# The Portfolio Channel of Capital Flows: A Small Open Economy Approach

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**Abstract**

In this paper we extend a new Keynesian small open economy model to include risk-averse FX dealers and FX intervention by the monetary authority. The former ingredients generate deviations from the uncovered interest parity (UIP) condition. More precisely, in this setup portfolio decisions of the dealers add endogenously a time variant risk-premium element to the traditional UIP that depends on FX intervention by the central bank and FX orders by foreign investors. We analyse the effectiveness of different strategies of FX intervention (e.g., unanticipated operations or via a pre-announced rule) to affect the volatility of the exchange rate and the transmission mechanism of the interest rate. Our findings are as follows: (i) FX intervention has a strong interaction with monetary policy in general equilibrium; (ii) FX intervention rules can have stronger stabilisation power than discretion in response to shocks because they exploit the expectations channel; (iii) there are some trade-offs in the use of FX intervention, since it can help to isolate the economy from external financial shocks, but it prevents some necessary adjustments on the exchange rate as a response to nominal and real external shocks; and (iv) the interaction between the portfolio balance channel and current account dynamics reduces the presence of a explosive response of exchange rate volatility, generating more stable equilibria.

*Key words:* Foreign exchange microestructure, Exchange rate dynamics, Exchange rate intervention, Monetary policy.

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*The views expressed in this paper are those of the authors and are not necessarily reflective of views at Banco Central de Reserva del Perú.

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# 1 Introduction

Interventions by central banks in foreign exchange (FX) markets have been common in many countries, and they have become even more frequent after the Great Financial Crisis (GFC), in both emerging market economies and some advanced economies.[1] These interventions have been particularly large during periods of capital inflows, when central banks bought foreign currency to prevent an appreciation of the domestic currency. Also, they have been recurrent during periods of financial stress and capital outflows, when central banks used their reserves to prevent sharp depreciations of their currencies. These FX interventions were sterilised in most cases, enabling central banks to keep short-term interest rates in line with policy rates.

Given the scale of interventions in FX markets by some central banks, it should be important for them to include this factor in their policy analysis frameworks. A variety of questions need to be addressed, such as: How does sterilised intervention affect the transmission mechanism of monetary policy? Which channels are at work? Are there benefits to intervention rules? What should be the optimal monetary policy design in the context of FX intervention? To analyse these questions we need an adequate framework of exchange rate determination in macroeconomic models.

There is substantial empirical evidence that traditional approaches of exchange rate determination (e.g., asset markets) fail to explain exchange rate movements in the short-run.[2] The literature shows that most exchange fluctuations at short- to medium-term horizons are related to order flows - the flow of transactions between market participants - as in the microstructure approach presented by Lyons (2006), and not to macroeconomic variables. However, in most of the models used for monetary policy analysis, the exchange rate is closely linked to macroeconomic fundamentals, as in the uncovered interest rate parity (UIP) condition. Such inconsistency between the model and real exchange rate determination in practice could lead in some cases to incorrect policy prescriptions such as the overestimation of the impact of fundamentals and the corresponding underestimation of the impact of *liquidity* trading. The latter include, *inter alia*, changes to the ownership of domestic currency instruments by non-residents, current account transactions such as trade in good and services, transfers in capital income, remittances, and tourism related flows which are not related to traditional macroeconomic fundamentals.

As an example Figure 1 presents the share of ownership of fixed income assets by non-residents for the case of Peru over the last decade. Foreign ownership increases during periods of domestic currency appreciation while the Central Bank intervenes purchasing dollars from the public. Moreover, the increase in foreign ownership has a negative correlation with the 10

[1] Domanski et al. (2016) reports that between 2009 and 2014 FX reserves rose from \$ 4 trillion to \$ 7 trillion and since then they decline by \$ 900 million. Notwithstanding significant fluctuations over the years, these shares are significantly higher now than they were a decade ago. Filardo et al. (2011) document how the central banks of Chile and Poland, which were inactive in the FX market for years, decided to resume FX interventions during the 2010-2011 period.

[2] See Meese and Rogoff (1983), Frankel and Rose (1995) and Cogley and Sargent (2005).

year bond yields. These dynamics, namely the positive correlation between the exchange rate and interest rates, constitute a challenge for models in which the exchange rate is determined by the interest rate differential. We present a model in which the *portfolio channel* can help explaining the dynamics observed during these episodes.

