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Foreign Exchange Intervention and Financial Stability

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Abstract

The effects of sterilized intervention are studied in a model with financial frictions. The central bank operates a managed float and issues sterilization bonds. In contrast with most of the existing literature, these bonds are held only by banks, and are imperfect substitutes to loans. The model is parameterized and used to study optimal policy responses to capital inflows associated with a transitory shock to world interest rates. The results show that sterilized intervention can be expansionary due to a *bank portfolio channel* and may exacerbate risks to financial stability. Full sterilization is optimal only when that channel is absent. The optimal degree of intervention is more aggressive when the central bank can choose simultaneously the degree of sterilization; in that sense, and conditional on intervention taking place, the instruments are complements. When the central bank's objective function also accounts for the implicit cost of sterilization, and concerns with that cost are sufficiently high, intervention and sterilization can be substitutes—independently of whether exchange rate and financial stability considerations also matter for policymakers.

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1 Introduction

Recent 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. (2022), for instance, in many of these countries central banks consistently react to foreign exchange market pressure or turbulent times not only with some degree of exchange rate flexibility but also, at times, with heavy intervention. This appears to be the case as well in the broader group of 49 IT and non-IT countries considered by Fratzscher et al. (2023). Moreover, there is evidence that the decision to intervene is increasingly driven by the goal of limiting exchange rate volatility, rather than concerns with its *level* (due to considerations related to competitiveness and the degree of exchange rate pass-through, for instance) or the need to build foreign reserves for precautionary reasons.[1] 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 and prices adjust relatively quickly—is the existence of a financial channel, which may amplify the effect of currency fluctuations induced by external shocks.[2] By lowering the cost of foreign borrowing (measured in domestic-currency terms) faced by local banks, an exchange rate appreciation, for instance, may reduce domestic borrowing costs and lead to an expansion in credit and aggregate demand, in addition to any positive wealth effect associated with downward

[1] At the same time, there are strong arguments to suggest that reserve accumulation through sterilized intervention can help to mitigate the frequency and severity of sudden stops, that is, a sharp current account contraction during episodes of global financial instability, through a precautionary effect (see Arce et al. (2022) and Davis et al. (2023)). However, doing so may involve a cost, in the form of lower consumption.

[2] For a more detailed discussion of the financial channel—sometimes also referred to as the international dimension of the risk-taking channel—see Shin (2015), Bruno and Shin (2015), Carstens (2019), and Akinci and Queralto (2024). Kearns and Patel (2016) and Georgiadis and Zhu (2019) provided some relevant empirical evidence.

pressure on domestic prices. If this channel is strong relative to the conventional (relative price) trade channel, as may be the case in turbulent times, domestic output may increase 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, mitigating exchange rate volatility *ex ante* through intervention becomes a key policy objective from a macroprudential perspective.[3]

The evidence also suggests that, in practice, in both IT and non-IT countries, intervention has often been highly sterilized, with the goal of avoiding 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 money 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. 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.[4]

There is substantial evidence to suggest that sterilized intervention through spot markets has been fairly effective in terms of stabilizing the exchange rate, as documented by Aizenman and Glick (2009), Palma and Portugal (2014) for Brazil, Blanchard et al. (2015), Daude et al. (2016), Ghosh et al. (2017), Kuersteiner et al. (2018), Fratzscher et al. (2019), Jara and Piña (2023), as well as Arango-Lozano et al. (2024), who conducted a meta-analysis of 279 estimations for 19 countries across five decades.[5] 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 common argument in this context is that if domestic and foreign currency-denominated

[3] As discussed by Hassan et al. (2023), mitigating exchange rate volatility may also have benefits in terms of increased investment and higher wages, through its impact on the value of domestic firms.

[4] As can be inferred from our analysis, foreign exchange intervention itself may trigger more capital flows if it creates expectations of future exchange rate appreciation. In turn, these capital flows can fuel credit growth and further stimulate spending. In addition, as argued by Blanchard et al. (2017), the *composition* of capital flows also matters: shocks to non-bond flows, which cannot be neutralized by sterilized intervention, may have a significant effect on credit and asset prices.

[5] For a more detailed discussion of the early empirical evidence, see Villamizar-Villegas and Perez-Reyna (2017, Appendix B) and Agénor and Pereira da Silva (2019).

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 *standard 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.

Some of the recent analytical literature has expanded on this channel by emphasizing various mechanisms through which financial frictions in the foreign exchange market may lead to significant and sustained deviations from uncovered interest rate parity (UIP), as documented by Du and Schreger (2022) and Maggiori (2022). Gabaix and Maggiori (2015) and Cavallino (2019) developed micro-founded models of the foreign exchange market in the presence of financial frictions, which can lead to equilibrium UIP deviations, due to a risk premium.[6] In these models, intermediaries (which are active risk takers in currency markets) are subject to credit constraints that limit their ability to take positions, because creditors recognize that the risk-bearing capacity of these borrowers is limited and that they may divert funds.[7] For these intermediaries to absorb any imbalance between demand and supply of assets denominated in different currencies and clear the foreign exchange market they require a premium, in the form of expected currency appreciation or depreciation. In this setting, sterilized intervention in response to shocks to capital flows alters the balance sheet of constrained intermediaries, which in turn generates changes in the risk premium that are large enough to eliminate the intermediation wedge and the resulting UIP deviation, inducing in the process fluctuations in consumption. By implication, without the credit friction, there would be no deviations from UIP because there would be no restrictions on the ability to intermediaries to take on foreign currency positions.

Another strand of the literature focuses on the case where the asset used for sterilization operations is held by commercial banks. In recent years, a growing number of countries

[6] See also Amador et al. (2020), Fanelli and Straub (2021), Itskhoki and Mukhin (2021, 2023), and Yakhin (2025).for important contributions to this literature. In Itskhoki and Mukhin (2021, 2023), for instance, endogenous UIP deviations result from limits to arbitrage—rather than borrowing constraints, as in Gabaix and Maggiori (2015)—faced by risk-averse intermediaries in an incomplete and segmented international financial market.

[7] Akinci and Queralto (2024) also developed a model in which agency frictions lead to imperfect arbitrage. The mechanism giving rise to UIP deviations in their paper is different from that in the previous contributions: in their case, agency frictions lead to limited arbitrage of the part of borrowers, resulting in the UIP premium being tied to the domestic premium on external finance. However, they do not discuss the issue of expansionary sterilization.

(including China, Brazil, and Indonesia) have indeed used central bank securities, in transactions involving local banks, to sterilize the effect of foreign exchange intervention on the domestic money supply. In this setting, sterilization entails changes in the composition of bank portfolios. In turn, these changes may affect directly the supply of loans and investment. Thus, even when fully sterilized, and effective at mitigating currency fluctuations, foreign exchange intervention, through this *bank portfolio channel*, may have broader consequences for the real and financial sectors.

The implication of both of these strands of the literature 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 in response to capital inflows, they may stimulate credit and activity (through either consumption or investment), and ultimately raise inflation—thereby contributing to a *real* appreciation and possible adverse effects on macroeconomic and financial stability.

Studies focusing on the macroeconomic effects of the bank portfolio channel of foreign exchange intervention are scant and largely ambiguous. In a study of five Asian countries, Cook and Yetman (2012) found that foreign reserve accumulation—largely sterilized through the issuance of non-monetary liabilities held by domestic banks—was accompanied by lower credit growth when pooled data are used. Hofmann et al. (2019), in a more recent study of Colombia, found a similar result. In formal models where domestic banks are subject to occasionally binding collateral or leverage constraints, Chang (2018) and Cavallino and Sandri (2019) also found that sterilized purchases of official reserves can be contractionary when these constraints bind. By contrast, Garcia (2016) argued that, in the presence of a credit channel, sterilized foreign exchange purchases may raise aggregate demand through an expansion of bank credit. Empirical evidence for Brazil appears to support the view that sterilized purchases of foreign exchange can be expansionary—even when intervention does not affect directly the exchange rate. Vargas et al. (2013), in a study focusing on Colombia, and Gadanecz et al. (2014), in a comprehensive multi-country empirical analysis, reached similar conclusions.

This paper addresses several issues that have not been considered explicitly, or thoroughly, in the existing literature. Our initial focus is on the extent to which the broader macroeconomic effects of sterilized intervention affects the central bank's decisions to intervene and sterilize. Intuitively, how much a central bank needs to sterilize should depend on how much it chooses to intervene, and conversely. We then also consider the extent to which the decisions to intervene and sterilize depend on the cost of sterilization—possibly because it affects perceptions of independence and credibility—and how much these decisions are altered when the central bank is also concerned with financial stability.

We address these issues in an open-economy DSGE model with financial frictions, which include monopolistic competition in the loan market, imperfect substitutability between banks' assets, and economies of scope in managing these assets.[8] Households transacting on world capital markets face an intermediation cost, which is increasing in the amount of foreign bonds held. Because they internalize the impact of their decisions on the cost that they face, uncovered interest rate parity does not hold; the intermediation friction implies that domestic and foreign government bonds are imperfect substitutes. At the same time, in order to focus as clearly as possible on the issues highlighted earlier, and to avoid making the model overly complex, our analysis abstracts from the UIP risk premium mechanism emphasized in the literature, as discussed earlier. 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 which, in contrast with almost all of the existing literature, are held only by commercial banks.[9] This is consistent with the fact that, in a growing number of countries, central banks sell their own bonds to domestic banks to sterilize their foreign exchange operations.[10] Importantly, because of economies of scope in managing bank assets, these bonds exhibit cost complementarity with investment loans.[11] The model is parameterized for a stylized 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. Our quantitative analysis also considers the case where the central bank's objective function accounts not only for household welfare but also the cost of sterilization

[8] In addition to being well-supported by the evidence (see, for instance, Carletti et al. (2024)) the assumption of monopolistic banking allows us to focus on the supply side of the credit market and makes the solution of the equilibrium loan rate highly intuitive, given the issue at stake.

