 21 percent, is also significant. At the same time, however, it is not optimal to fully sterilize (that is, $\kappa^F = 1$)—even if sterilization costs are not accounted for, as is the case for now.

When both the degrees of intervention and sterilization are chosen jointly (regime C), the optimal policy involves more aggressive *leaning against the wind* compared to unsterilized intervention (regime A), as well as a significant degree of sterilization. By intervening more, the gain from greater exchange rate stability, which occurs through increased price and interest rate stability, are magnified. Because at the same time the liquidity effect is stronger, it is optimal to sterilize (κ^F increases from 0 in regime A to 0.33), albeit less than under regime B. Put differently, the fact that sterilization is available as an instrument under regime C means that the central bank can intervene more than under regime A; but because of the portfolio balance effect, it cannot sterilize as much as under regime B. In addition, once again, full sterilization is not optimal; through the bank portfolio (or balance sheet) channel, sterilization magnifies the impact of intervention on the loan rate, which exacerbates fluctuations in output and employment, as well as the bond rate, consumption, and real money balances, thereby mitigating welfare gains. As under regime B, the combination of policies generates a fairly substantial gain in welfare—both compared to free floating (of the order of 26.3 percent) and to unsterilized intervention (of the order of 23.9 percent). As expected, when the cost parameter γ (and thus the bank portfolio effect) is weaker, under regime C the optimal degree of foreign exchange intervention remains essentially the same but the scope for sterilization is much stronger; κ^F is of the order of 0.68 when $\gamma = 0.05$, compared to 0.33 when $\gamma = 0.1$. Note also that in both cases there is no conflict in the use of intervention and sterilization: both κ^F and φ_2^R are higher under regime C, compared to regime A. In that sense, the optimal policy entails *burden deepening*; the two instruments are complements.

The first column of Table 4 displays the asymptotic variances of a range of variables, real and financial, for $\gamma = 0.1$ and 0.05, under alternative regimes. The results indicate that regime C (joint optimization) performs better than either free floating or unsterilized intervention (regime A) or conditional sterilized intervention (regime B) for a wide range of variables—including employment, the real exchange rate, and inflation), but not for others, such as domestic output sales, the loan rate, and the loan-to-output ratio. The reason is that under sterilization (regimes B and C), the central bank bonds-domestic loans ratio, and thus the rate of return on sterilization bonds, are a lot more variable (due to the expansionary effect alluded to earlier), and this affects (as a result of cost complementarity) the cost of borrowing for domestic producers. The expansionary effect associated with sterilized intervention therefore explains why investment and domestic output sales are noticeably more variable under regimes B and C. The implication is that while sterilized intervention may maximize welfare, it may also raise financial stability risks through its impact on credit flows.[22]

[22] Similar results are obtained when the cost of sterilization is accounted for in the central bank's objective function, as discussed next.

6.2 Accounting for Sterilization Costs

Consider now the case where the central bank's objective function accounts for sterilization costs. This is captured by adding the term $-\varkappa_S \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s SC_{t+s}$ to (33), where $\varkappa_S \geq 0$ is a parameter that measures the welfare cost associated with sterilization, as defined in (30). The approximation (34) is now replaced by

$$\mathcal{W}_t \simeq \frac{1}{1-\Lambda}\left\{\tilde{u} - \frac{\tilde{C}^{1-\varsigma^{-1}}}{2\varsigma}\text{Var}(\hat{C}_t) - \frac{\tilde{N}^{1+\psi_N}}{2\eta_N^{-1}\psi_N^{-1}}\text{Var}(\hat{N}_t) - \frac{\eta_x}{2}\text{Var}(\hat{x}_t)\right\} - \varkappa_S \mathbb{E}_t \sum_{s=0}^{T} \Lambda^s SC_{t+s}, \tag{35}$$

where T is a fairly large number imposed to approximate the infinite sum of discounted current and future sterilization costs.[23]

The presence of sterilization costs in the central bank's objective function is consistent with the view that central banks' quasi-fiscal losses undermine their operational independence. Indeed, given that in many middle-income countries governments have no statutory requirements to make up for central bank losses, or provide capital when the monetary authority's net worth becomes negative, persistent losses may hamper their ability to conduct monetary policy.[24] When these losses are large markets may also cast doubts on the central bank's long-term ability to preserve price stability, and this may have an adverse effect on its credibility. This, in turn, may generate greater persistence in inflation expectations and increased financial volatility.[25] If central banks are concerned with their credibility and independence, their objective function may reflect not only the welfare of the representative household but also, as captured in (35), the magnitude of sterilization costs.

Column (1) in the upper part of Table 5 shows the results when sterilization costs matter in the central bank's welfare objective, again for $\gamma = 0.1$ and 0.05, and with $\varkappa_S = 0.004$.[26] Under Regime A, it is now optimal to intervene less (implying therefore

[23] In our computations we set $T = 6,000$. Again, given that the housing market is always in equilibrium, and that the supply of housing is constant, the volatility of real house prices does not enter directly in (34).

[24] In particular, the accumulation of central bank losses may limit either their capacity to mop up excess liquidity or their ability to raise interest rates when conducting open-market-operations, as these become an undesirable source of monetization that may need to be sterilized subsequently.

[25] See Stella and Lonnberg (2008) and Schwarz et al. (2014) for a more general discussion, and Perera et al. (2013) for empirical evidence of a negative link between central bank financial strength and inflation.

[26] This small value of $\varkappa_S$ is partly due to differences in magnitudes between the variables included in the welfare function and our measure of sterilization costs. It is also sufficient for illustrative purposes.

a smaller welfare gain compared to free floating), whereas under regime B it is (as expected) optimal to sterilize more, even though the cost of sterilization now matters; the optimal value of κ^F is 0.76, compared to 0.47 in Table 3. Under regime C, it is optimal to intervene less compared to regime A, and also less aggressively than when the cost of sterilization is not accounted for ($\varphi_2^R = 7$ in Table 5, compared to 48 in Table 3). At the same time, it is optimal to *fully sterilize*—despite the cost of this policy. At low levels of intervention, *leaning against the wind* more aggressively reduces exchange rate volatility, and thus the need for the central bank to issue sterilization bonds. This leads to a reduction in sterilization costs and weaker expansionary effects associated (as discussed earlier) with the bank portfolio channel. This also contributes to mitigating exchange rate volatility and leads to full sterilization being optimal. By contrast, at high levels of intervention—as occurs, for instance, when exchange rate stability is an explicit objective of the central bank, as can be inferred from a comparison of the results in columns (1)-(2) and (3)-(4) in Tables 3 and 5—a more aggressive policy magnifies these expansionary effects, which leads to full sterilization being suboptimal. Although not reported here (to save space), these results remain the same when the sterilization cost parameter $\varkappa_S$ is raised to higher values.

The important point, therefore, is that from the perspective of the optimal joint policy, the central bank's concern with sterilization costs does *not* imply (as partial equilibrium analysis would suggest) that it should sterilize less aggressively; rather, as a result of general equilibrium effects, it should intervene less aggressively to mitigate, in the first place, the need to accumulate foreign reserves. By doing so, it can act more forcefully to neutralize the conventional liquidity channel, without facing an excessively high cost associated with the bank portfolio channel. Thus, the optimal policy involves *burden sharing* between intervention and the degree of sterilization; the two instruments are (partial) substitutes.

Similar results are obtained when the cost parameter γ is smaller. At the same time, when γ is high (low), the welfare gain associated with regime C, compared to either free floating or unsterilized intervention is slightly higher (lower) than when sterilization costs are not accounted for in the central bank's objective function.

6.3 Accounting for Financial Stability

In the foregoing discussion it was argued that accounting for sterilization costs could reflect, as least in part, concerns with financial stability. More generally, since the global financial crisis, an important issue has been the extent to which central banks should account more explicitly for financial stability considerations in the conduct of monetary policy. Given that, as discussed earlier, foreign exchange intervention and the degree of sterilization may have a significant impact on the volatility of a wide range of financial variables, we now examine how the optimal policy varies when the central bank's objective function is adjusted to reflect also financial stability considerations.