Regarding the effectiveness of FX intervention, the empirical evidence remains inconclusive. Reviews by Menkhoff (2012) and Chamon et al. (2012) suggest that interventions in some cases have a systematic impact on the rate of change in exchange rates, while in other cases they have been able to reduce exchange rate volatility. Intervention appears to be more effective when it is consistent with monetary policy (Amato et al. (2005), Kamil (2008)). This evidence suggests that the impact of FX interventions depend on the specific episode and instrument used. Clearly, the effectiveness of central bank intervention also needs to be evaluated against its policy goal.

Benes et al. (2013) provide a framework for the joint analysis of hybrid inflation targeting (IT) regimes with FX interventions strategies (e.g., exchange rate corridors, pegged or crawling exchange rates, managed floats.), where the central bank can exercise control over the exchange rate as an instrument independent of monetary policy and the policy interest rate.[3] Their strategy consists of introducing imperfect substitutability between central bank securities - used for purposes of sterilization - and private sector bank loans in a model where banks hold local currency denominated assets and foreign currency liabilities. An increase in the supply of central bank securities pushes banks to increase their overall exposure to exchange rate risk. This has an effect on interest rates as banks charge a higher premium to compensate for the higher risk they bear. In a related work, which also assumes imperfect substitutability of assets, Vargas et al. (2013) find that sterilised FX interventions can have an effect on credit supply by changing the balance sheet composition of commercial banks. Chang (2018) presents a model in which imperfect substitution across assets denominated in different currencies occurs only when banks face a binding borrowing constraint. In this region of the state-space, FX interventions by the central bank become effective.

We follow a market microstructure approach as in Montoro and Ortiz (2016) by introducing risk-averse FX dealers and FX intervention by the monetary authority. These ingredients generate deviations from the uncovered interest parity (UIP) condition. More precisely, dealers' portfolio decisions endogenously add a time-variant exchange rate risk premium element to the traditional UIP that depends on FX intervention by the central bank and FX orders by foreign investors. Moreover, we explicitly account for the role that exchange rate volatility plays in the deviation from the UIP, and how FX intervention rules can impact the economy through their effect on this volatility. Our model shows how central bank FX intervention can affect exchange

[3] Chamon et al. (2012) discusses the use of hybrid IT schemes in emerging market economies (EME). Authors recommend the use of a two-instrument IT framework as a way to reinforce its commitment to a low inflation rate.

rate determination through three channels: (i) the portfolio balance channel, (ii) the expectations channel and (iii) the volatility channel. In the first one, a sterilised intervention alters the value of the currency because it modifies the ratio between domestic and foreign assets held by the private sector; according to the second, the expectations of future interventions impacts the current exchange rate. The latter makes explicit that central bank interventions have an impact on the volatility of exchange rates and consequently on the willingness of FX dealers to absorb *liquidity* based changes in their portfolios. Thus, in our model, the *trading mechanism* and the *players*, two of the three key elements in the microstructure approach according to Lyons (2006), affect the determination of the exchange rate. In recent years, several authors have introduced market microstructure elements to general equilibrium models of exchange rate determination. Gabaix and Maggiori (2015) present a setup with imperfect capital mobility in which the risk-baring capacity of financiers and capital flows affect the exchange rate via a balance sheet effect. Cavallino (2018) uses this framework to obtain optimal FX intervention and monetary policy. Fanelli and Straub (2018) introduce convex costs to carry traders in a similar setup, reducing the central bank's incentives to curtail exchange rate volatility.

Our findings show that in general equilibrium, FX intervention can have important implications for central bank stabilization policies. In some cases, FX intervention can mute the monetary transmission mechanism through exchange rates, reducing the impact on aggregate demand and prices, while in others it can amplify the impact. We also show that there are some trade-offs in the use of FX intervention, in line with the results in Benes et al. (2013). On the one hand, it can help isolate the economy from external financial shocks, but on the other it prevents some necessary adjustments of the exchange rate in response to nominal and real external shocks. Finally, regarding FX intervention policy design, we observe that monetary and FX intervention policies can either complement or hinder each other. A careful identification of shocks is key for effectively using both tools.

In the next section we introduce the model, with a special focus on the FX market and the channels through which FX intervention operates. Section 3 shows results from the simulation of the model. The last section concludes.