[9] In Adler et al. (2019), for instance, the central bank also issues its own sterilization bonds, but these are held only by households.

[10] These countries include Brazil, China, India, and Turkey. Brazil's central bank, for instance, started as early as 2002 to issue its own notes—or LBCs, short-term securities that pay a market-based interest rate—to sterilize its operations.

[11] A nonseparable cost function similar to ours is also introduced in Vargas et al. (2013)—without an explicit reference to economies of scope—to generate imperfect substitution between loans and sterilization bonds. However, they abstract from capital accumulation and consider only lending to households in studying the expansionary efffect of sterilized intervention. In addition, they do not solve for optimal policy rules.

(as noted earlier) and financial stability considerations, to reflect the possibility of biased policy preferences.

Our main results can be summarized as follows. First, whether sterilized intervention is expansionary or not depends on the relative strengths of the standard liquidity effect and the bank portfolio channel alluded to earlier; the stronger the portfolio effect, the more expansionary sterilized purchases of foreign exchange are. This result is at variance with some of the theoretical contributions emphasizing UIP deviations, discussed earlier, such as Cavallino (2019), Amador et al. (2020), and Fanelli and Straub (2021), in which—conditional on a given monetary policy stance—the way the central bank finances its foreign reserve purchases is irrelevant because of Ricardian equivalence. However, even with far-sighted households subject to lump-sum taxation, in more elaborate models such as ours—which accounts, in particular, for a range of financial frictions—the conditions for this result to hold are not satisfied. Second, when the central bank aims solely to maximize household welfare, the optimal degree of intervention is significantly more aggressive (compared to unsterilized intervention) when the central bank can choose simultaneously the degree of sterilization. In that sense, intervention and sterilization are complements at the margin, and sterilized intervention generates sizable welfare gains, both relative to free floating and unsterilized intervention. However, the presence of the bank portfolio channel implies that full sterilization is not optimal. Intuitively, sterilized intervention tends to mitigate volatility in interest rates and consumption (as a result of intertemporal substitution) through the liquidity effect, as described earlier. At the same time, if economies of scope in banking are sufficiently large, sterilized intervention tends to amplify volatility. The existence of this trade-off implies indeed that full sterilization is not optimal—even when the central bank is also explicitly concerned (in addition to household welfare) with exchange rate stability or financial volatility. By contrast, when economies of scope are absent, the bank portfolio channel no longer operates and full sterilization is always optimal—regardless of whether the central bank has additional concerns, beyond household welfare. At the same time, the degree of intervention, when the central bank can choose simultaneously how much to intervene and to sterilize, is the same as under no sterilization, which suggests that the two instruments are again complements.

Third, when sterilization costs are accounted for in the central bank's objective function, and concern with these costs is sufficiently high, the optimal simple policy rule for the central bank is to intervene less and sterilize fully—regardless of whether economies of scope exist. The reason is that for a given degree of sterilization, intervening less mitigates the liquidity effect and lowers the cost of sterilization; as a result, the central bank can sterilize more aggressively. In that sense, there is *burden sharing* between instruments, and intervention and sterilization are now (partial) substitutes. In the absence of the bank portfolio channel, a policy mix that involves less aggressive intervention and full sterilization is also optimal—even when the central bank is concerned as well with financial stability.

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), Alla et al. (2020), Adrian et al. (2022), and Montoro and Ortiz (2023), and consistent with what has become common practice in middle-income countries, 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.[12] Sterilized intervention changes banks' relative holdings of central bank liabilities and therefore affects the exchange rate both directly and indirectly. In the presence of economies of scope, a price-setting condition relating the loan rate directly to the ratio of loans to firms and central bank bonds is derived, and this creates a key channel through which sterilization may affect the economy. 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. Our numerical results replicate the main stylized facts associated with the transmission of shocks to world interest rates, and therefore validate the use of the model as an adequate tool to study the performance of alternative simple rules aimed at insulating the economy to these shocks. Optimal simple rules (both in terms of the degree of exchange rate smoothing and the degree of sterilization) are 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

[12] 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.

independence and credibility); and the case where financial stability considerations also matter. The last two sections consider various extensions of the analysis.

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. Households own real estate property (housing or land), which generates utility-enhancing services; they also make it available, free of charge, to the CG producer that they own, for use as collateral for one-period bank loans.

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. While the deposit market is competitive, monopolistic competition prevails in the credit market. In addition to being consistent with the evidence (see Carletti et al. (2024)), this assumption allows us to capture in a fairly simple manner how default risk affects the pricing of loans. Specifically, the loan rate set by commercial banks incorporates a premium, above and beyond the marginal cost of funding from the central bank. In turn, the premium varies inversely with the probability of loan repayment, which itself depends on collateral values (which fluctuate with real house prices) and cyclical output (which affects unit monitoring costs). Thus, through both channels, the model captures some of the financial amplification effects that figure prominently in modern-day macroeconomics.[13]

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, as is the case in practice. Importantly, these bonds are imperfect substitutes to loans.

[13] See, for instance, Brunnermeier et al. (2013) and Agénor (2020, Chapter 1) for a comprehensive review of alternative approaches.

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

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

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 $\eta_N, \eta_x, \eta_H > 0$ are 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:

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

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

Households derive utility from the liquidity services provided by both cash and bank deposits. At the same time, these assets are imperfect substitutes, because there is no direct return to cash. In addition, the utility benefit of deposits drives a wedge in the spread between the return on domestic government bonds and the return on deposits. Both assets are accounted for because in the model the domestic bond rate is solved from the equilibrium condition of the money market. In turn, accounting for the money market explicitly is essential to capture how sterilization operates, given that in the absence of (full) sterilization, the money supply responds endogenously to changes in official reserves.

The household's flow budget constraint is

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

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 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, defined as

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

with $\theta_0^{FB} > 0$. Thus, the cost of holding foreign bonds is increasing in the amount of bonds held by each individual household. By implication, as discussed next, all households internalize the impact of their decisions on the cost that they face. This specification provides a simple way to introduce imperfect substitutability between domestic and foreign bonds.

Households choose 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, $\{b_{t+s},\ B_{t+s}^F\}_{s=0}^{\infty}$, and housing services, $\{H_{t+s}\}_{s=0}^{\infty}$, so as to maximize (1) subject to (2) to (5), taking the path of domestic interest rates (i_t^B and i_t^D), the world risk-free rate (i_t^W), wages, prices, and inflation (ω_t, p_t^H, and π_t) and all lump-sum transfers and taxes (J_t^B, J_t^I, J_t^K, and T_t), as given. The first-order conditions are

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

$$N_t^j = \left(\frac{\omega_t C_t^{-1/\varsigma}}{\eta_N} \right)^{1/\psi_N}, \qquad \forall j \in (0,1), \tag{7}$$

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

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

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

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

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 and (11) defines implicitly household demand for foreign bonds in the presence of intermediation costs. It yields the standard uncovered interest parity condition when $\theta_0^{FB} \to 0$.

2.2 Commercial Banks

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

$$l_t^{K,i} + b_t^{CB,i} = d_t^i + z_t L_t^{FC,i} + l_t^{B,i}, \tag{12}$$

where $l_t^{K,i}$ represents one-period investment loans, $b_t^{CB,i}$ holdings of sterilization bonds issued by the central bank, $L_t^{FC,i}$ foreign borrowing (in foreign-currency terms), and $l_t^{B,i}$ borrowing from the monetary authority.

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:

$$i_t^{D,i} = i_t^R, \tag{13}$$

where i_t^R is the marginal cost of borrowing from the central bank, or equivalently the refinance rate.

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

$$l_t^{K,i} = (\frac{1 + i_t^{L,i}}{1 + i_t^L})^{-\zeta^L} l_t^K, \tag{14}$$

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

$$1 + i_t^{FC,i} = (1 + i_t^W)(1 + \theta_t^{FC,i}), \tag{15}$$

where $\theta_t^{FC,i}$ is an intermediation cost, which increases with the amount borrowed:

$$\theta_t^{FC,i} = \frac{\theta_0^{FC}}{2} L_t^{FC,i}, \tag{16}$$

where $\theta_0^{FC} > 0$. Thus, the intermediation cost depends on each bank's borrowing. As shown next, all banks internalize the impact of their decisions on the cost that they face.

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

$$\mathbb{E}_t J_{t+1}^{B,i} = q_t^i (1 + i_t^{L,i}) l_t^{K,i} + (1 - q_t^i) \kappa^i \mathbb{E}_t p_{t+1}^H H_t + (1 + i_t^{CB}) b_t^{CB,i} \tag{17}$$

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

where i_t^{CB} the interest rate on central bank bonds. Equation (17) 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 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, $(1 + i_t^{FC,i})\mathbb{E}_t(E_{t+1}/E_t)z_t L_t^{FC,i}$, with the latter accounting for expected depreciation. The term

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, $\Gamma_{l^K b^{CB}} \leqq 0$, that is, higher holdings of central bank bonds lower the cost of lending. There is therefore cost complementarity or economies of scope, that is, lower costs of managing assets jointly, compared to the sum of costs incurred when managing them individually.

Because the issuance of central bank sterilization bonds is a relatively recent phenomenon, we are not aware of formal empirical studies focusing specifically on economies of scope in managing this type of assets and loans. However, there is substantial empirical evidence, most notably by Rossi and Beccalli (2018), Zhang and Malikov (2022), Wu (2024), and Zong et al. (2025), showing that in managing loans and securities—which include government bonds—banks benefit from significant economies of scope in costs. These benefits have been shown to occur through several channels, such as shared infrastructure and expertise (the use of the same risk assessment tools, portfolio management tools, compliance systems, and staff expertise to manage both loan portfolios and holdings of securities), risk diversification, and shared information and technology. Thus, although once again there is no direct evidence of economies of scope related to central bank bonds and loans, there is no reason to believe that banks would not operate so as to reap the benefits resulting from joint management of these assets. In fact, in their regression analysis Gadanecz et al. (2014) found that the expansionary effect of sterilized intervention on bank credit also exists when an *aggregate* measure consisting of government and central bank securities is used.[14] Nevertheless, as discussed later on, we consider the behavior of the loan rate, and conduct the model's simulations, with and without economies of scope, in order to assess how bank portfolio decisions determine the expansionary effect of sterilized intervention.