To do so, the term $-\varkappa_Z \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s (Z_{t+s} - \tilde{Z})^2$ is added the objective function (33), with Z_t denoting a financial indicator and $\varkappa_Z \geq 0$ a parameter that measures the welfare cost associated with volatility in that variable. Thus, approximation (34) is now replaced by

$$\mathcal{W}_t \simeq \frac{1}{1-\Lambda}\left\{\tilde{u} - \frac{\tilde{C}^{1-\varsigma^{-1}}}{2\varsigma}\text{Var}(\hat{C}_t) - \frac{\tilde{N}^{1+\psi_N}}{2\eta_N^{-1}\psi_N^{-1}}\text{Var}(\hat{N}_t) - \frac{\eta_x}{2}\text{Var}(\hat{x}_t)\right\} - \varkappa_Z \frac{\text{Var}(\hat{Z}_t)}{1-\Lambda}, \tag{36}$$

and similarly in the presence of sterilization costs, as in (35).

To define the financial stability indicator Z_t, we consider three alternative measures. First, we consider the credit-to-output ratio, with a cost parameter of $\varkappa_Z = -0.5$. The focus on that variable is consistent with the large body of evidence suggesting that excessive credit expansion has often been associated with financial instability and financial crises, both in developed and developing countries.[27] Second, in line with the recent focus on the risks associated with currency fluctuations from the perspective of financial stability, and how sterilization can help to mitigate these risks, we take Z_t to be the nominal exchange rate volatility, with a cost parameter of $\varkappa_Z = -0.0001$. Finally, both measures are considered together, with the same cost parameters.[28] These alternative measures, which are referred to as (2), (3) and (4), respectively, in Tables 3 and 5, can be compared to the benchmark case where relative welfare is either defined in conventional fashion (Table 3) or adjusted only for the cost of sterilization (Table 5),

[27] See Agénor and Montiel (2015) and Taylor (2015) for a discussion.

[28] The last term in (36) is therefore replaced by $-(1-\Lambda)[0.5\text{Var}(l_t^K/Y_t) + 0.0001\text{Var}(\hat{E}_t)]$. Again, our choice for the values of the cost parameters is partly dictated by the magnitude of the variables included in the objective function. They are sufficient to illustrate how the optimal policies may vary financial stability considerations are taken into account.

which in both cases is referred to as measure (1).

Consider first the results in the upper part of Table 3, that is, the case where the cost of sterilization is not accounted for ($\varkappa_S = 0.0$) and $\gamma = 0.1$. Adding the volatility of the credit-to-output ratio does not have a substantial effect on the degree of intervention under regime A. However, it induces the central bank to both lean less heavily against currency fluctuations and to sterilize less under regime C, compared to the case where volatility of that variable is not accounted for in the central bank's objective function. The reason for a less aggressive stance on sterilization is, of course, its expansionary effect on credit, through the bank portfolio channel discussed earlier. As a result, and even though the impact of sterilization on volatility is mitigated, consumption, real money balances, and employment are more volatile, which implies that the welfare gain associated with the optimal joint policy (regime C) relative to either free floating or unsterilized intervention (regime A) is significantly lower under measure (2) than with measure (1).

When exchange rate volatility is added to the welfare measure, as expected the optimal degree of foreign exchange intervention increases substantially, both under regimes A and C. The degree of sterilization is slightly less aggressive (because of its indirect effect, through interest rates, on the exchange rate), which implies that the gain of the optimal joint policy (regime C) is significantly larger under measure (3) compared to the benchmark measure (1). Finally, when both measures of volatility are added to the welfare function (33), that is, under measure (4), the optimal degree of intervention increases further under regime A, and the welfare gain relative to free floating remains positive relative to the benchmark case (1)—just as under measure (3). At the same time, under regime C, while the optimal response parameter in the intervention rule remains about the same, the optimal degree of sterilization drops dramatically, just as it did under measure (2). The reason again is that fluctuations in the credit-to-output ratio, by increasing financial volatility, are costly from the perspective of the central bank. Qualitatively similar results hold when the strength of the bank portfolio effect, as measured by γ is smaller (lower part of Table 3).

When the cost of sterilization is accounted for (Table 5, $\varkappa_S = 0.004$), *burden sharing* (or partial substitutability) continues to prevail between foreign exchange intervention and sterilization—regardless of whether exchange rate and financial stability also matter in the central bank's objective function. Under regime C full sterilization remains optimal, as in the standard case, when financial volatility is measured in terms of the volatility of the credit-to-output ratio, while at the same time intervention is less aggressive compared to regime A. When exchange rate volatility matters, whether individually or in combination with the volatility of the credit-to-output ratio (measures (2) and (3)), intervention is more aggressive than under measures (1) and (2) but full sterilization is no longer optimal. Intuitively, this is because the bank portfolio effect implies that sterilization has an indirect impact on exchange rate fluctuations.

7 Expectation Formation

Finally, we consider the case where exchange rate expectations, instead of being fully rational, are formed on the basis of a hybrid mechanism. Specifically, the one-period ahead expected exchange rate in (11) and (21) is now replaced by a weighted average of the rational forecast, $\mathbb{E}_t E_{t+1}$, and a bounded forecast, $E^a_{t+1|t}$. The composite forecast is thus defined as

$$E_{t+1|t} = (\mathbb{E}_t E_{t+1})^{\varkappa_1^E} (E^a_{t+1|t})^{1-\varkappa_1^E}, \tag{37}$$

where $\varkappa_1^E \in (0,1)$ is the relative weight on the alternative schemes.[29] The case considered previously corresponds therefore to $\varkappa_1^E = 1$.

With respect to the bounded forecast, we use two alternative specifications. The first is the standard adaptive mechanism, which depends on the deviation of the current exchange rate and the expectation of that variable at t, based on information available at $t-1$:

$$E^a_{t+1|t} = E^a_{t|t-1}(\frac{E_t}{E^a_{t|t-1}})^{\varkappa_2^E}, \tag{38}$$

where $\varkappa_2^E \in (0,1)$ measures the speed of adjustment. The second specification assumes, as in Mankiw and Reis (2002) and Gelain et al. (2013), for instance, that the bounded forecast at $t+1$ depends on the deviation of the past forecast at t from the rational expectations forecast at $t+1$:

$$E^a_{t+1|t} = E^a_{t|t-1}(\frac{\mathbb{E}_t E_{t+1}}{E^a_{t|t-1}})^{\varkappa_2^E}, \tag{39}$$

[29] In a model with heterogeneous agents and more elaborate microfoundations of the foreign exchange market, coefficient $\varkappa_1^E$ can be taken to represent explicitly the fraction of foreign exchange market operators whose expectations are formed in accordance with the rational expectations hypothesis.

where $\varkappa_2^E \in (0,1)$.[30]

Figure 4 shows the impulse response functions under the original rational expectations specification and the two hybrid regimes defined by (37), (38), and (39), with values of $\varkappa_1^E = 0.2$ and $\varkappa_2^E = 0.5$, and sterilized intervention ($\varphi_2^R = 5$ and $\kappa^F = 1.0$, as in Figures 3 and 4). The results show that although the hybrid-forward specification imparts greater volatility to most variables, real and financial, the path of almost all variables is qualitatively similar to those obtained under full rational expectations for both specifications. Thus, the optimal analysis (which is not reported here to save space) yields outcomes that are similar to those discussed earlier, both with and without accounting for sterilization costs, and alternative measures of financial stability.

It is worth noting, however, that the results would be different in the presence of a *signalling channel*, that is, if intervention affects market expectations of future exchange rates. As documented by Patel and Cavallino (2019), this channel is viewed by many central banks as very important—if not the most important—in practice. In particular, as discussed by Fanelli and Straub (2017), the effects of future interventions on future exchange rates propagate back in time—assuming that the signal is credible—through the uncovered interest parity relation and affect the spot exchange rate. The potential signaling effect of foreign exchange intervention is not captured here, but it could affect the weights $\varkappa_1^E$ and $\varkappa_2^E$ under hybrid expectations.