## 2 The Model

The model describes a small open economy with nominal rigidities, in line with the contributions from Obstfeld and Rogoff (1995), Chari et al. (2002), Galí and Monacelli (2005), Christiano et al. (2005) and Devereux et al. (2006), among others. To maintain the concept of general equilibrium, we use a two-country framework taking the size of one of these economies close to zero, such that the small (domestic) economy does not affect the large (foreign) economy.[4]

[4]We acknowledge the general equilibrium perspective introduces a series of linear relationships among the foreign economy variables. The disadvantage of following this modelling strategy is that shocks to foreign variables

## 2.1 FX Dealers

Dealers invest each period in both domestic and foreign bonds, maximising their portfolio returns. This is a cashless economy. The monetary authority intervenes directly in the FX market selling or purchasing foreign bonds in exchange for domestic bonds. The central bank issues the domestic bonds and sets the nominal interest rates paid by these assets. The central bank can control the interest rate regardless of the FX intervention, that is we assume the central bank can always perform fully sterilised interventions.[5]

There is a continuum of dealers $\iota$ in the interval $[0, 1]$ who operate in the secondary bond market. Each dealer $\iota$ takes a position in foreign currency bonds while borrowing in pesos, absorbing exchange rate risk. In turn, dealers receive purchase and sale orders from the central bank and foreign investors, respectively. These orders will affect the net position of dealers in foreign and domestic currency.[6] Each dealer receives the same amount of orders from households, foreign investors and the central bank.

The exchange rate $S_t$ is defined as the price of foreign currency in terms of domestic currency, such that a decrease (increase) of $S_t$ corresponds to an appreciation (depreciation) of the domestic currency. At the end of the period, any profits -either positive or negative- are transferred to the households.

$$\max_{\varpi_t^{\iota,d,*}} -E_t e^{-\gamma\Omega_{t+1}^{\iota}}$$

where $E_t$ is the rational expectations operator, $\gamma$ is the coefficient of absolute risk aversion and $\Omega_{t+1}$ is the peso return on the portofolio, given by:

$$\begin{aligned}
\Omega_{t+1}^{\iota} &= (1+i_t)\varpi_t^{\iota,d} + (1+i_t^*)S_{t+1}\varpi_t^{\iota,d,*} - (1+i_t)\left[A_t^{\iota,S}\right] \\
&= (1+i_t^*)S_{t+1}\varpi_t^{\iota,d,*} - (1+i_t)\left[S_t\varpi_t^{\iota,d,*}\right] \\
&\approx (i_t^* - i_t + s_{t+1} - s_t)\varpi_t^{\iota,d,*}
\end{aligned}$$

We have log-linearised the excess of return on the foreign bond position and $s_t = \ln S_t$. Since the only non-predetermined variable is $s_{t+1}$, assuming it is normal distributed with time-invariant

will not be observed independently, as only combination of foreign variables will impact the domestic economy. This would not allow us to analyse the impact of shocks to foreign variables independently (and the impact would depend as well on the calibration of the foreign economy.) The literature favours the approach followed here. For examples see Adolfson et al. (2008).

[5]However, in practice sterilised interventions have limits. For example, the sale of foreign bonds by the central bank is limited by the level of foreign reserves. On the other hand, the sterilised purchase of foreign currency is limited by the availability of instruments to sterilise those purchases (e.g., given by the demand for central bank bonds or by the stock of treasury bills in the hands of the central bank). Also, limits to the financial losses generated by FX intervention can represent a constraint for intervention itself.

[6]Recall these are one period bonds, hence the flows and stocks are equivalent. At the beginning of each period the stock of bonds in possession of dealers is zero.

variance, the first order condition for the dealers is:[7]

$$0 = -\gamma \left( i_t^* - i_t + E_t s_{t+1} - s_t \right) + \gamma^2 \omega_t^{\iota,d,*} \sigma^2$$

where $\sigma^2 = var_t \left( \Delta s_{t+1} \right)$ is the conditional variance of the depreciation rate. Then, the demand for foreign bonds by dealers is given by the following portfolio condition:

$$\varpi_t^{\iota,d,*} = \frac{i_t^* - i_t + E_t s_{t+1} - s_t}{\gamma \sigma^2} \tag{1}$$

Aggregating over FX dealers, we obtain the total household holdings of foreign bonds given by:

$$\int_0^1 \varpi_t^{\iota,d,*} d\iota = B_t^{d,*} \tag{2}$$

Thus exchange rate dynamics will be affected by the aggregated domestic agents position of foreign currency bonds.

$$E_t s_{t+1} - s_t = i_t - i_t^* + \gamma \sigma^2 (b_t^{d,*}) \tag{3}$$

Where $b_t^{d,*}$ is the log-deviation of the dealers net foreign asset position. Similarly, aggregating over profits we obtain the total transfers from FX dealers to households.