For tractability, we will focus on the case where $\Gamma()$ takes the form of a generalized, linear homogeneous Leontief function

$$\Gamma(l_t^{K,i}, b_t^{CB,i}) = \gamma_B b_t^{CB,i} + \gamma_L l_t^{K,i} - 2\gamma\sqrt{b_t^{CB,i} l_t^{K,i}}, \tag{18}$$

where $\gamma_B, \gamma_L > 0$ and $\gamma \geq 0$.[15] As discussed later on, parameter γ captures the degree to which economies of scope prevail and plays a critical role in our simulation experiments.

The last term, $x_t^{M,i}$ represents the monitoring cost faced by bank i, and is defined as

$$x_t^{M,i} = \Phi_t \frac{(q_t^i)^2}{2} l_t^{K,i},$$

where Φ_t is a unit cost parameter, which is taken as given by each individual bank.

Each bank determines the lending rate, foreign borrowing, the intensity of monitoring, and holdings of central bank bonds, so as to maximize expected profits (17) subject to (12)-(16) and (18). 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), Cordella et al. (2018), and Carletti et al. (2024)—and that (unit) monitoring costs are countercyclical, as documented in several studies, including Cao

[14] At the same time, it is also possible for holdings of public sector bonds to crowd out lending by commercial banks during episodes of financial stress. This is indeed what appears to have occurred during some recent episodes, as documented by Fratianni and Marchionne (2014), Acharya and Steffen (2015), Gennaioli et al (2018), Bouis (2019), and Pietrovito and Pozzolo (2023) with respect to a shift towards *government* bonds—in effect, a flight to safety. Put differently, the two arguments are not inconsistent.

[15] See Vargas et al. (2013), Agénor and Pereira da Silva (2017), and Agénor et al. (2024) for a similar specification. To ensure that Γ_{l^K} and $\Gamma_{b^{CB}}$ are both positive, the restrictions $\gamma_B \geq \gamma(l_t^{K,i}/b_t^{CB,i})$ and $\gamma_L \geq \gamma(b_t^{CB,i}/l_t^{K,i})$ must hold.

et al. (2023), the solution of the bank's optimization problem in a symmetric equilibrium is shown in Appendix B to be

$$1+i_t^L=\frac{\zeta^L}{(\zeta^L-1)q_t}\left\{1+i_t^R+\gamma_L-\gamma(\frac{b_t^{CB}}{l_t^K})^{0.5}\right\}, \tag{19}$$

$$L_t^{FC}=\frac{(1+i_t^R)-(1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}{\theta_0^{FC}(1+i_t^W)\mathbb{E}_t(E_{t+1}/E_t)}, \tag{20}$$

$$q_t=\varphi_0(\frac{\kappa\mathbb{E}_t p_{t+1}^H/\tilde{p}^H}{l_t^K/\tilde{l}^K})^{\varphi_1}(\frac{Y_t}{\tilde{Y}})^{\varphi_2}, \tag{21}$$

$$\frac{b_t^{CB}}{l_t^K}=\frac{\gamma^2}{(i_t^R+\gamma_B-i_t^{CB})^2}, \tag{22}$$

where $\varphi_1,\varphi_2>0$ and $\tilde{Y}$ is the steady-state level of final output and $\tilde{p}^H$ and $\tilde{l}^K$ are steady-state values of real house prices and real lending, respectively.[16] 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.

If economies of scope do not exist ($\gamma=0$), and ζ^L is large enough, equation (19) gives $q_t(1+i_t^L)\simeq 1+i_t^R+\gamma_L$ whereas equation (22) yields $i_t^{CB}=i_t^R+\gamma_B$; combining these two expressions yields $1+i_t^{CB}-\gamma_B=q_t(1+i_t^L)-\gamma_L$, which indicates that cost-adjusted, expected rates of return on loans and central bank bonds must be equal.[17] Thus, bank loans and holdings of central bank bonds are perfect substitutes. As discussed further later on, in such conditions the bank portfolio channel is inoperative.

Substituting equation (22) in (19) yields

$$1+i_t^L=\frac{\zeta^L}{(\zeta^L-1)q_t}\left\{1+i_t^R+\gamma_L-\frac{\gamma^2}{i_t^R+\gamma_B-i_t^{CB}}\right\}, \tag{23}$$

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 (19), (22) and (23) help to illustrate, in partial equilibrium, the bank portfolio channel associated with sterilized intervention.

[16] The countercyclicality of monitoring costs, which relate to existing loans, is alo consistent with the broader literature showing that bank credit standards (including screening and origination) tend to tighten during economic contractions and loosen during expansions.

[17] If the cost parameters γ_B and γ_L are the same, this condition takes the standard form $1+i_t^{CB}=q_t(1+i_t^L)$.

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 (19)) 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 (22)) an increase on their rate of return and (as implied by (23)) 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 (30)), 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 economies of scope exist (that is, $\gamma > 0$ in the cost function (18)), 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.

Note also that borrowing from the central bank, $l_t^{B,i}$, is derived residually from the balance sheet constraint (12), once banks have determined how much sterilization bonds they want to hold and how much to borrow abroad—as determined from (20) and (22)—and given the amount of deposits households want to hold and the amount of loans that firms require to finance investment. Put differently, central bank lending is *not* an independent policy instrument.

2.3 Central Bank

As noted earlier, the central bank supplies liquidity to commercial banks through a standing facility: its supply of funds is perfectly elastic at the prevailing policy rate. It also operates a managed float regime and engages in sterilized intervention. Its balance sheet is given by

$$z_t R_t^F + l_t^B = m_t^s + b_t^{CB} + nw_t, \tag{24}$$

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.

To model foreign exchange intervention, we follow most of the literature by relating directly changes in foreign reserves to exchange rate fluctuations through a simple symmetric rule:

$$R_t^F = (R_{t-1}^F)^{\varphi_1^R}[R_m^F(\frac{E_t}{E_t^T})^{-\varphi_2^R}]^{1-\varphi_1^R}, \tag{25}$$

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

$$E_t^T = E_{t-1}^{\varphi^E}\tilde{E}^{1-\varphi^E}, \tag{26}$$

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*, that is, mitigating exchange rate fluctuations. With $\varphi^E = 1$, rule (25) is similar to the rule specified in Devereux and Yetman (2014), Benes et al. (2015), Lama and Medina (2020), and Katagiri (2024), for instance.[18] 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.[19]

[18] An alternative specification would be to assume that the central bank intervenes systematically to stabilize the *real* exchange rate, as in Vargas et al. (2013) and Adrian et al. (2024), for instance, rather than the nominal value of the currency, as in (25). However, there is scant empirical evidence to support such a rule. Moreover, the difference may not matter greatly if the degree of price stickiness is relatively high.

[19] In principle, of course, not all movements in the exchange rate warrant an intervention—only those that can be described as non-fundamental, such as, for instance, those driven by risk appetite shocks. However, in the real world, given the time frame of intervention, policymakers rarely have the ability to distinguish between exchange rate changes due to fundamentals and other factors. As a result, there is inevitably some degree of inefficiency associated with simple rules of the type discussed in this paper.

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

$$b_t^{CB} - \frac{b_{t-1}^{CB}}{1+\pi_t} = \kappa^F z_t \Delta R_t^F, \tag{27}$$

where $\kappa^F \in (0,1)$ measures the degree of sterilization. Unsterilized intervention corresponds therefore to $\kappa^F = 0$. Substituting (25) in (27), and the result in the loan rate equation (19), shows that sterilized intervention, in the presence of economies of scope, creates a channel through which exchange rate fluctuations may affect credit market conditions.

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 (24) expressed in nominal terms and substituting (27) in the resulting expression yields[20]

$$m_t^s = \frac{m_{t-1}^s}{1+\pi_t} + (1-\kappa^F) z_t \Delta R_t^F + (l_t^B - \frac{l_{t-1}^B}{1+\pi_t}), \tag{28}$$

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. It is important to note that in this model, changes in bank lending are *not* a policy instrument and therefore cannot be used to "sterilize" changes in foreign reserves. As discussed earlier, with the supply of liquidity by the central bank being perfectly elastic at the going refinance rate, l_t^B is determined residually from the balance sheet of commercial banks.[21]

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. This cost can be significant. In Brazil, for instance, the quasi-fiscal cost of foreign reserves amounted to 2.7 percent of GDP during 2010-11 (see Garcia (2016)). As

[20] In nominal domestic-currency terms, equation (24) 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 (27), $P_{t-1}/P_t = 1/(1+\pi_t)$, 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 (28).

[21] For simplicity, and given the focus of this paper, we abstract from open-market operations (through the sale and purchase of short-term government securities) aimed at sterilizing the impact of liquidity injections associated with central bank lending to commercial banks. As a result, changes in domestic bank borrowing have a one-to-one effect on the monetary base, as shown in equation (28). Accounting for these operations would not qualitatively affect our results as long as they are not complete.

estimated by Adler and Mano (2021), 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.[22]

Measured in gross domestic-currency terms per unit, this quasi-fiscal cost can be written as $1 + i_t^{CB} - (1 + i_t^W)E_t/E_{t-1}$.[23] Alternatively, in net terms, the total cost of sterilization, SC_t, can be defined at the beginning of period t as[24]

$$SC_t = i_{t-1}^{CB} \frac{b_{t-1}^{CB}}{1+\pi_t} - [\frac{(1+i_{t-1}^W)E_t}{E_{t-1}} - 1]z_t R_{t-1}^F. \tag{29}$$

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

$$\frac{1+i_t^R}{1+\tilde{\imath}^R} = (\frac{1+i_{t-1}^R}{1+\tilde{\imath}^R})^{\chi} \left\{ (\frac{1+\pi_t}{1+\pi^T})^{\varepsilon_1} (\frac{Y_t}{\tilde{Y}})^{\varepsilon_2} \right\}^{1-\chi}, \tag{30}$$

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:

$$\frac{1+i_t^W}{1+\tilde{\imath}^W} = (\frac{1+i_{t-1}^W}{1+\tilde{\imath}^W})^{\rho_W} \exp(\xi_t^W), \tag{31}$$

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, and central bank liquidity. In particular, (as noted

[22] Note that these costs are *quasi*-fiscal because they are calculated *ex post*, in the absence of default. See Amador et al. (2020) for a further discussion of measurement issues associated with the costs of sterilized foreign exchange intervention.