Finally, we tested for the existence of a financial channel of exchange rates (as discussed in the introduction) by specifying the premium at which domestic banks borrow on capital markets in terms of the domestic-currency value of foreign debt, instead of its foreign-currency value, as defined in (17). Thus, under symmetry, $\theta_t^{FB} = \theta_0^{FB} z_t L_t^{FB}/2$. However, given our calibration, this change does not make a significant difference quantitatively. By implication, there are very little differences in terms of the optimal analysis discussed in the benchmark case. The reason is that while the real appreciation (a fall in z_t) does raise foreign borrowing, L_t^{FB}, the net effect on $z_t L_t^{FB}$ is muted. Moreover, in the model, the change in the domestic-currency value of foreign debt affects borrowing by the central bank (which is determined residually), without any direct effect on the cost of lending to domestic producers. Put differently, the financial channel operates in the model only in the standard fashion discussed earlier—an appreciation lowers inflation,

[30] In a more elaborate specification of the market for foreign exchange, $\varkappa_2^E$ would measure now the share of operators who update their forecast to the most recent rational forecast. Note also that in both (38) and (39), in the initial steady state $\tilde{E}^a = \tilde{E}$.

which in turn lowers the refinance rate and the loan rate, inducing an expansion in investment. There is no significant amplification effect on capital flows operating through the premium at which banks borrow abroad, and no magnifying effect on credit and investment.[31] There are therefore no additional gains associated with optimal foreign exchange intervention and sterilization.

8 Concluding Remarks

Using an open-economy model with financial frictions, a managed float, and imperfect capital mobility, this paper studied the effects of sterilized intervention on financial stability. In response to capital inflows induced by a transitory shock to world interest rates, the central bank was assumed to issue sterilization bonds that are imperfect substitutes for investment loans in bank portfolios. This portfolio or balance sheet channel was shown to play a critical role in determining whether sterilized intervention can lead to an expansion in credit and output. The optimal degrees of exchange rate smoothing and sterilization, individually and jointly, were derived under the assumption that the central bank's objective function accounts not only for household welfare but also for the quasi-fiscal cost of sterilization—the difference between the yield received for holding foreign assets and the yield paid on domestic liabilities issued for sterilization purposes—and for financial stability concerns.

The main results of the paper were summarized in the introduction and need not be repeated here. One direction for future research would be to study the joint optimal determination of the degree of sterilized intervention and other countercyclical instruments of macroprudential regulation, such as capital buffers or reserve requirements, in a setting where, in addition to the central bank, a national regulator is also concerned with financial stability.[32] A related direction would be to analyze, as in some contributions, whether capital controls can be either a complement or a substitute for sterilized foreign exchange intervention in managing surges in capital inflows.[33] However, most of

[31] If the net effect on the domestic-currency value of bank foreign debt is positive, there may actually be a dampening effect on consumption, instead of an expansionary effect on investment. In that case, central bank borrowing will fall, thereby lowering the supply of cash. To maintain equilibrium of the money market, the demand for cash must also fall, and this requires an increase in the nominal bond rate. Because the exchange rate appreciation lowers inflation, the real bond rate rises unambiguously as well. This leads to a reduction in current consumption through intertemporal substitution. However, this attenuation effect is also weak in our calibration.

[32] See, for instance, Agénor et al. (2018) and the references therein.

[33] See Liu and Spiegel (2015), Prasad (2018), and Kuersteiner et al. (2018), for instance. The latter

these contributions have focused on capital controls on household portfolios. Instead, as in Aoki et al. (2016) and Agénor and Jia (2020), for instance, the model could be used to study the case where the central bank imposes a tax on bank external borrowing—a policy that can be viewed either as a capital control or a prudential regulation designed to limit banks' foreign exchange exposures, as discussed in the literature—and assess whether the degree of sterilization and the tax rate are complements of substitutes (at the margin) for a given degree of exchange rate flexibility. Depending on the cost of sterilization, capital controls and sterilized intervention may well be complements in maximizing welfare and promoting financial stability.

Yet another issue to explore would be intervention on forward markets, which involves no actual change in foreign reserves—in contrast to intervention (as modeled in this paper) on spot markets, which remain the norm (see Kohlscheen and Andrade (2014), Domanski et al. (2016), and Patel and Cavallino (2019)). For some observers, transactions in derivative markets, through swaps and forwards, offer an indirect instrument for intervention that can be equally effective at affecting the spot exchange rate. Because they are sometimes settled in domestic currency, they can increase the capacity to intervene beyond a particular stock of reserves. A number of middle-income countries have used this type of intervention in recent years, particularly in Latin America. Barroso (2019), Gonzalez et al. (2019), and Nedeljkovic and Saborowski (2019), for instance, studied the experience of Brazil—a country where spot and non-deliverable futures based intervention have been used together for more than a decade. In particular, Gonzalez et al. (2019) found that the Central Bank of Brazil's intervention in foreign exchange derivatives markets during the 2013 taper tantrum mitigated the impact of currency depreciation on domestic credit supply in the country.[34] However, a well documented feature of intervention in forward markets is that over time it may also contribute to a build-up of perceived vulnerabilities on the central bank's balance sheet—ultimately with similar adverse effects (as discussed earlier) on inflation expectations and financial volatility associated with the quasi-fiscal losses created by intervention in spot markets. Indeed, markets may well continuously monitor the total notional value of these contracts against total reserves, and test the commitment of the central bank to defend the

study, in particular, found that capital controls amplify the effects of foreign exchange intervention.

[34] Countries in other regions intervened in forward markets as well. The Bank of Thailand did so in the early phases of the East Asian financial crisis, and so did South Africa's Reserve Bank in 1998-99. Indonesia has also recently started to intervene through non-deliverable forward transactions.

exchange rate. A more systematic comparison of the two types of intervention would be warranted, in terms not only of their analytical underpinnings but also their differences in communication strategies, and implications for macroeconomic and financial volatility.

Appendix A
Production Side and Market-Clearing Conditions

This Appendix describes the other components of the model's structure–production of the final good, production of intermediate goods, production of capital goods, the government, and market-clearing conditions.

Final Good

To produce the final good, Y_t, a basket of domestically-produced differentiated intermediate goods, Y_t^D, is combined with a basket of imported intermediate goods, Y_t^F:

$$Y_t = [\Lambda_D (Y_t^D)^{(\eta-1)/\eta} + (1-\Lambda_D)(Y_t^F)^{(\eta-1)/\eta}]^{\eta/(\eta-1)}, \tag{A1}$$

where $\Lambda_D \in (0,1)$ and $\eta > 0$ is the elasticity of substitution between the two baskets, each of which defined as

$$Y_t^i = \left\{ \int_0^1 [Y_{jt}^i]^{(\theta_i-1)/\theta_i} dj \right\}^{\theta_i/(\theta_i-1)}. \quad i = D, F \tag{A2}$$

In this expression, $\theta_i > 1$ is the elasticity of substitution between intermediate domestic goods among themselves ($i = D$), and imported goods among themselves ($i = F$), and Y_{jt}^i is the quantity of type-j intermediate good of category i, with $j \in (0,1)$.

Cost minimization yields the demand functions for each variety of intermediate goods:

$$Y_{jt}^i = (\frac{P_{jt}^i}{P_t^i})^{-\theta_i} Y_t^i, \quad i = D, F \tag{A3}$$

where P_{jt}^D (P_{jt}^F) is the price of domestic (imported) intermediate good j, and P_t^D and P_t^F are price indices, which are given from the zero-profit condition as

$$P_t^i = \left\{ \int_0^1 (P_{jt}^i)^{1-\theta_i} dj \right\}^{1/(1-\theta_i)}, \quad i = D, F \tag{A4}$$

so that $P_t^i Y_t^i = \int_0^1 P_{jt}^i Y_{jt}^i dj$. Demand functions for baskets of domestic and foreign intermediate goods are

$$Y_t^D = \Lambda_D^\eta (\frac{P_t^D}{P_t})^{-\eta} Y_t, \quad Y_t^F = (1-\Lambda_D)^\eta (\frac{P_t^F}{P_t})^{-\eta} Y_t, \tag{A5}$$

where P_t is the price of final output, given by

$$P_t = [\Lambda_D^\eta (P_t^D)^{1-\eta} + (1-\Lambda_D)^\eta (P_t^F)^{1-\eta}]^{1/(1-\eta)}. \tag{A6}$$

We assume that prices of foreign goods are set in the sellers' currency (producer currency pricing), with imperfect pass-through and no transportation costs. The domestic-currency price of imported good j is thus given by

$$P_{jt}^F = E_t^{\mu^F} E_{t-1}^{1-\mu^F}, \tag{A7}$$

where the foreign-currency price is normalized to unity and $\mu^F \in (0,1)$ measures the degree of exchange rate pass-through. Thus, the law of one price holds only in the steady state.