We assume an exogenous external demand for domestic bonds, in the shape of foreign investors who change their dollar positions for peso ones.

$$B_t^c + S_t B_t^{c,*} = 0$$

### 2.2 Central Bank

We introduce a central bank that additional to its inflation stabilization role, intervenes in FX markets. Its balance sheet is given by:

$$S_t B^{cb,*} + B_t^{cb} = M_t^s + NW_t^{cb}$$

where $B_t^{cb,*}$ represents the central bank's foreign reserves and $B_t^{cb}$ are bond issued by the central bank (deposit certificates) used for sterilized FX interventions. $M_t^s$ is the money supply and $NW_t^{cb}$ represents the bank's net worth. The Central Bank flow constraint is given by:

$$B_{t+1}^{cb} + S_{t+1} B_{t+1}^{cb,*} - M_{t+1}^s + P_t \Gamma_t^{cb} = (1 + i_t) B_t^{cb} + (1 + i_t^*) S_{t+1} B_t^{cb,*} - M_t^s$$

where $\Gamma_t^{cb}$ are the Central Bank's transfers to the population. Now, Central Bank transfers are given back to households in the form of domestic bonds to keep the Central Bank's net worth bounded. For the time being we can abstract from money and Central Bank's net worth by setting $M_t^s = \bar{M_t}^s = 0$ and $NW_t^{cb} = 0$. With these assumptions:

$$B_t^{cb} + S_t B^{cb,*} = 0 \tag{4}$$

[7] We perform two normality tests on the simulated series for the variations of the exchange rate after solving the model. Both the Anderson-Darling test and the Lilliefors test consistently fail to reject the null hypothesis that the simulated sample of 5000 data points comes from a Normal distribution.

Thus, the evolution of Central Bank asset composition will be a function of asset returns and sterilized intervention. When the Central Bank sells reserves it will do it against domestic bonds. Regarding monetary policy, the generic form of the interest rate rule that the central bank uses is given by:

$$\frac{(1+i_t)}{(1+\bar{i})} = \left(\frac{\Pi_t}{\overline{\Pi}}\right)^{\varphi_\pi} \left(\frac{Y_t}{\overline{Y}}\right)^{\varphi_y} \exp\left(\varepsilon_t^{MON}\right) \tag{5}$$

where $\varphi_\pi > 1$. $\overline{\Pi}$ and $\bar{i}$ are the levels in steady state of inflation and the nominal interest rate. The term $\varepsilon_t^i$ is a random monetary policy shock distributed according to $N \sim \left(0, \sigma_i^2\right)$.

Note that by abstracting from money balances in the Central Bank's balance sheet all FX interventions will be sterilized. We leave the study of non-sterilized FX interventions for future research.

### 2.3 Traders and Financial Market Clearing

The market clearing for peso denominated bonds is given by:

$$B_t^d + B_t^{cb} + B_t^c = 0. \tag{6}$$

When foreign investors increase their demand for peso denominated bonds, either domestic households or the central bank will provide these bonds. The additional needs for external finance will be determined by the current account. We assume the financial instruments for these operations are denominated in foreign currency.

A key aspect of the model is that dealers do not consider the Central Bank's portfolio as part of their own, therefore agents will not undo the shifts in the Central Bank portfolio against their own, a result observed in the canonical model. Our view is that domestic portfolio managers do not consider the Central Bank portfolio as theirs, demanding a premium for shifts in their exposure generated by Central Bank FX interventions. A weaker restriction can be introduced into the model as agents do not have full information regarding the portfolio held by the Central Bank. Thus, when the Central Bank takes dollars from domestic agents, agents are unable to offset the changes in their portfolio.[8]

#### 2.3.1 FX intervention

We assume the central bank's purpose to intervene is to reduce the overall volatility caused by external shocks. As Mihaljek (2005) documents, central banks that intervene in foreign markets claim as one of the main reasons the need of stabilizing exchange rate markets, preventing exchange rate volatility to affect other sectors of the economy.[9]

[8] For example, the Central Reserve Bank of Peru only reports the total value of their assets but not the specific way in which these assets are invested. This can be motivated by political constraints, as reporting where the Central Bank assets are invested could generate pressure by politicians to try to divert funds to specific assets in which they have a vested interest.