[23] A similar measure is used in Adrian et al. (2022).

[24] As indicated 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. Note also that, as argued by Cukierman (2019), the cost of sterilization could be measured in *foreign*-currency terms; but this made little difference to our results.

earlier) 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 (30). The market for cash determines the equilibrium value of the nominal interest rate on government bonds, which therefore adjusts to changes in the money supply under partial sterilization operations.[25] Combining the model's budget constraints and these equilibrium conditions yields the balance of payments (or external balance) equilibrium condition, from which changes in the economy's net foreign asset position, defined as $F_t = R_t^F + B_t^F - L_t^{FC}$, can be determined.

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 and government bonds must all be equal, that is, $\tilde{\imath}^R = \tilde{\imath}^B = \Lambda^{-1} - 1$. The no-arbitrage condition (13) 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 $\tilde{B}^F = (\tilde{\imath}^W - \tilde{\imath}^B)/\theta_0^{FB}(1 + \tilde{\imath}^W)$, 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 $\tilde{L}^{FC} = (\tilde{\imath}^R - \tilde{\imath}^W)/\theta_0^{FC}(1 + \tilde{\imath}^W)$. 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.

[25] Thus, in contrast to simpler models where the endogeneity of the government bond rate is ignored, our setting does *not* require the policy rate to respond to money supply fluctuations when foreign exchange market intervention is not fully sterilized.

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 relative weight of labor in the utility function, η_N, is set at 25, to ensure that in the steady state households devote one third of their time endowment (normalized to unity) 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 is similar to the value used by Akinci (2021) and 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.[26] 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. the capital adjustment cost parameter, Θ_K, is set at 14 to generate a path for investment that is about three to four times more volatile than output in response to shocks, as documented in empirical studies.

With respect to commercial banks, consistent with the evidence on the difficulty of seizing collateral in middle-income countries, the effective share of the housing stock used as collateral, 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 0.2, the same value as θ_0^{FB}. 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 channel, as captured by γ, is relatively strong initially.[27]

Regarding the central bank, 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 also set at 0.8, consistent with greater emphasis on *leaning against the wind* by the central bank.

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.

[26] See for instance Ollivaud et al. (2015) and Adler et al. (2023). 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.

[27] An empirical strategy could be developed to pin down the value of γ more accurately. However, our goal here is to illustrate theoretically how the bank portfolio channel operates, and why it matters; consequently, we focus on a comparison of the model's performance with different values of γ.

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.[28] 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 $\theta_0^{FC} = 0.2$, and with the same values of $\tilde{\imath}^W$ and $\tilde{\imath}^B$, the ratio of bank foreign debt to final output $\tilde{L}^{FC} = (\tilde{\imath}^B - \tilde{\imath}^W)/[\theta_0^{FC}(1+\tilde{\imath}^W)]$ is 8.4 percent. By implication, with the initial level of foreign reserves $\tilde{R}^F = 0.05$ percent of output, the economy's net stock of foreign assets, $\tilde{F} = \tilde{R}^F + \tilde{B}^F - \tilde{L}^{FC}$, is negative, at -23.5 percent of final output. Thus, the country considered is a net debtor initially.

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.[29] 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 ($\kappa^F = 1.0$). In both cases, economies of scope are assumed to prevail, so that $\gamma = 0.1$.[30]

[28] To calibrate the deposit rate, and ensure that $\tilde{\imath}^D < \tilde{\imath}^B$ for deposits take a finite value (see (9)), we account for required reserves, as a ratio $\mu \in (0,1)$, and therefore (13) is replaced by $i_t^{D,i} = (1-\mu)i_t^R$. This ratio is set at 0.2, consistent with the data reported by Cordella et al. (2014) for a group of large economies in Latin America.

[29] See, for instance, Friedrich and Guérin (2020) 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. An alternative financial shock to consider would be a shock to the demand for international assets, as in Itskhoki and Mukhin (2021), for instance.

[30] Under unsterilized intervention, the stock of central bank bonds does not change, so the portfolio effect (and its impact on the loan rate) operates only through changes in the supply of investment loans.

The results are shown in Figure 2.[31] 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.[32] 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. In addition, because the reduction in the refinance rate lowers the deposit rate and the level of deposits, while investment loans increase, borrowing from the central bank increases—despite higher foreign borrowing. As can be inferred from (28), this also contributes to an increase money supply. 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 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 in the absence of sterilization is consistent with the well-established stylized facts associated with the transmission of shocks to world interest rates—as documented by Agénor and Montiel (2015, Chapter 13), for instance—and their macroeconomic effects on middle-income countries: a capital inflow (a *sudden flood*, as discussed in chapter 1), a currency appreciation (both nominal and real),

[31] In the initial steay state, stocks of foreign reserves and central bank bonds take positive values. Thus, under pure floating, changes in both the real stock of these bonds and the sterilization cost are not exactly zero, due to valuation effects associated with inflation, and (in the case of the sterilization cost) fluctuations in the foreign interest rate and the exchange rate. However, for clarity, results uner a pure float are not reported in the figures.

[32] As implied by equation (A5) in Appendix A, 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.

increased liquidity, an expansion in credit and aggregate demand (the latter occurring both through higher consumption and investment), and a current account deficit. The ability of our parameterized model to replicate these stylized facts in the benchmark case of unsterilized intervention validates its use later on to study the performance of alternative simple rules in response to global financial shocks.

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. Because the reduction in the refinance rate lowers the deposit rate and the level of deposits, while investment loans increase, central bank borrowing increases once again, despite higher foreign borrowing. This is accompanied by an increase in liquidity. However, because intervention is sterilized, this increase is smaller than before; the drop in the nominal bond rate required to maintain equilibrium of the money market is therefore also smaller, which mitigates the initial fall in the real bond rate and the expansion in consumption.[33] At the same time, for commercial banks to willingly hold the greater supply of sterilization bonds, the interest rate on these bonds must increase.[34] 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.[35]

To assess the role of the strength of the bank portfolio channel, Figure 3 shows the

[33] 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.

[34] As implied by (22), $i_t^{CB} = i_t^R + \gamma_B - \gamma(l_t^K/b_t^{CB})^{0.5}$. 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. At the same time, as implied by (19), 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.

[35] As can be inferred from formula (29), 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.

impulse responses under full sterilization ($\kappa^F = 1.0$), when the cost parameter γ is close to 0.0 and equal to the benchmark value of 0.1, for the same values of $\varphi_2^R = 5$ as in Figure 2. The figure shows, as expected, that the drop in the loan rate is less significant when economies of scope are absent. As a result, the increase in investment is 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; without economies of scope, the expansionary effect of sterilized intervention is mitigated. As discussed next, this result has important implications for the solution of optimal policy rules.

6 Optimal Simple Rules

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 ($\varphi_2^R = \varphi_2^R\big|_A$, $\kappa^F \geq 0$), which essentially captures a sequential policy decision process; 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 (policy combination), the optimal policy rule under that regime may differ significantly from what is obtained under regime B (conditional sterilized intervention). Policies are computed under commitment, that is, under the assumption that policymakers have the ability to deliver on past promises—no matter what the current situation is today.

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. As discussed earlier, these considerations may reflect concerns with central bank independence and credibility, as well as a broader institutional mandate delegated by society, as suggested by the evidence since the global financial crisis.

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

$$W_t = \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s u(C_{t+s}, N_{t+s}, x_{t+s}), \tag{32}$$

where $u()$ is the period utility function, which is given from (1) as $u() \simeq (1-\varsigma^{-1})^{-1}C_t^{1-\varsigma^{-1}} - \eta_N(1+\psi_N)^{-1}N_t^{1+\psi_N} + \eta_x \ln x_t$.[36]

To calculate numerically the optimal policy rules, we solve for the conditional welfare-maximizing value of the reaction parameters φ_2^R in (25) and κ^F in (27), individually or jointly, based on a second-order approximation of both the model and the objective function (32), subject to the initial state of the economy ($t = 0$) being the deterministic steady state. As shown in Appendix D, the approximation of (32) gives

$$\mathcal{W}_t \simeq \frac{1}{1-\Lambda}\left\{\tilde{u} - \frac{\tilde{C}^{1-\varsigma^{-1}}}{2\varsigma}\text{Var}(\hat{C}_t) - \eta_N\psi_N\frac{\tilde{N}^{1+\psi_N}}{2}\text{Var}(\hat{N}_t) - \frac{\eta_x}{2}\text{Var}(\hat{x}_t)\right\}, \tag{33}$$

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 γ close to 0.0. 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

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

on volatility; as a result, welfare under activism follows an inverted U-shape, which is well illustrated in Figures 4 and 5. 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 (to a lower extent, given our calibration) real money balances. This also stabilizes output and employment. Thus, welfare tends to increase at first. However, as intervention becomes more aggressive, the expansion in domestic liquidity is amplified. 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 $\gamma = 0.1$ and 3.6 percent when γ is close to 0.0.

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 ($\psi_F = 0.47$ when $\gamma = 0.1$). The reason is that the degree of sterilization also has a nonlinear effect on volatility and 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 the loan rate and investment—which eventually leads to more volatility in output and prices, the policy and bond rates, as well as consumption and money holdings. At the optimal value of the sterilization coefficient (the point at which positive and negative effects on welfare 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, $\psi_F = 1$), even if sterilization costs are not accounted for, as is the case for the moment.