Exports, Y_t^X, depend on the domestic-currency price of exports, P_t^X, relative to the price of goods sold domestically, P_t^S:

$$Y_t^X = (\frac{P_t^X}{P_t^S})^{\varkappa} Y^F, \qquad \varkappa > 0 \tag{A8}$$

where Y^F is foreign output, assumed exogenous.

Local currency pricing is assumed, that is, changes in nominal exchange rates feed only partially into export prices. This is captured by assuming that the domestic-currency price of exports depends on both the current exchange rate and its steady-state value:

$$P_t^X = E_t^{\mu^X} \tilde{E}^{1-\mu^X} WP^X, \tag{A9}$$

where WP^X denoting the foreign-currency price of exports, assumed constant and normalized to unity and $\mu^X \in (0,1)$. The dependence of P_t^X on the steady-state value of the exchange rate captures the view that exporters base their decisions on a longer-term perspective on the domestic currency's value, rather than how it fluctuates in the short term. As noted in the text, this assumption is consistent with the evidence that greater integration in global value chains has weakened in the short run the trade channel associated with the exchange rate.

Total output is thus also given by

$$Y_t = Y_t^S + Y_t^X, \tag{A10}$$

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

Intermediate Goods

Output of intermediate good j, Y_{jt}^D, is sold on a monopolistically competitive market and is produced by combining labor, N_t^j, and beginning-of-period capital, K_t^j:

$$Y_t^{D,j} = (N_t^j)^{1-\alpha}(K_t^j)^{\alpha}, \quad \alpha \in (0,1) \tag{A11}$$

Capital is rented from a randomly matched CG producer (at the rate r_t^K) and paid for after the sale of output. Cost minimization yields the demand functions for labor and capital as

$$K_t^j = (\frac{\alpha}{1-\alpha})^{1-\alpha}(\frac{\omega_t}{r_t^K})^{1-\alpha}, \tag{A12}$$

$$N_t^j = (\frac{\alpha}{1-\alpha})^{-\alpha}(\frac{\omega_t}{r_t^K})^{-\alpha}. \tag{A13}$$

Dividing (A12) and (A13) yields the capital-labor ratio as

$$\frac{K_t^j}{N_t^j} = (\frac{\alpha}{1-\alpha})(\frac{\omega_t}{r_t^K}), \quad \forall j \tag{A14}$$

From (A11), (A12) and (A13), the unit real marginal cost, mc_t^j, is given by

$$mc_t^j = \frac{\omega_t N_t^j + r_t^K K_t^j}{Y_t^{D,j}}. = (\frac{r_t^K}{\alpha})^\alpha (\frac{\omega_t}{1-\alpha})^{1-\alpha}. \tag{A15}$$

Each IG firm j chooses a sequence of prices so as to maximize the discounted present value of its profits:

$$\{P_{t+s}^{D,j}\}_{s=0}^\infty = \arg\max \mathbb{E}_t \sum_{s=0}^\infty \Lambda^s \lambda_{t+s} J_{t+s}^{D,j}, \tag{A16}$$

where $\Lambda^s \lambda_{t+s}$ measures the marginal utility value to the representative household of an additional unit of real profits, $J_{t+s}^{D,j}$, received in the form of dividends at $t+s$. In Rotemberg fashion, prices are costly to adjust; profits are thus defined as

$$J_t^{D,j} = (\frac{P_t^{D,j}}{P_t^D}) Y_t^{D,j} - mc_t^j Y_t^{D,j} - \frac{\phi_D}{2}(\frac{P_t^{D,j}}{P_{t-1}^{D,j}} - 1)^2 Y_t^D, \tag{A17}$$

where $\phi_D \geq 0$.

Using (A3), the first-order condition for this problem takes the standard form

$$(1-\theta_D)(\frac{P_t^{D,j}}{P_t^D})^{-\theta_D} \frac{1}{P_t^D} + \theta_D (\frac{P_t^{D,j}}{P_t^D})^{-\theta_D - 1} \frac{mc_t^j}{P_t^D} \tag{A18}$$

$$-\phi_D \left\{ (\frac{P_t^{D,j}}{P_{t-1}^{D,j}} - 1) \frac{1}{P_{t-1}^{D,j}} \right\} + \Lambda \phi_D \mathbb{E}_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} (\frac{P_{t+1}^{D,j}}{P_t^{D,j}} - 1) \frac{P_{t+1}^{D,j}}{(P_t^{D,j})^2} \frac{Y_{t+1}^D}{Y_t^D} \right\} = 0.$$

Capital Goods

The capital stock of the representative CG producer, K_t, is obtained by combining gross investment, I_t, with the existing capital stock, adjusted for depreciation and adjustment costs:

$$K_{t+1} = I_t + \left\{ 1 - \delta_K - \frac{\Theta_K}{2}(\frac{K_{t+1} - K_t}{K_t})^2 \right\} K_t, \tag{A19}$$

where $\delta_K \in (0,1)$ is the depreciation rate and $\Theta_K > 0$.

Investment goods must be paid for in advance. The representative CG producer must therefore borrow from banks $l_t^K = I_t$. The matched household makes its housing stock, $\bar{H}$, available to the CG producer without any direct charge, who uses it as collateral against which it borrows from banks. Repayment is uncertain and occurs with probability $q_t \in (0,1)$, which depends on average behavior and is thus taken as given by each CG producer. Expected repayment is thus $q_t(1+i_t^L)I_t + (1-q_t)\kappa z_t^H \bar{H}$, where $\kappa = \int_0^1 \kappa^i di$ and $\kappa^i \in (0,1)$ is the fraction of the housing stock pledged as collateral to each bank i.

Subject to (A19) and $l_t^K = I_t$ the CG producer chooses the level of capital K_{t+1} so as to maximize the value of the discounted stream of dividend payments to the matched household. The solution to this problem yields[35]

$$\mathbb{E}_t r_{t+1}^K \simeq q_t(1+i_t^L)\mathbb{E}_t \left\{ \left[1 + \Theta_K (\frac{K_{t+1}}{K_t} - 1) \right] (\frac{1+i_t^B}{1+\pi_{t+1}}) \right\} \tag{A20}$$

[35] See Agénor (2020, Chapter 4) for a detailed derivation. Equation (A20) boils down to the standard arbitrage condition $\mathbb{E}_t r_{t+1}^K \simeq i_t^B - \mathbb{E}_t \pi_{t+1} + \delta_K$ in the absence of borrowing and adjustment costs.

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

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

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

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

$$l^{K,i}_t = (\frac{1+i^{L,i}_t}{1+i^L_t})^{-\zeta^L} l^K_t, \tag{A21}$$

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

Government

The government budget constraint is given by

$$b_t - \frac{b_{t-1}}{1+\pi_t} = G_t - T_t + \frac{i^B_{t-1}b_{t-1}}{1+\pi_t} - z_t i^W_{t-1} R^F_{t-1} - (\frac{i^R_{t-1}l^B_{t-1} - i^{CB}_{t-1}b^{CB}_{t-1}}{1+\pi_t}), \tag{A22}$$

where b_t is the real stock of riskless one-period bonds, $z_t i^W_{t-1} R^F_{t-1} + (1+\pi_t)^{-1}(i^R_{t-1}l^B_{t-1} - i^{CB}_{t-1}b^{CB}_{t-1})$ the real value of net interest income earned by the central bank (transferred entirely to the government), and G_t real expenditure, which represents a fraction $\psi_G \in (0,1)$ of output of the final good:

$$G_t = \psi_G Y_t. \tag{A23}$$

The government keeps its real stock of debt constant ($b_t = b$, for all t) and balances its budget by adjusting lump-sum taxes.