[9] Mihaljek (2005) presents a survey on 23 central banks from emerging markets. Out of the 18 banks in the sample which intervened during the 2002-2004 Q3 period, 16 claimed interventions were effective or sometimes effective calming disorderly exchange rate markets.

We assume the central bank performs rule based interventions, following three different strategies. First, we assume takes into account the changes in the exchange rate. We call this strategy "the $\Delta s$ rule".

$$B_t^{cb,*} = -\phi_{\Delta s}\Delta s_t + \varepsilon_t^{cb,1} \tag{7}$$

According to this rule, when there are depreciation (appreciation) pressures on the domestic currency, the central bank sells (purchases) foreign bonds to prevent the exchange rate from fluctuating. $\phi_{\Delta s}$ captures the intensity of the response of the FX intervention to pressures in the FX market.

As a second case, the monetary authority can take into account misalignments of the real exchange rate as a benchmark for FX intervention. We call this strategy "the $RER$ rule".

$$B_t^{cb,*} = -\phi_{rer} rer_t + \varepsilon_t^{cb,2} \tag{8}$$

Finally, we assume that the monetary authority reacts to offset the portfolio flows directly.

$$B_t^{cb,*} = -\phi_{b^{c,*}} B_t^{c,*} + \varepsilon_t^{cb,3} \tag{9}$$

We contrast rule based interventions with (comparable) discretional interventions in order to gauge the impact of expectations in FX stabilization. The difference between discretional interventions and no intervention will be given by the effect of the variance of the discretional interventions shock on the overall exchange rate volatility. According to strategy, FX intervention by the central bank is never anticipated.

$$B_t^{cb,*} = \varepsilon_t^{cb,0} \tag{10}$$

We assume the frequency of decisions is the same for dealers and other economic agents. Households consume final goods, supply labour to intermediate goods producers and save in domestic bonds. Firms produce intermediate and final goods. Additionally, we include monopolistic competition and nominal rigidities in the retail sector, price discrimination and pricing to market in the export sector, and incomplete pass-through from the exchange rate to imported good prices - characteristics that are important to analyse the transmission mechanism of monetary policy in a small open economy. We also consider as exogenous processes foreign variables such as output, inflation, the interest rate and non-fundamental capital flows.[10]

## 2.4 Households

The world economy is populated by a continuum of households of mass 1, where a fraction $n$ of them is allocated in the home economy, whereas the remaining $1-n$ is in the foreign economy.

[10] There is an extensive empirical literature addressing the determinants of portfolio capital flows to emerging economies. Moreover, Arias et al. (mimeo) find that lagged FX interventions impact portfolio capital inflows, however this factor is significantly lower than 1, implying that FX interventions can still be an effective instrument to counter portfolio capital inflows.

Each household $j$ in the home economy enjoys utility from the consumption of a basket of final goods, $C_t^j$ , and receives disutility from working, $L_t^j$. Households preferences are represented by the following utility function:

### 2.4.1 Preferences

$$\mathcal{U}_t = E_t \left[ \sum_{s=0}^{\infty} \beta^{t+s} U \left( C_{t+s}^j, L_{t+s}^j, \right) \right], \tag{11}$$

where $E_t$ is the conditional expectation on the information set at period $t$ and $\beta$ is the intertemporal discount factor, with $0 < \beta < 1$. In particular we assume the instantaneous utility is given by:

$$U\left(C_t, L_t\right) = \frac{C_t^{1-\gamma_c}}{1-\gamma_c} - \frac{L_t^{1+\chi}}{1+\chi}, \quad \text{if } \gamma_c \neq 1. \tag{12}$$

when $\gamma_c = 1$, this function becomes:

$$U\left(C_t, L_t\right) = \ln C_t - \frac{L_t^{1+\chi}}{1+\chi} \tag{13}$$

The consumption basket of final goods is a composite of domestic and foreign goods, aggregated using the following consumption index:

$$C_t \equiv \left[ \left(\gamma^H\right)^{1/\varepsilon_H} \left(C_t^H\right)^{\frac{\varepsilon_H - 1}{\varepsilon_H}} + \left(1-\gamma^H\right)^{1/\varepsilon_H} \left(C_t^M\right)^{\frac{\varepsilon_H - 1}{\varepsilon_H}} \right]^{\frac{\varepsilon_H}{\varepsilon_H - 1}}, \tag{14}$$

where $\varepsilon_H$ is the elasticity of substitution between domestic ($C_t^H$) and foreign goods ($C_t^M$), and $\gamma^H$ is the share of domestically produced goods in the consumption basket of the domestic economy. In turn, $C_t^H$ and $C_t^M$ are indices of consumption across the continuum of differentiated goods produced in the home country and those imported from abroad, respectively. These consumption indices are defined as follows:

$$C_t^H \equiv \left[ \left(\frac{1}{n}\right)^{\frac{1}{\varepsilon}} \int_0^n C_t^H(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}}, C_t^M \equiv \left[ \left(\frac{1}{1-n}\right)^{\frac{1}{\varepsilon}} \int_n^1 C_t^M(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{15}$$

where $\varepsilon > 1$ is the elasticity of substitution across goods produced within the home economy, denoted by $C_t^H(z)$, and within the foreign economy, $C_t^M(z)$. Household's optimal demands for home and foreign consumption are given by:

$$C_t^H(z) = \frac{1}{n} \gamma^H \left( \frac{P_t^H(z)}{P_t^H} \right)^{-\varepsilon} \left( \frac{P_t^H}{P_t} \right)^{-\varepsilon_H} C_t, \tag{16}$$

$$C_t^M(z) = \frac{1}{1-n} \left(1-\gamma^H\right) \left( \frac{P_t^M(z)}{P_t^M} \right)^{-\varepsilon} \left( \frac{P_t^M}{P_t} \right)^{-\varepsilon_H} C_t \tag{17}$$

This set of demand functions is obtained by minimising the total expenditure on consumption $P_t C_t$, where $P_t$ is the consumer price index. Notice that the consumption of each type of goods is increasing in the consumption level, and decreasing in their corresponding relative prices. Also, it is easy to show that the consumer price indices, under these preference assumptions, is determined by the following condition:

$$P_t \equiv \left[\gamma^H \left(P_t^H\right)^{1-\varepsilon_H} + \left(1-\gamma^H\right)\left(P_t^M\right)^{1-\varepsilon_H}\right]^{\frac{1}{1-\varepsilon_H}} \tag{18}$$

where $P_t^H$ and $P_t^M$ denote the price level of the home-produced and imported goods, respectively. Each of these price indexes is defined as follows:

$$P_t^H \equiv \left[\frac{1}{n}\int_0^n P_t^H(z)^{1-\varepsilon}dz\right]^{\frac{1}{1-\varepsilon}}, P_t^M \equiv \left[\frac{1}{1-n}\int_n^1 P_t^M(z)^{1-\varepsilon}dz\right]^{\frac{1}{1-\varepsilon}} \tag{19}$$

where $P_t^H(z)$ and $P_t^M(z)$ represent the prices expressed in domestic currency of the variety $z$ of home and imported goods, respectively.

### 2.4.2 Households' budget constraint

We assume domestic households invest the total of their portfolio on the FX dealers at the domestic currency interest rate. The budget constraint in units of home currency is given by:

$$A_t^S = (1+i_t)A_{t-1}^S - \frac{\psi}{2}\left(A_t^S - \overline{A}^S\right)^2 + W_tL_t - P_tC_t + P_t\Gamma_t^f + P_t\Gamma_t^d + P_t\Gamma_t^{cb} \tag{20}$$

where $A_t$ is the total financial assets expressed in domestic currency, $W_t$ is the nominal wage, $i_t$ is the domestic nominal interest rate, and $\Gamma_t^f$, $\Gamma_t^d$ and $\Gamma_t^{cb}$ are the real profits distributed in the home economy to the households from firms, dealers and the central bank, respectively. Each household owns the same share of firms and dealer agencies in the home economy. Households also face portfolio adjustment costs, for adjusting wealth from its long-run level.[11] Households maximise (11) subject to (20).