When the degrees of intervention and sterilization are chosen jointly (regime C), and $\gamma = 0.1$, the optimal policy rule 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 reduced volatility in prices and interest rates, 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 aggressively than under regime A; but because of the bank portfolio channel, it cannot sterilize more than 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 prices, 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). Under both regimes B and C, the key reason why the welfare gain is fairly large relative to free floating (as well as regime A) is because more aggressive intervention mitigates more significantly exchange rate volatility. These outcomes are illustrated in the left-hand side of Figures 4 and 5, for $\gamma = 0.1$ and γ close to 0.0.

As expected, when economies of scope are absent (that is, parameter γ is close to 0) the bank portfolio channel is shut down; under both regimes B and C it is now optimal to fully sterilize ($\kappa^F = 1$). Note also that in both cases there is no conflict in the use of intervention and sterilization: κ^F is higher, while φ_2^R is the same, under regimes B and C, compared to regime A. In that sense, the optimal policy rule entails *burden deepening*; the two instruments are complements—conditional of course on intervention taking place, given that otherwise sterilization is irrelevant.

The first column of Table 4 displays the asymptotic variances of a range of variables, real and financial, for $\gamma = 0.1$, 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 when intervention is sterilized (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.[37]

6.2 Accounting for Sterilization Costs

Consider now the case where the central bank's objective function accounts for sterilization costs. The key reason for doing so is the broader view that quasi-fiscal losses may 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.[38] 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.[39] This, in turn, may generate greater persistence in inflation expectations and increased financial volatility. 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 (34), the magnitude of sterilization costs.

It is important also to note that the sterilization cost, as defined in (29), is an *implicit* cost, which captures policymakers' concerns with balance sheet vulnerabilities, and is therefore not directly reflected in the household welfare function or, more specifically, mean consumption.[40] If the central bank cares more about this cost than the representative agent, and the distortion that it creates is taken to be invariant to the exchange rate policy regime, it should be accounted for explicitly when solving for optimal policy rules. Indeed, if the central bank's policy objective accounts not only for welfare of the representative

[37] Similar results are obtained when sterilization costs are accounted for in the central bank's objective function, as discussed next.

[38] 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.

[39] See Stella and Lonnberg (2008), Cook and Yetman (2012), 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.

[40] Because central bank profits are transferred to the government, and households benefit from lump-sum transfers by the government (as shown in Appendix A), central bank profits and losses from sterilization do matter to them. However, what we are emphasizing here are the balance sheet vulnerabilities that the central bank is concerned with.

household but also the cost of sterilization, as defined in (34)—implying therefore *biased preferences*, as discussed in a related context by Agénor and Jackson (2022)—the optimal degrees of exchange rate smoothing and sterilization may both be affected.

We capture sterilization costs by adding the term $-\varkappa_S \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s SC_{t+s}$ to (32), where SC_t is defined in (29) and $\varkappa_S \geq 0$ is a parameter. Instead of (33), the approximation that we use is now defined as

$$\mathcal{W}_t \simeq \frac{1}{1-\Lambda}\left\{\tilde{u} - \frac{\tilde{C}^{1-\varsigma^{-1}}}{2\varsigma}\text{Var}(\hat{C}_t) - \frac{\tilde{N}^{1+\psi_N}}{2\eta_N^{-1}\psi_N^{-1}}\text{Var}(\hat{N}_t) - \frac{\eta_x}{2}\text{Var}(\hat{x}_t)\right\} - \varkappa_S \mathbb{E}_t \sum_{s=0}^{T} \Lambda^s SC_{t+s}, \tag{34}$$

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

To perform this experiment, we set $T = 6,000$ to compute the last term of (34) and we vary the parameter $\varkappa_S$ between 0.001 and 0.01, with a step of 0.001.[41] The results show that, below a value of 0.002, the conclusions reached earlier remain essentially the same; in particular, full sterilization is optimal when the bank portfolio channel is absent (γ close to 0.0), and intervention and sterilization are complements when both can be chosen optimally by the central bank. Above that value, however, while the first result continues to hold, the second does not.

To illustrate outcomes when sterilization costs matter in the central bank's objective function, column (1) in Table 5 shows the results with $\varkappa_S = 0.005$. For comparative purposes, we naturally assume that under regime A (no sterilization) the central bank does not care about the cost of sterilization. Thus, the results shown in Table 5 under that regime are the same as in Table 3. For the other regimes, consider first the case where $\gamma = 0.1$. Under regime B it is (as expected) optimal to sterilize less; the optimal value of κ^F is 0.44, compared to 0.47 in Table 3. However, the difference is not large, because under that regime the central bank intervenes as much as under regime A. Under regime C, it is now optimal to intervene *significantly less* compared to regime A (and thus B), and also less aggressively than under the same regime 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. The intuition is that at low levels

[41] The choice of these relatively low values of $\varkappa_S$ are dictated in part by the fact that our measure of sterilization costs is defined in level terms, which are therefore of a diffferent order of magnitude compared to the variances which comprise the second-order approximation of the utility function. The range considered is also sufficient to illustrate our results.

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—which is the case when, for instance, 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 in the interval $(0.005, 0.01)$ and beyond.

Consider now the case where the cost parameter γ is close to 0.0. Under regime C it is optimal to fully sterilize—as is the case when $\varkappa_S = 0$, discussed previously (see Table 3). At the same time, it is again optimal to intervene *less* than in regime A (and thus B). The welfare gain associated with regime C, compared to either free floating or unsterilized intervention, is now substantially higher than under regimes A and B.[42]

The important point, therefore, is that from the perspective of the optimal joint policy rules, the central bank's concern with sterilization costs does not imply (as intuition, based on partial equilibrium analysis, would suggest) that it should *sterilize* less aggressively; rather, if that concern is strong enough, it should *intervene* less aggressively to mitigate, in the first place, the accumulation of foreign reserves and the potential cost of sterilization operations. By doing so, it can act more forcefully to neutralize the adverse effects associated with the conventional liquidity channel—regardless of whether the bank portfolio channel is present or not. Thus, the optimal policy rule involves *burden sharing* between intervention and the degree of sterilization; the two instruments are (partial) substitutes.[43]

[42] Welfare gains under regimes B and C in Tables 3 and 5 are not strictly comparable, given that in the latter case sterilization costs are also accounted for in the central bank's objective function.

[43] Our results are therefore more nuanced than those of Kletzer and Spiegel (2004), who found—in a setting where the central bank chooses the exchange rate to minimize a quadratic intertemporal loss function, defined in terms of output deviations and changes in the exchange rate—that when faced with increased sterilization costs, the central bank would choose to limit sterilization operations and allow the nominal exchange rate to move more freely.

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 (see, for instance, Adrian and Liang (2018)). This matters in part because the transmission mechanisms of monetary and cost-based macroprudential policies are highly intertwined. In some countries, the central bank's institutional mandate has been altered to reflect explicit concerns with financial instability (see Edge and Liang (2019)). As discussed in Agénor and Flamini (2022), Agénor and Jackson (2022), and Agénor et al. (2024), these broader mandates may lead to either a two-stage welfare maximization approach or again to biased preferences, in which the policy authority's objective function accounts not only for household welfare but also for a specific mandate—traditional or not—delegated by society. 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, a natural extension of our analysis is therefore to examine how the optimal policy rule varies when the central bank's objective function reflect also financial stability considerations.

To do so, consider the case where the objective function (32) is augmented with a term $-\varkappa_Z \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda^s (Z_{t+s} - \tilde{Z})^2$, 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 (33) is now replaced by

$$\mathcal{W}_t \simeq \frac{1}{1-\Lambda}\left\{\tilde{u} - \frac{\tilde{C}^{1-\varsigma^{-1}}}{2\varsigma}\text{Var}(\hat{C}_t) - \frac{\tilde{N}^{1+\psi_N}}{2\eta_N^{-1}\psi_N^{-1}}\text{Var}(\hat{N}_t) - \frac{\eta_x}{2}\text{Var}(\hat{x}_t)\right\} - \varkappa_Z \frac{\text{Var}(\hat{Z}_t)}{1-\Lambda}, \quad (35)$$

and similarly in the presence of sterilization costs, as in (34).

To define the financial stability indicator Z_t, we consider three alternative measures. First, 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.[44] Second, in line with the recent focus on the financial stability risks associated with currency fluctuations, and how sterilization can help to mitigate these risks, we take Z_t to be the nominal exchange rate, with a cost parameter

[44] See Agénor and Montiel (2015) and Taylor (2015) for a discussion. Fluctuations in real house prices could also be accounted for, although their predictive power for financial crises is weaker.

of $\varkappa_Z = -0.0001$. Finally, both measures are considered together, with the same cost parameters. The last term in (35) is therefore replaced by $-(1-\Lambda)^{-1}[0.5\text{Var}(l_t^K/Y_t) + 0.0001\text{Var}(\hat{E}_t)]$.[45] 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), 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, under regime C it induces the central bank to both lean less heavily against currency fluctuations and to sterilize less, 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, money holdings, and employment are more volatile, which implies that the welfare gain associated with the optimal joint policy rules (regime C) relative to either free floating or unsterilized intervention (regime A) is significantly lower under measure (2) than with measure (1). These outcomes are illustrated in the right-hand side of Figures 4 and 5 for $\gamma = 0.1$ and γ close to 0.0.

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) under free floating. Finally, when both measures of volatility are added to the welfare function (32), that is, under measure (4), compared to measure (1) the optimal degree of intervention increases significantly under Regime A, and so does the welfare gain relative to free floating—with magnitudes similar to those obtained with 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

[45] 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.

ratio, by increasing financial volatility, are costly from the perspective of the central bank. By contrast, when the bank portfolio channel is absent, that is, when γ is close to zero (lower part of Table 3), it is optimal to fully sterilize—regardless of how financial stability is accounted for. These results are consistent with those obtained in the benchmark case.