Equilibrium Conditions

In a symmetric equilibrium, $K_{jt} = K_t$, $N_{jt} = N_t$, $Y_{jt} = Y_t$, $P^{i,j}_t = P^i_t$, for all $j \in (0,1)$ and $i = D, F$. Equilibrium in the goods market requires that sales on the domestic market be equal to domestic absorption, inclusive of price adjustment costs, which are paid in real units:

$$Y^S_t = C_t + G_t + I_t + \frac{\phi_D}{2}(\frac{P^D_t}{P^D_{t-1}} - 1)^2(\frac{P^D_t}{P^S_t})Y^D_t, \tag{A24}$$

with the price of sales on the domestic market determined through the identity

$$P_t Y_t = P^S_t Y^S_t + P^X_t Y^X_t. \tag{A25}$$

Domestic government bonds are in zero net supply. The equilibrium condition of the currency market is

$$m_t = m^s_t, \tag{A26}$$

where m_t and m^s_t are defined in (8) and (29), respectively.

The equilibrium condition of the housing market is

$$H_t = \bar{H}, \tag{A27}$$

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

The equilibrium condition of the labor market is, from (7) and (A13),

$$(\frac{\omega_t C_t^{-1/\varsigma}}{\eta_N})^{1/\psi_N} = (\frac{\alpha}{1-\alpha})^{-\alpha}(\frac{\omega_t}{r_t^K})^{-\alpha}, \tag{A28}$$

which can be solved for the real wage.

Finally, the balance of payments is given by

$$Y_t^X - Y_t^F + i_{t-1}^W F_{t-1} - \theta_{t-1}^{FB} B_{t-1}^{FP} - \theta_{t-1}^{FC} L_{t-1}^{FB} - \Delta F_t = 0, \tag{A29}$$

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

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Table 1
Benchmark Parameterization: Key Parameter Values

Parameter	Value	Description
Households		
Λ	0.95	Discount factor
ς	0.5	Elasticity of intertemporal substitution
η_N	25.0	Preference parameter for leisure
ψ_N	1.4	Inverse of Frisch elasticity of labor supply
η_x	0.001	Preference parameter for money holdings
η_H	0.02	Preference parameter for housing
ν	0.35	Share parameter in index of money holdings
θ_0^{FB}	0.2	Sensitivity of premium, household holdings of foreign bonds
Producers		
Λ_I	0.7	Distribution parameter, final good
η	1.5	Elasticity of substitution, baskets of intermediate goods
μ^F	1.0	Exchange rate pass-through, imported goods
μ^X	0.5	Exchange rate pass-through, exports
$\varkappa_X$	0.9	Price elasticity of exports
θ_I, θ_F	6.0	Elasticity of demand within groups, intermediate goods
α	0.35	Share of capital, domestic intermediate goods
ϕ_I	25	Adjustment cost parameter, domestic intermediate goods prices
δ_K	0.025	Depreciation rate of capital
Θ_K	14	Adjustment cost parameter, investment
Commercial banks		
κ	0.2	Effective collateral-loan ratio
φ_1	0.05	Elasticity of repayment probability, collateral
φ_2	0.4	Elasticity of repayment probability, cyclical output
ζ^L	4.5	Elasticity of substitution, loans to CG producers
θ_0^{FC}	0.2	Sensitivity of premium, bank foreign borrowing
γ_B	1.0	Direct cost parameter, sterilization bonds
γ_L	0.1	Direct cost parameter, loans
γ	0.1	Joint cost parameter, sterilization bonds and loans
Central bank		
μ	0.2	Required reserve ratio
χ	0.8	Degree of interest rate smoothing
ε_1	2.0	Response of refinance rate to inflation deviations
ε_2	0.4	Response of refinance rate to output deviations
φ_1^R	0.8	Persistence parameter, foreign exchange intervention rule
φ^E	0.8	Relative weight of lagged exchange rate in exchange rate target
φ_1^B	0.8	Persistence parameter, capital controls rule
Government		
ψ_G	0.18	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
Initial Steady-State Values: Key Variables
(In proportion of final output, unless indicated otherwise)

Variable	Description	Value
Real sector		
C	Household consumption	0.6
$I = l^K$	Investment loans to CG producers	0.1
K	Capital stock	4.0
r^K	Rental rate of capital (percent)	0.079
G	Public expenditure	0.18
Financial sector		
q	Repayment probability, loans to CG producers (percent)	0.93
i^B, i^R	Government bond rate, central bank refinance rate (percent)	0.053
i^{CB}	Sterilization bond rate	0.053
i^D	Bank deposit rate (percent)	0.042
i^L	Loan rate, investment lending to CG producers (percent)	0.095
B^F	Household holdings of foreign assets	−0.211
b^{CB}	Stock of sterilization bonds	0.01
b^{CB}/l^K	Ratio of bank loans to sterilization bonds (percent)	10.0
L^{FB}	Foreign borrowing, commercial banks	0.084
F	Net foreign assets	−0.235

Table 3
Negative Shock to World Interest Rate:
Optimal Policy Responses and Welfare Gains, $\varkappa_S = 0.0$

	(1)	(2)	(3)	(4)
Benchmark case: $\gamma = 0.1$				
Regime A $(\kappa^F = 0, \varphi_2^R \geq 0)$				
Optimal response parameter, φ_2^R	22	27	42	45
Gain relative to free floating	0.031	0.039	0.142	0.141
Regime B $(\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A)$				
Optimal response parameter, κ^F	0.47	0.19	0.34	0.12
Gain relative to free floating	0.235	0.076	0.323	0.168
Gain relative to unsteril. intervention	0.210	0.039	0.212	0.032
Regime C $(\kappa^F \geq 0, \varphi_2^R \geq 0)$				
Optimal response parameters, κ^F, φ_2^R	0.33, 48	0.19, 27	0.29, 64	0.12, 47
Gain relative to free floating	0.263	0.076	0.339	0.169
Gain relative to unsteril. intervention	0.239	0.039	0.230	0.032
Alternative case: $\gamma = 0.05$				
Regime A $(\kappa^F = 0, \varphi_2^R \geq 0)$				
Optimal response parameter, φ_2^R	23	27	43	45
Gain relative to free floating	0.034	0.041	0.141	0.139
Regime B $(\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A)$				
Optimal response parameter, κ^F	0.95	0.39	0.68	0.25
Gain relative to free floating	0.249	0.079	0.329	0.167
Gain relative to unsterilized intervention	0.222	0.040	0.220	0.032
Regime C $(\kappa^F \geq 0, \varphi_2^R \geq 0)$				
Optimal response parameters, κ^F, φ_2^R	0.68, 47	0.40, 26	0.58, 64	0.25, 46
Gain relative to free floating	0.272	0.079	0.343	0.167
Gain relative to unsterilized intervention	0.247	0.040	0.235	0.033

Notes: Under regime A (unsterilized intervention) the central bank solves for the degree of exchange rate smoothing under unsterilized intervention. Under regime B (conditional sterilized intervention) the central bank solves for the degree of sterilization, for a given degree of exchange market intervention. under Regime C (optimal policy combination) the central bank solves jointly for the degree of exchange rate smoothing and the degree of sterilization. Welfare gains are measured as percentage changes relative to welfare under free floating or no sterilization. The different columns are: (1) standard welfare, as shown in (33); (2) welfare augmented with volatility of the credit-to-output ratio, with a weight of 0.5; (3) welfare augmented with nominal exchange rate volatility, with a weight of 0.0001; and (4) welfare augmented with volatility of both the nominal exchange rate and the credit-to-output ratio, using the same weights.

Table 4
Negative Shock to World Interest Rate: Asymptotic Standard Deviations under Alternative Policy Regimes, $\gamma = 0.1$, $\varkappa_S = 0.0$

	Free floating	Regime A	Regime B	Regime C
Real variables				
Domestic final sales	0.0058	0.0059	0.0075	0.0080
Employment	0.0022	0.0018	0.0014	0.0010
Consumption	0.0026	0.0028	0.0025	0.0026
Investment	0.0025	0.0024	0.0039	0.0043
Real exchange rate	0.0446	0.0400	0.0406	0.0375
Exports	0.0036	0.0026	0.0032	0.0027
Inflation	0.0058	0.0044	0.0045	0.0034
Financial variables				
Base policy rate	0.0051	0.0037	0.0043	0.0035
Refinance rate	0.0051	0.0037	0.0043	0.0035
Loan rate	0.0052	0.0038	0.0133	0.0147
Government bond rate	0.0044	0.0044	0.0043	0.0044
Real house prices	0.0013	0.0013	0.0012	0.0012
Repayment probability	0.0015	0.0011	0.0017	0.0016
Loan-to-output ratio	0.0021	0.0020	0.0035	0.0039
Bank foreign borrowing	0.0175	0.0230	0.0262	0.0321
Net foreign liabilities	0.0326	0.0282	0.0301	0.0284
Sterilization bonds-loan ratio	0.6034	0.3698	7.1568	8.3974
Sterilization bond rate	0.0329	0.0209	0.3577	0.4197
Policy instruments				
Central bank foreign reserves	−−	0.0132	0.0151	0.0259
Sterilization bonds	−−	−−	0.0075	0.0088

Note: See Note to Table 3 for the definition of regimes A, B and C. Standard deviations for the stock of sterilization bonds are for the nominal value under free floating and regime A, and the real value under regimes B and C.