When the cost of sterilization is accounted for (Table 5), *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. When the bank portfolio channel operates, 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 by itself or in combination with the volatility of the credit-to-output ratio (measures (3) and (4)), intervention is more aggressive than under measures (1) and (2) but full sterilization is no longer optimal. Intuitively, this is because the bank portfolio channel implies that sterilization has an indirect impact on exchange rate fluctuations. By contrast, what that channel is absent (γ close to zero), full sterilization is again optimal, regardless of how financial stability is measured. Put differently, while it is always optimal to intervene less, regardless of the specification of the central bank's objective function, it is optimal to fully sterilize only when doing so generates no expansionary effect.[46]

7 Extensions

Appendix E considers two main extensions of the analysis. The first involves assuming that exchange rate expectations, instead of being fully rational, are formed on the basis of a hybrid mechanism. It is now well established that alternative assumptions about expectations formation, such as adaptive learning or rational inattention theory, can affect significantly the effects of policy and exogenous shocks (see, for instance, Farhi and Werning (2019) and Gabaix (2020)). In particular, interactions between learning, forecast errors, and financial frictions may amplify financial accelerator effects if misperceptions about future asset prices affect collateral-loan values, which in turn (as in the present model)

[46] Note that in Table 5, under regime B, it is optimal not to sterilize at all under (3) and (4) and γ close to zero. The reason is that the degree of intervention is kept at the same high level established under regime A, and this has a substantial effect (as a result of the central bank issuing a large amount of bonds) on the cost of sterilization.

may amplify fluctuations in investment. It is thus useful to explore how departures from rationality, with respect to exchange rate expectations specifically, affect the response of the model to external shocks and the determination of the optimal sterilization policy.

As shown in Appendix E, the one-period ahead expected exchange rate can now be defined in terms of a weighted average of the rational forecast, and a bounded forecast, which is itself defined using either a standard adaptive mechanism or, as in Mankiw and Reis (2002) and Gelain et al. (2013), for instance, as in terms of the deviation of the past forecast at t from the rational expectations forecast at $t+1$. 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 policy analysis yields outcomes that are similar to those discussed earlier, both with and without accounting for sterilization costs, and alternative measures of financial stability. However, the results could be different in the presence of a *signalling channel*, that is, if intervention affects market expectations of future exchange rates. In particular, as discussed by Fanelli and Straub (2020), 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 second extension involves testing for the existence of a financial channel of exchange rates 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 (16). 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 policy analysis discussed in the benchmark case. A key reason is that, in the model, changes 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. But again, it is possible that a different modeling of the financial channel of the exchange rate (through, for instance, private borrowers' currency mismatches) could alter these results.

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, which are held by banks only and are imperfect substitutes for investment loans. This bank portfolio channel, which is absent in most of the existing literature, 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 (for a given degree of intervention) the joint optimal determination of the degree of sterilization with either monetary policy (possibly through an augmented Taylor rule) or 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.[47] A macroprudential tax on loans, for instance, could neutralize a strong bank portfolio channel and ensure that sterilization does not amplify aggregate fluctuations. A related direction would be to analyze, as in Prasad (2018), Kuersteiner et al. (2018), and Davis et al. (2021), for instance, whether capital controls can be either a complement or substitute to sterilized intervention in managing surges in capital inflows.[48] However, most of 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

[47] See, for instance, Agénor et al. (2018) and the references therein. Note again that, as in Arce et al. (2022) and Davis et al. (2023), official reserves themselves could be viewed as a macroprudential instrument, to the extent that they can help to mitigate the frequency and severity of sudden stops.

[48] Kuersteiner et al. (2018), in particular, found that capital controls amplify the effects of foreign exchange intervention. By contrast, Davis et al. (2021) showed that, under certain conditions, foreign exchange intervention is equivalent to an optimal tax on foreign capital.

banks' foreign exchange exposures, as discussed in the literature—and assess whether the degree of sterilization and the tax rate are complements or substitutes (at the margin) for a given degree of exchange rate flexibility. If the cost of sterilization is high, capital controls and sterilized intervention may well be complements in maximizing welfare and promoting financial stability.[49] The analysis could also be extended to account, as in Bianchi et al. (2021), for the case where banks hold asset and liabilities denominated in domestic and foreign currencies, and the risk of sudden outflows induces them to hold a buffer of liquid assets in foreign currency. This may add an important dimension to the bank portfolio channel and its implications for exchange rate fluctuations.

Yet another issue to explore would be intervention on forward markets, which involves no actual change in foreign reserves, rather than spot markets, as modeled in this paper. Intervention on spot markers remains the norm (see Kohlscheen and Andrade (2014), Domanski et al. (2016), and Patel and Cavallino (2019)). But 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 intervention in spot and non-deliverable forward markets have been used together for quite some time.[50] 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.[51]

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

[49] See Agénor and Pereira da Silva (2023) for a discussion of combinations involving monetary policy, foreign exchange intervention, macroprudential regulation, and capital controls in a simple integrated framework.

[50] Non-deliverable forwards are offshore dollar-settled currency derivatives used by investors with limited access to onshore markets to hedge their exposure or speculate. By their very nature, there is no actual delivery of the underlying currency, and the contracts are merely used to synthetically generate a forward hedge.

[51] Countries in other regions have 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 in domestic (onshore) non-deliverable forward markets, to stabilize its currency.

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 exchange rate. A 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 their implications for macroeconomic and financial stability.

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

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

where WP_{jt}^{F} is the foreign-currency price, is normalized to unity in what follows, 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 in what follows, 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, H_t, 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 $q_t(1+i_t^L)I_t + (1-q_t)\kappa\mathbb{E}_t p_{t+1}^H H_t$, 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, defined as

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

and taking $\{i^L_{t+s}\}^\infty_{s=0}$, $\{p^H_{t+s+1}\}^\infty_{s=0}$, $\{q_{t+s}\}^\infty_{s=0}$, and $\{r^K_{t+s}\}^\infty_{s=0}$ as given. In this expression, $\lambda_t = C_t^{-1/\varsigma}$ is the marginal utility value (in terms of units of consumption) of an additional currency unit of real profits and $\mathbb{E}_t(\Lambda^s \lambda_{t+s} J^K_{t+s+1})$ denotes expected profits at the end of period $t+s$, discounted at the rate $\Lambda^s \lambda_{t+s}$.

The solution to this problem yields[52]

$$\mathbb{E}_t r^K_{t+1} \simeq q_t(1+i^L_t)\mathbb{E}_t \left\{[1+\Theta_K(\frac{K_{t+1}}{K_t}-1)](\frac{1+i^B_t}{1+\pi_{t+1}})\right\} \tag{A20}$$

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

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

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

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 intermediation cost $\Gamma(l^{K,i}_t, b^{CB,i}_t)$ appears in (A22) because it is assumed to be a private resource cost for the banks, not a social cost. This assumption helps to keep the focus on the distortions introduced by economies of scope.

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

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

be equal to domestic absorption, inclusive of price adjustment costs, which are paid in real units:

$$Y_t^S = C_t + G_t + I_t + \frac{\phi_D}{2}(\frac{P_t^D}{P_{t-1}^D} - 1)^2(\frac{P_t^D}{P_t^S})Y_t^D, \tag{A24}$$

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

$$P_t Y_t = P_t^S Y_t^S + P_t^X Y_t^X. \tag{A25}$$

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

$$m_t = m_t^s, \tag{A26}$$

where m_t and m_t^s are defined in (8) and (28), 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, combining budget constraints, the balance of payments is given by

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

where $F_t = R_t^F + B_t^F - L_t^{FC}$ 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	Relative weight of labor in utility function
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		
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
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	0.011
b^{CB}/l^K	Ratio of bank loans to sterilization bonds (percent)	10.0
L^{FC}	Foreign borrowing, commercial banks	0.084
R^F	Foreign reserves, central bank	0.05
F	Net foreign assets	−0.235

Table 3
Negative Shock to World Interest Rate:
Optimal Simple 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: $\gamma \simeq 0.0$				
Regime A ($\kappa^F = 0, \varphi_2^R \geq 0$)				
Optimal response parameter, φ_2^R	24	27	43	45
Gain relative to free floating	0.036	0.043	0.140	0.138
Regime B ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\|_A$)				
Optimal response parameter, κ^F	1.0	1.0	1.0	1.0
Gain relative to free floating	0.037	0.043	0.141	0.138
Gain relative to unsterilized intervention	0.001	0.000	0.001	0.000
Regime C ($\kappa^F \geq 0, \varphi_2^R \geq 0$)				
Optimal response parameters, κ^F, φ_2^R	1.0, 24	1.0, 28	1.0, 43	1.0, 46
Gain relative to free floating	0.037	0.043	0.141	0.138
Gain relative to unsterilized intervention	0.001	0.000	0.001	0.001

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 Simple Policy Responses and Welfare Gains, $\varkappa_S = 0.005$

	(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 ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\vert_A$)				
Optimal response parameter, κ^F	0.44	0.19	0.24	0.09
Gain relative to free floating	0.256	0.085	0.255	0.151
Gain relative to unsterilized intervention	0.232	0.049	0.132	0.011
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	0.44, 20	0.21, 22
Gain relative to free floating	0.329	0.165	0.284	0.164
Gain relative to unsterilized intervention	0.307	0.131	0.166	0.027
Alternative case: $\gamma \simeq 0.0$				
Regime A ($\kappa^F = 0, \varphi_2^R \geq 0$)				
Optimal response parameter, φ_2^R	24	27	43	45
Gain relative to free floating	0.036	0.043	0.140	0.138
Regime B ($\kappa^F \geq 0, \varphi_2^R = \varphi_2^R\big\vert_A$)				
Optimal response parameter, κ^F	0.19	0.15	0.00	0.00
Gain relative to free floating	0.053	0.050	0.140	0.138
Gain relative to unsterilized intervention	0.017	0.008	0.000	0.000
Regime C ($\kappa^F \geq 0, \varphi_2^R \geq 0$)				
Optimal response parameters, κ^F, φ_2^R	1.0, 6	1.0, 6	1.0, 8	1.0, 8
Gain relative to free floating	0.137	0.124	0.161	0.149
Gain relative to unsterilized intervention	0.104	0.084	0.025	0.013

Note: See notes to Table 3. under Regimes B and C, welfare gains are not strictly comparable between Tables 3 and 5, given that in the latter the central bank's objective function accounts for sterilization costs.