Table 5
Negative Shock to World Interest Rate:
Optimal Policy Responses and Welfare Gains, $\varkappa_S = 0.004$

	(1)	(2)	(3)	(4)
Benchmark case: $\gamma = 0.1$				
Regime A ($\kappa^F = 0, \varphi_2^R \geq 0$)				
Optimal response parameter, φ_2^R	11	17	36	39
Gain relative to free floating	0.006	0.013	0.114	0.115
Regime B ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A$)				
Optimal response parameter, κ^F	0.76	0.31	0.29	0.11
Gain relative to free floating	0.271	0.084	0.258	0.142
Gain relative to unsterilized intervention	0.266	0.071	0.163	0.030
Regime C ($\kappa^F \geq 0, \varphi_2^R \geq 0$)				
Optimal response parameters, κ^F, φ_2^R	1.0, 7	1.0, 5	0.38, 25	0.16, 28
Gain relative to free floating	0.281	0.120	0.265	0.145
Gain relative to unsterilized intervention	0.276	0.108	0.171	0.034
Alternative case: $\gamma = 0.05$				
Regime A ($\kappa^F = 0, \varphi_2^R \geq 0$)				
Optimal response parameter, φ_2^R	12	18	36	39
Gain relative to free floating	0.008	0.015	0.112	0.113
Regime B ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A$)				
Optimal response parameter, κ^F	1.0	0.44	0.30	0.13
Gain relative to free floating	0.241	0.083	0.191	0.131
Gain relative to unsterilized intervention	0.235	0.069	0.089	0.020
Regime C ($\kappa^F \geq 0, \varphi_2^R \geq 0$)				
Optimal response parameters, κ^F, φ_2^R	1.0, 11	1.0, 8	1.0, 12	0.55, 14
Gain relative to free floating	0.243	0.133	0.238	0.143
Gain relative to unsterilized intervention	0.237	0.120	0.142	0.034

Notes: See notes to Table 3.

Table 6
Negative Shock to World Interest Rate:
Optimal Policy Responses and Welfare Gains, $\gamma = 0.1$, $\varkappa_S = 0.0$, and $\varkappa_1^E = 0.2$

	(1)	(2)	(3)	(4)
Bounded forecast: Adaptive specification, $\varkappa_2^E = 0.5$				
Regime A ($\kappa^F = 0, \varphi_2^R \geq 0$)				
Optimal response parameter, φ_2^R	10	15	42	47
Gain relative to free floating	0.010	0.015	0.176	0.173
Regime B ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A$)				
Optimal response parameter, κ^F	0.67	0.31	0.31	0.14
Gain relative to free floating	0.197	0.074	0.358	0.217
Gain relative to unsterilized intervention	0.188	0.060	0.221	0.053
Regime C ($\kappa^F \geq 0, \varphi_2^R \geq 0$)				
Optimal response parameters, κ^F, φ_2^R	0.30, 53	0.30, 16	0.26, 79	0.14, 52
Gain relative to free floating	0.248	0.074	0.387	0.218
Gain relative to unsterilized intervention	0.240	0.060	0.256	0.054
Bounded forecast: Mankiw-Reis specification, $\varkappa_2^E = 0.5$				
Regime A ($\kappa^F = 0, \varphi_2^R \geq 0$)				
Optimal response parameter, φ_2^R	4	4	40	44
Gain relative to free floating	0.003	0.003	0.218	0.203
Regime B ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A$)				
Optimal response parameter, κ^F	1.00	0.87	0.28	0.15
Gain relative to free floating	0.196	0.085	0.393	0.253
Gain relative to unsterilized intervention	0.193	0.083	0.223	0.062
Regime C ($\kappa^F \geq 0, \varphi_2^R \geq 0$)				
Optimal response parameters, κ^F, φ_2^R	0.29, 44	0.87, 4	0.23, 98	0.14, 52
Gain relative to free floating	0.226	0.086	0.437	0.254
Gain relative to unsterilized intervention	0.223	0.083	0.280	0.064

Notes: See notes to Table 3.