Figure 1
Agents and Main Financial Flows

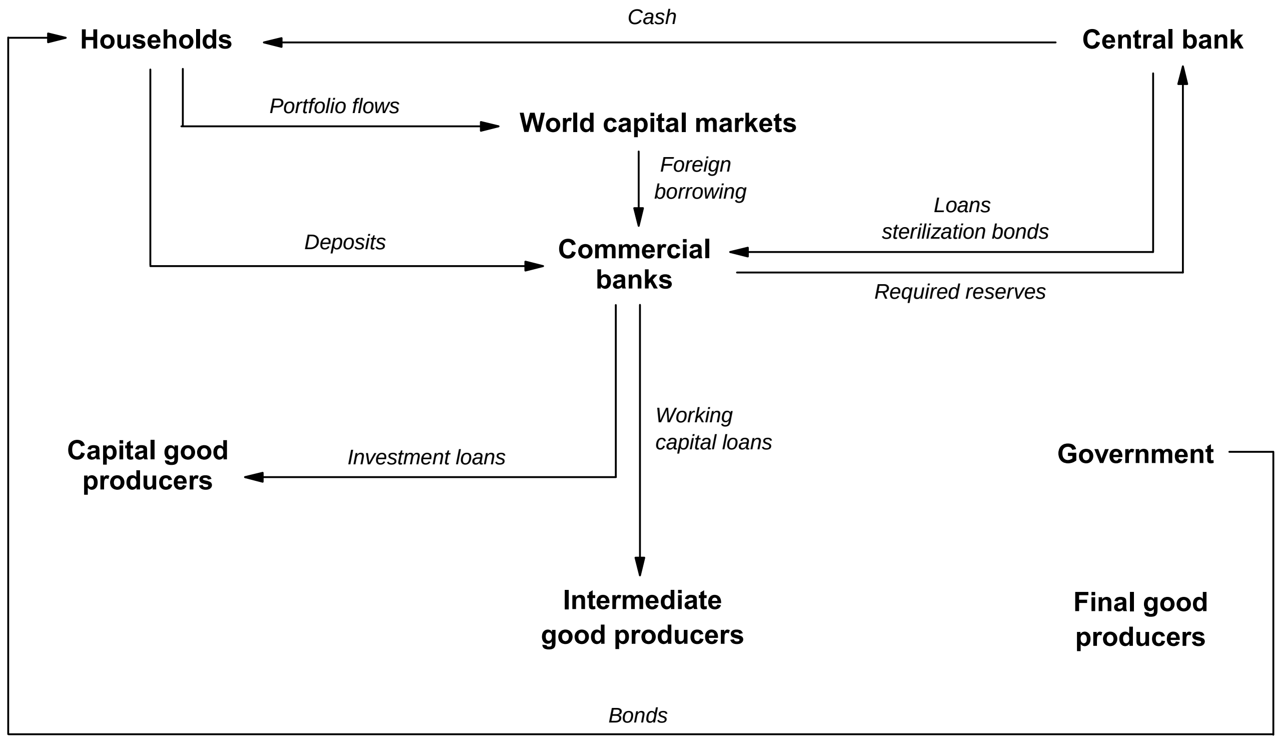
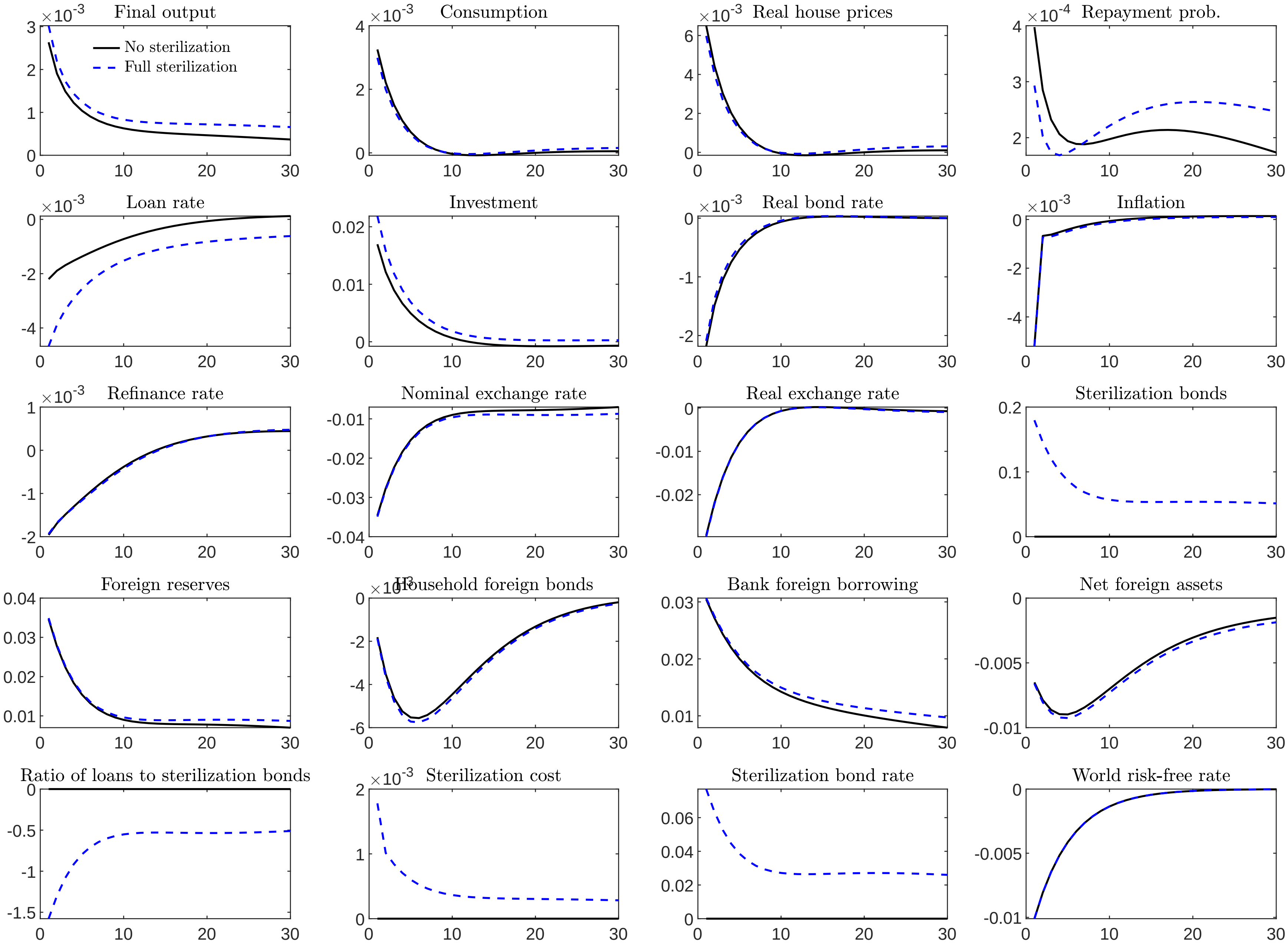
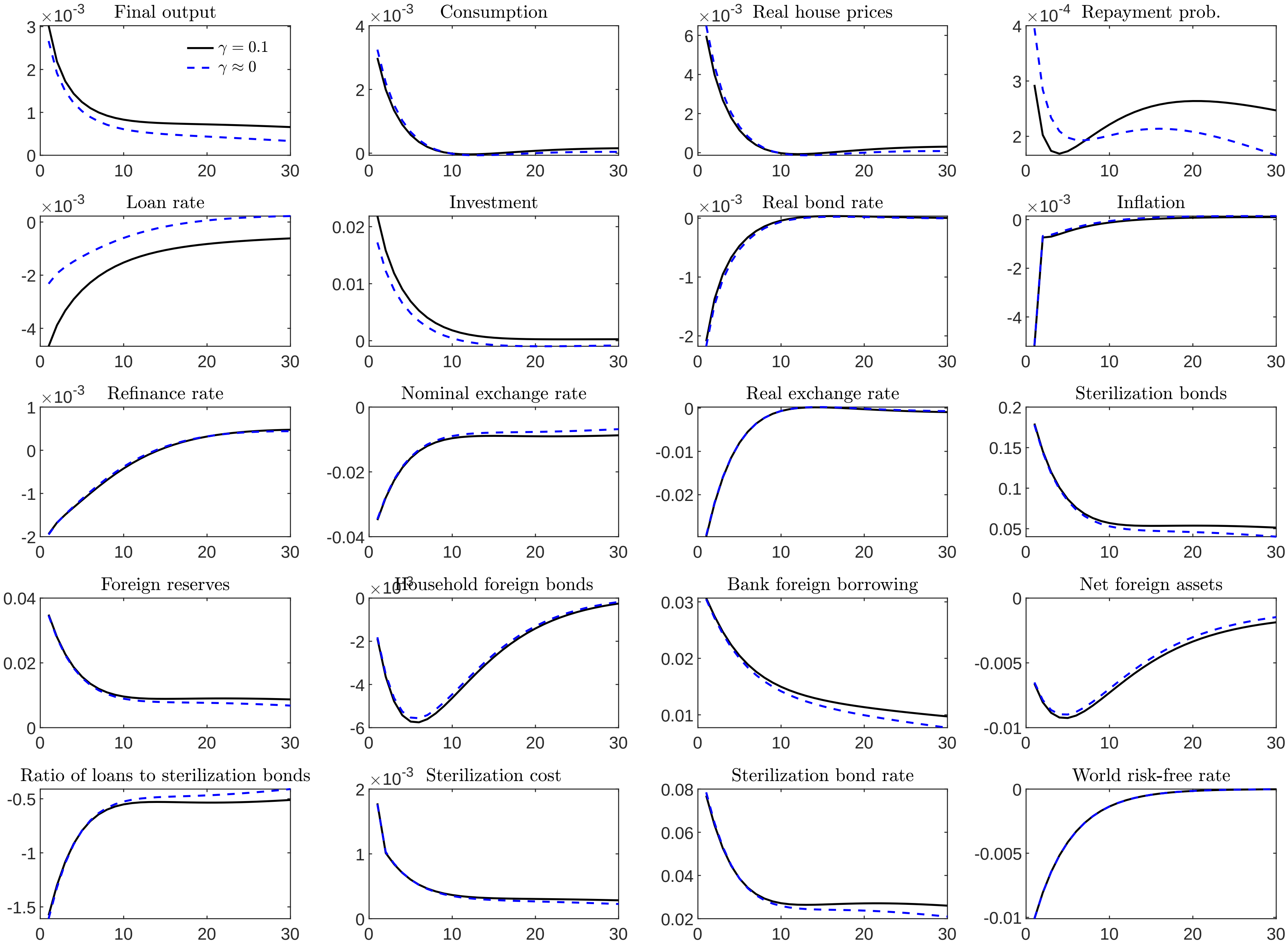