Figure 1
Structure of the Model

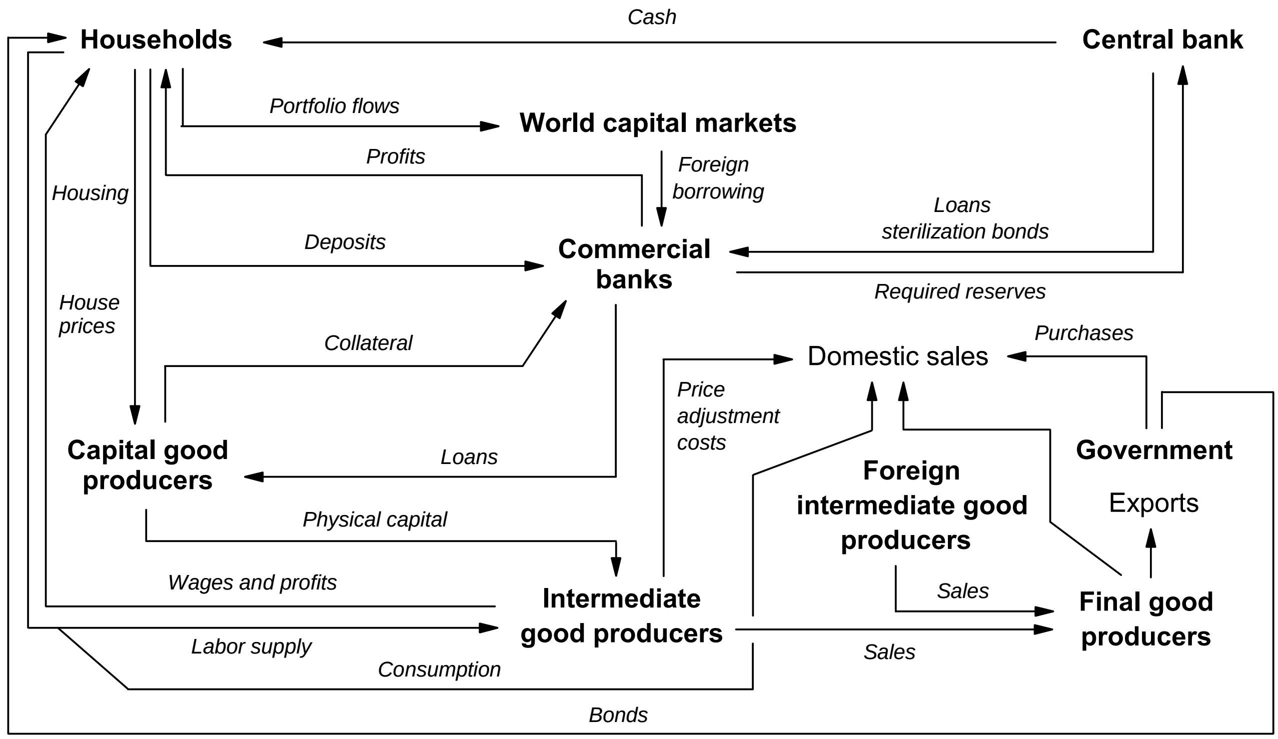
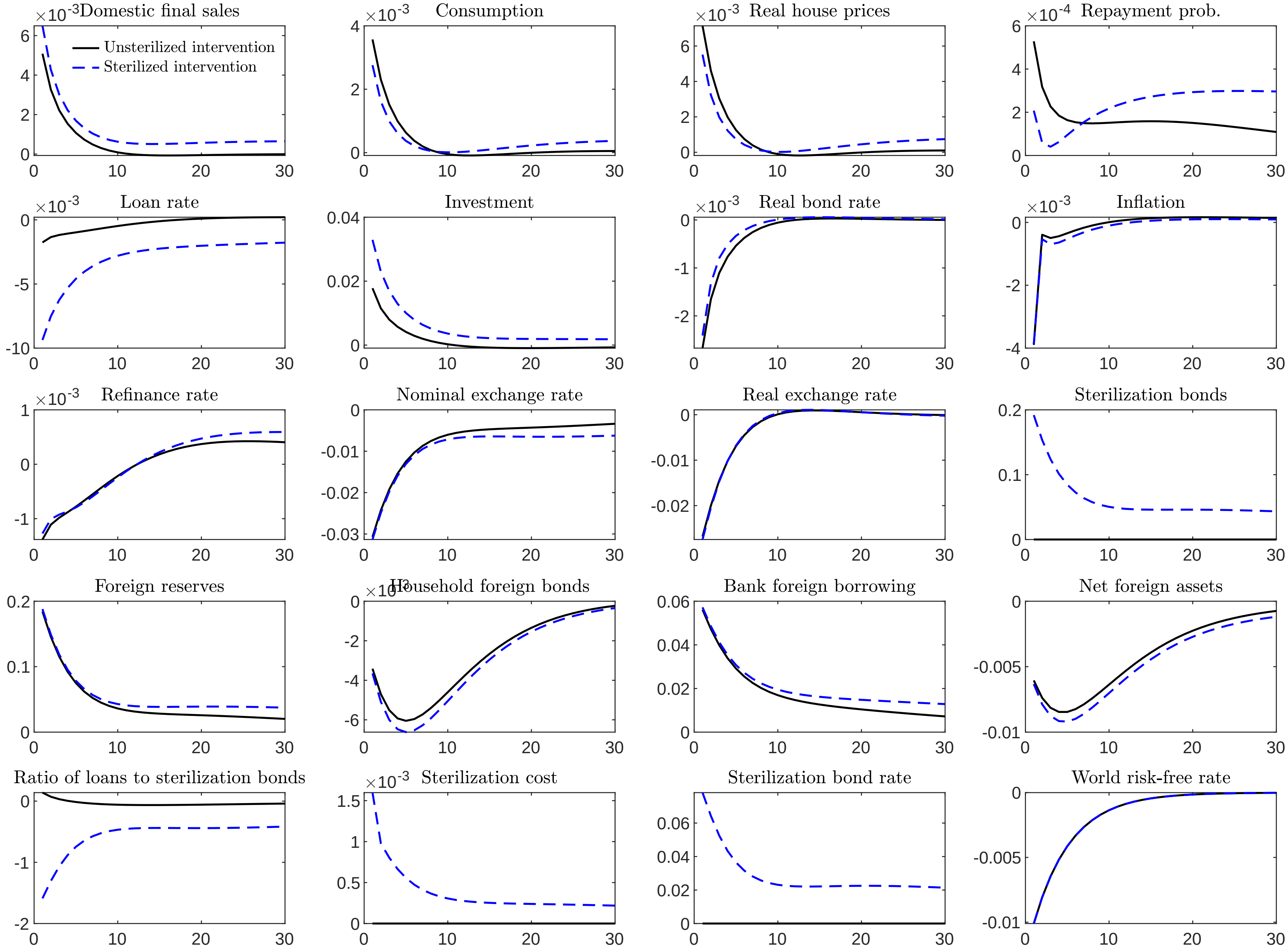
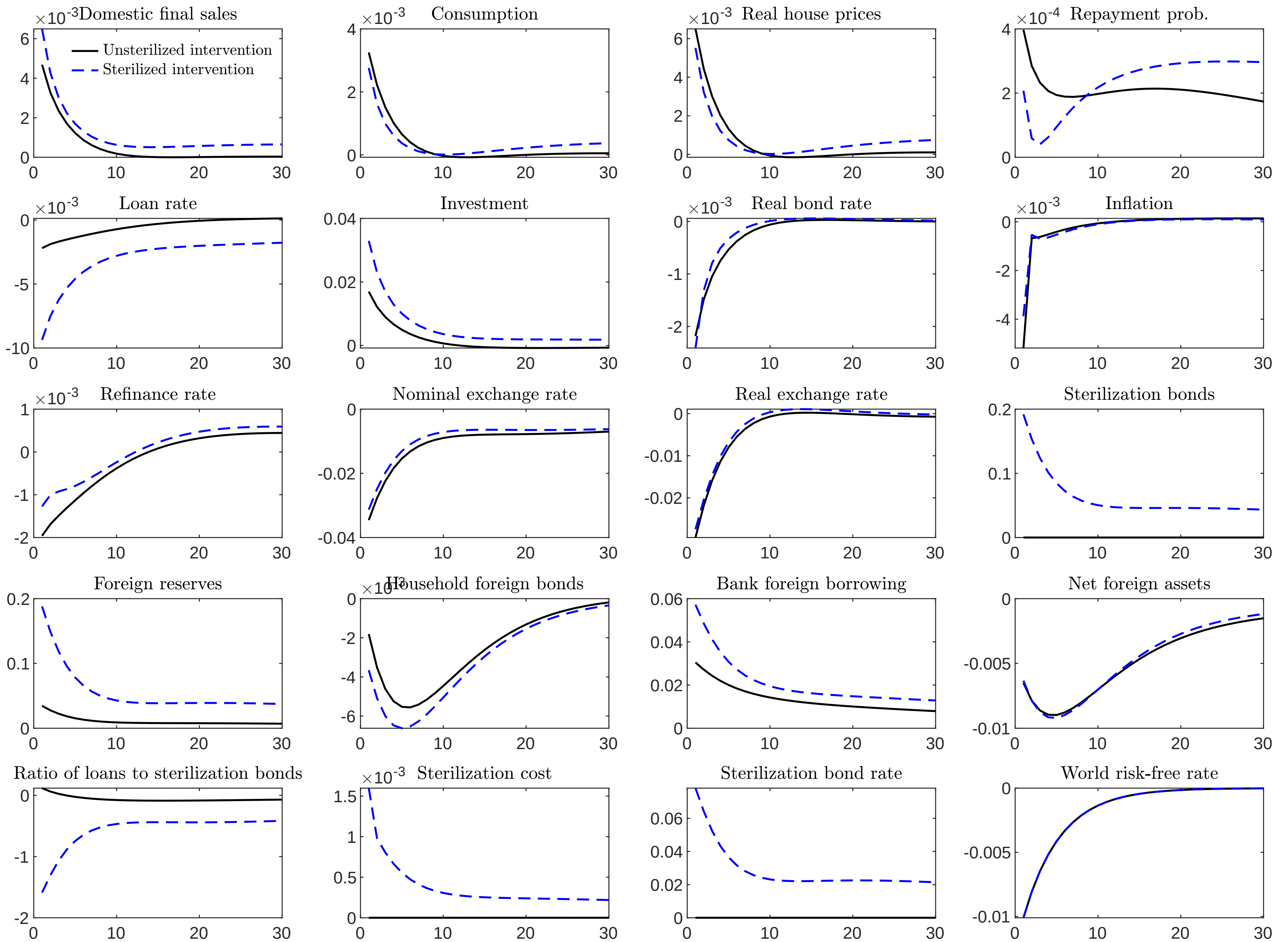