Figure 2
Negative Shock to World Risk-Free Interest Rate: Benchmark Case



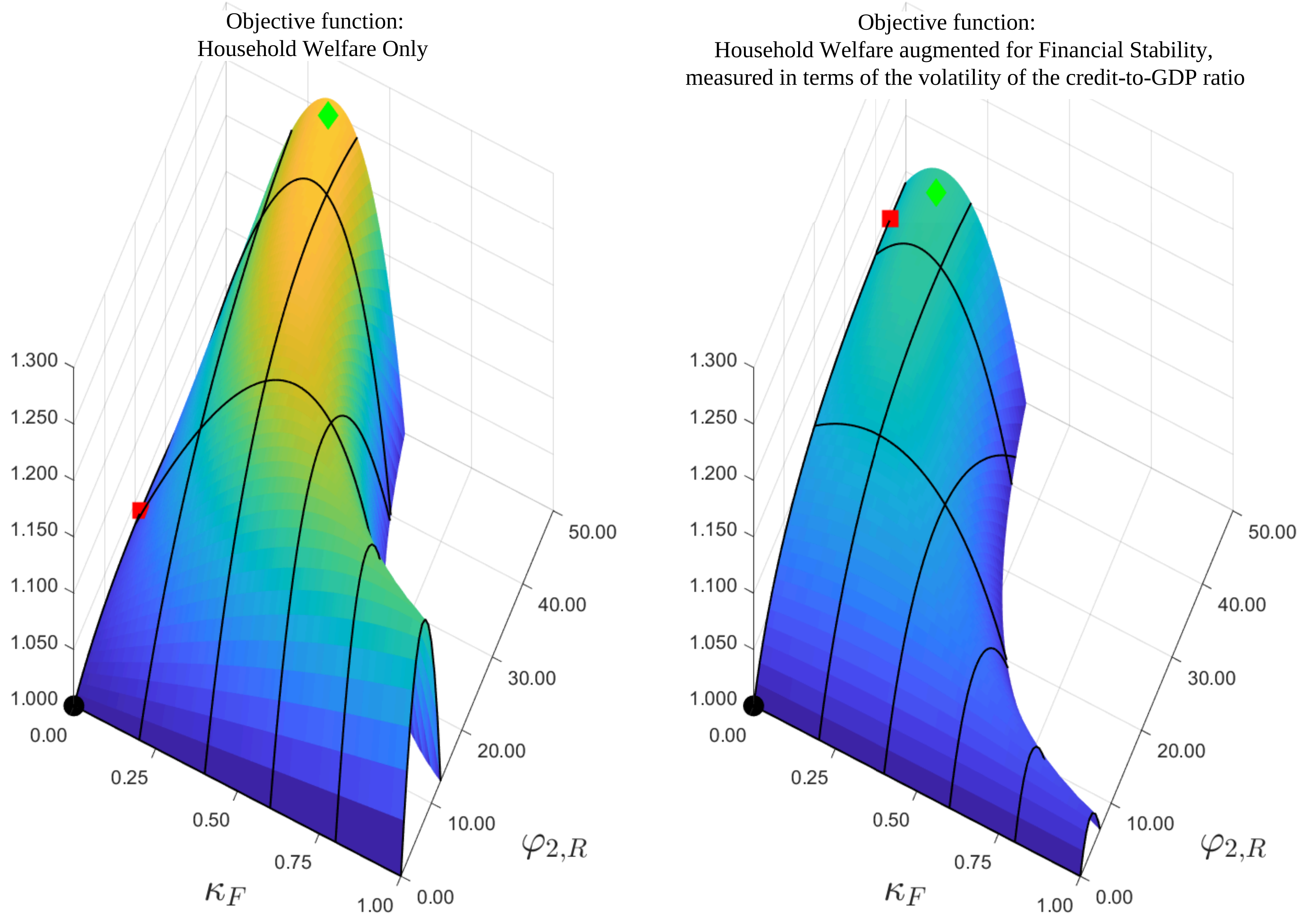
Notes: The responses of consumption, investment, final output, real house prices, bank foreign borrowing, foreign reserves, foreign bonds, and the nominal and real exchange rates are expressed as percent deviations from their steady-state values. The responses of the loan rate, the refinance rate, the 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: Strength of Bank Portfolio Effect under Full Sterilization



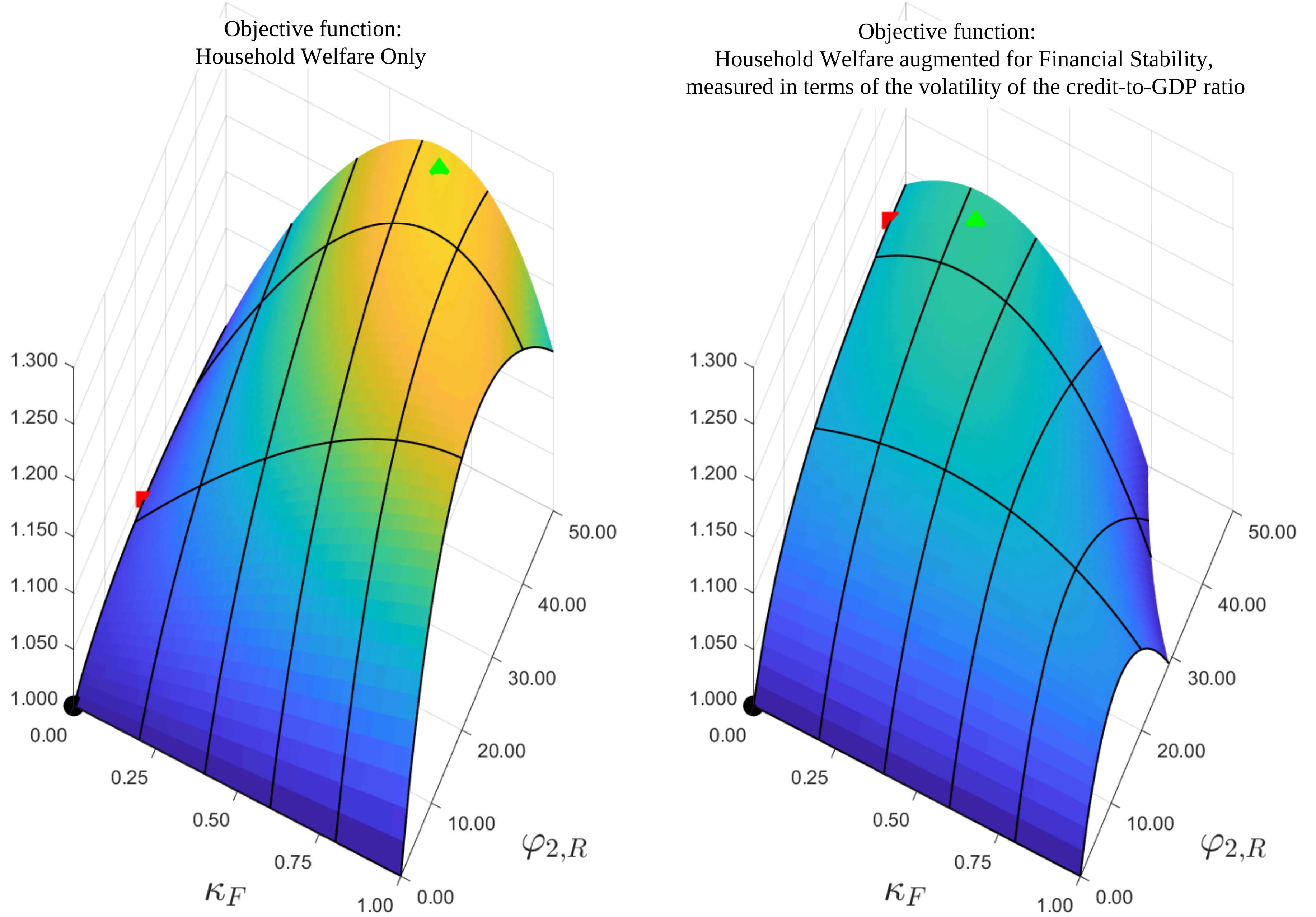
Note: See Notes to Figure 2.

Figure 4
Negative Shock to World Risk-Free Interest Rate: Relative Welfare and Optimal Policy Responses with a Bank Portfolio Channel



Note: The (black) circle corresponds to no intervention (and thus no sterilization, Regime A), the (red) to optimal unsterilized intervention (Regime B), and the (green) diamond to optimal sterilized intervention, in which both the degrees of intervention and sterilization are chosen jointly (Regime C). The vertical axis represents relative welfare, scaled by the level of welfare under no intervention.

Figure 5
Negative Shock to World Risk-Free Interest Rate: Relative Welfare and Optimal Policy Responses without a Bank Portfolio Channel



Note: See Notes to Figure 4.

Previous volumes in this series

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