Figure 2
Negative Shock to World Risk-Free Interest Rate: Benchmark Case



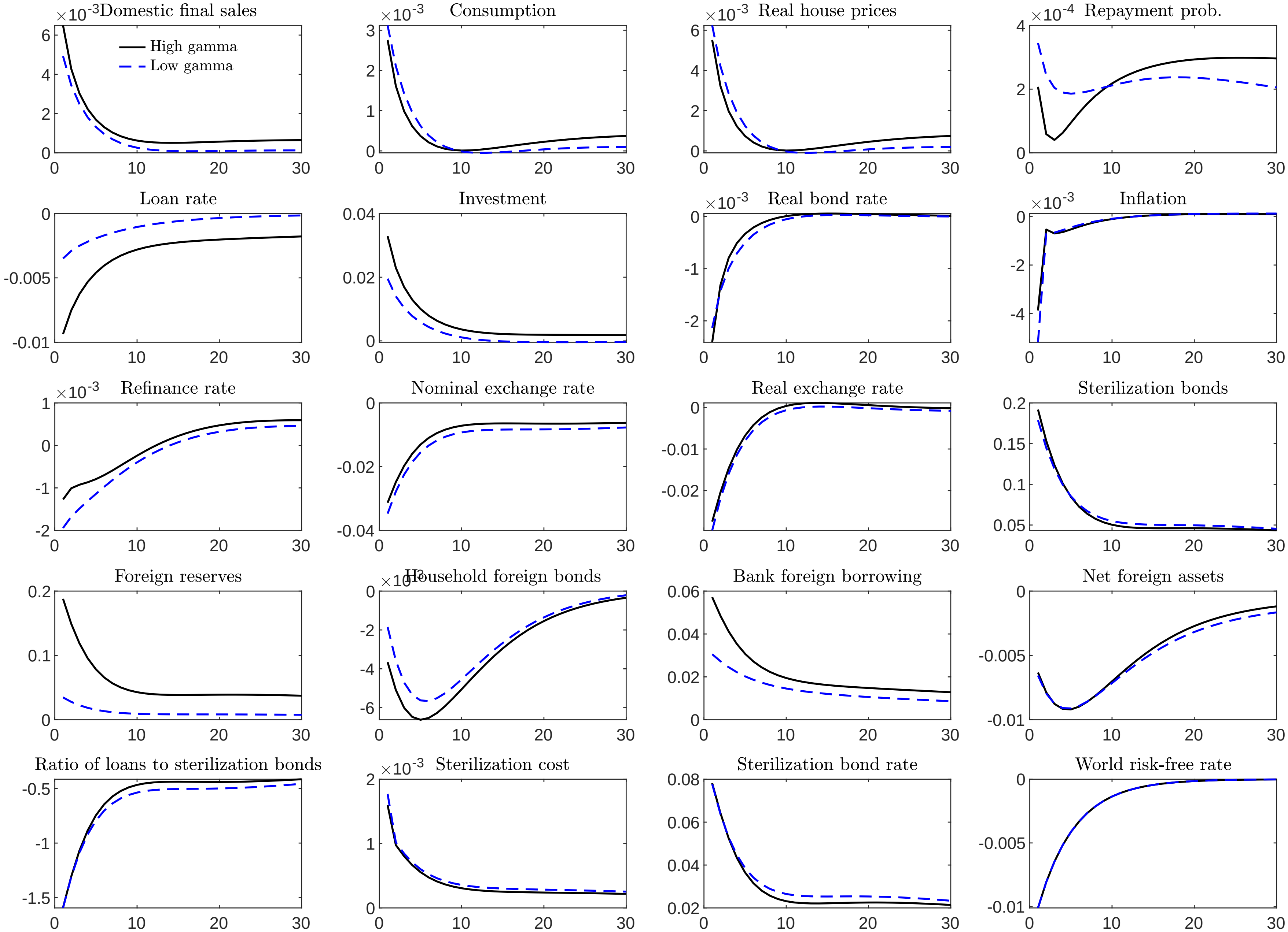
Note: The responses of consumption, investment, domestic sales, real house prices, bank foreign borrowing, foreign reserves, foreign bonds, and the nominal and real exchange rates are expressed as percent deviations from their steady-state values. The responses of the loan rate, the refinance rate, the expected real bond rate, the repayment probability, the inflation rate, and the world risk-free interest rate are expressed as absolute deviations (or percentage points) from their steady-state values.

Figure 2
Negative Shock to World Risk-Free Interest Rate: Benchmark Case



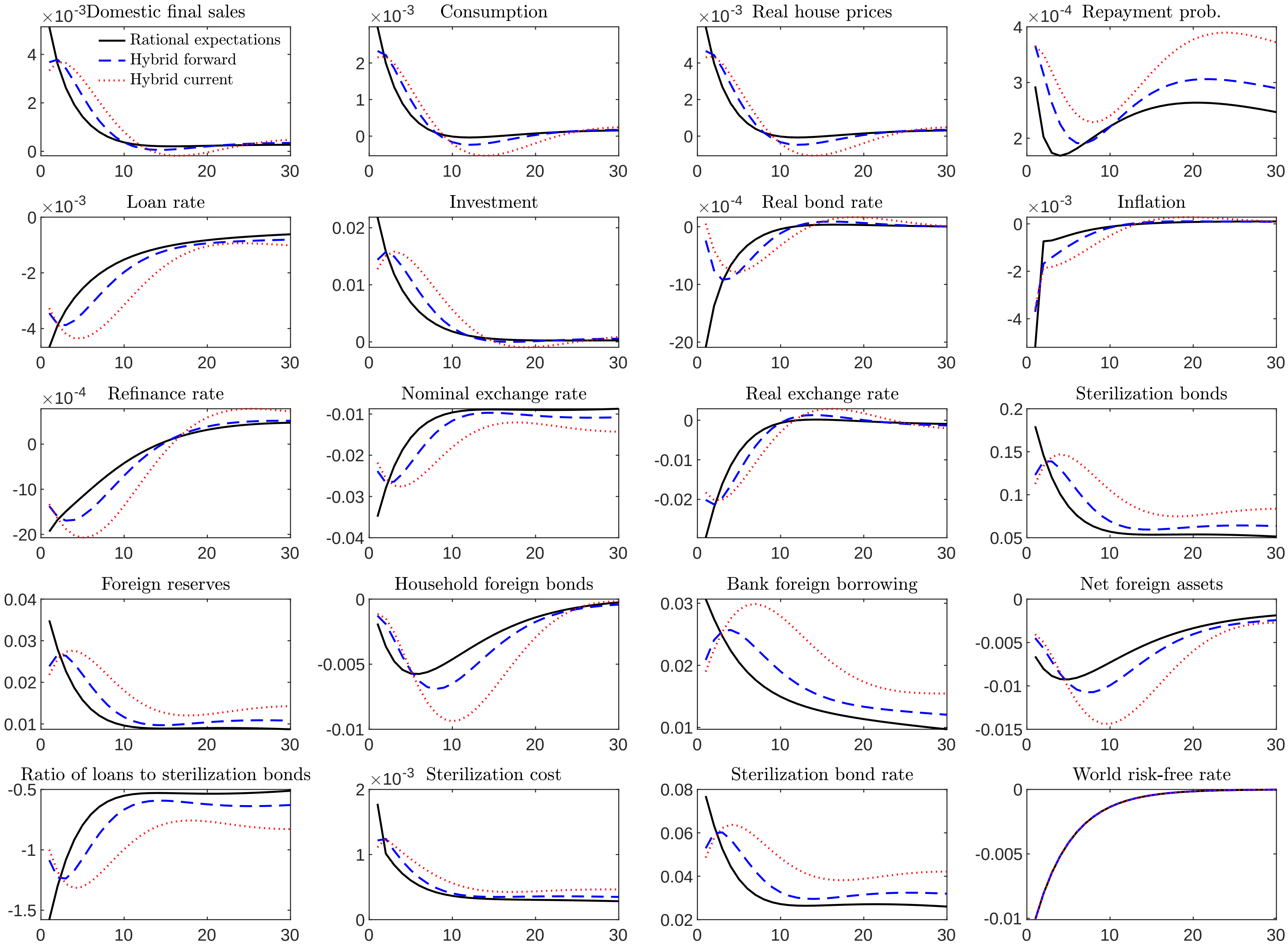
Note: The responses of consumption, investment, domestic sales, real house prices, bank foreign borrowing, foreign reserves, foreign bonds, and the nominal and real exchange rates are expressed as percent deviations from their steady-state values. The responses of the loan rate, the refinance rate, the expected real bond rate, the repayment probability, the inflation rate, and the world risk-free interest rate are expressed as absolute deviations (or percentage points) from their steady-state values.

Figure 3
Negative Shock to World Risk-Free Interest Rate: Weaker Portfolio Effect under Sterilized Intervention



Note: See Note to Figure 2.

Figure 4
Negative Shock to World Risk-Free Interest Rate: Alternative Expectations Schemes under Sterilized Intervention



Note: See Note to Figure 2.