### 2.4.3 Consumption decisions and the supply of labour

The conditions characterising the optimal allocation of domestic consumption are given by the following equation:

$$U_{C,t} = \beta E_t\left\{U_{C,t+1}\frac{1+i_t}{1+\psi\left(A_t^S - \overline{A}^S\right)}\frac{P_t}{P_{t+1}}\right\} \tag{21}$$

where we have eliminated the index $j$ for the assumption of representative agent. $U_{C,t}$ denotes the marginal utility for consumption. Equation (21) corresponds to the Euler equation that determines the optimal path of consumption for households in the home economy, by equalising the marginal benefits of savings to its corresponding marginal costs. The first-order conditions that determine the supply of labour are characterised by the following equation:

$$-\frac{U_{L,t}}{U_{C,t}} = \frac{W_t}{P_t} \tag{22}$$

[11] This assumption is necessary to provide stationarity in the asset position held by the households. See Schmitt-Grohe and Uribe (2003).

where $\frac{W_t}{P_t}$ denotes real wages. In a competitive labour market, the marginal rate of substitution equals the real wage, as in equation (22).

#### 2.4.4 The small open economy assumption

Following Sutherland (2005), we parameterise the participation of foreign goods in the consumption basket of home households, $\left(1-\gamma^H\right)$, as follows: $\left(1-\gamma^H\right) = (1-n)(1-\gamma)$, where $n$ represents the size of the home economy and $(1-\gamma)$ the degree of openness. In the same way, we assume the participation of home goods in the consumption basket of foreign households, as a function of the relative size of the home economy and the degree of openness of the world economy, that is $\gamma^F = n(1-\gamma^*)$.

This particular parameterisation implies that as the economy becomes more open, the fraction of imported goods in the consumption basket of domestic households increases, whereas as the economy becomes larger, this fraction falls. This parameterisation allows us to obtain the small open economy as the limiting case of a two-country economy model when the size of the domestic economy approaches zero, that is $n \to 0$. In this case, we have that $\gamma^H \to \gamma$ and $\gamma^F \to 0$. Therefore, in the limiting case, the use in the foreign economy of any home-produced intermediate goods is negligible, and the demand condition for domestic, imported and exported goods can be re-written as follows:

$$Y_t^H = \gamma \left(\frac{P_t^H}{P_t}\right)^{-\varepsilon_H} C_t \tag{23}$$

$$M_t = (1-\gamma)\left(\frac{P_t^M}{P_t}\right)^{-\varepsilon_H} C_t \tag{24}$$

$$X_t = (1-\gamma^*)\left(\frac{P_t^X}{P_t^*}\right)^{-\varepsilon_F} C_t^* \tag{25}$$

Thus, given the small open economy assumption, the consumer price index for the home and foreign economy can be expressed in the following way:

$$P_t \equiv \left[\gamma\left(P_t^H\right)^{1-\varepsilon_H} + (1-\gamma)\left(P_t^M\right)^{1-\varepsilon_H}\right]^{\frac{1}{1-\varepsilon_H}} \tag{26}$$

$$P_t^* = P_t^F \tag{27}$$

Given the small open economy assumption, the foreign economy variables that affect the dynamics of the domestic economy are foreign output, $Y_t^*$, the foreign interest rate, $i^*$, the external inflation rate, $\Pi^*$, and capital inflows, $\varpi_t^*$. To simplify the analysis, we assume these four variables follow an autoregressive process in logs.

### 2.5 Firms

#### 2.5.1 Intermediate goods producers

A continuum of $z$ intermediate firms exists. These firms operate in a perfectly competitive market and use the following linear technology:

$$Y_t^{int}(z) = A_t L_t(z) \tag{28}$$

$L_t(z)$ is the amount of labour demand from households, $A_t$ is the level of technology.

These firms take as given the real wage, $W_t/P_t$, paid to households and choose their labour demand by minimising costs given the technology. The corresponding first order condition of this problem is:

$$L_t(z) = \frac{MC_t(z)}{W_t/P_t} Y_t^{int}(z)$$

where $MC_t(z)$ represents the real marginal costs in terms of home prices. After replacing the labour demand in the production function, we can solve for the real marginal cost:

$$MC_t(z) = \frac{W_t/P_t}{A_t} \tag{29}$$

Given that all intermediate firms face the same constant returns to scale technology, the real marginal cost for each intermediate firm $z$ is the same, that is $MC_t(z) = MC_t$. Also, given these firms operate in perfect competition, the price of each intermediate good is equal to the marginal cost. Therefore, the relative price $P_t(z)/P_t$ is equal to the real marginal cost in terms of consumption unit ($MC_t$).

#### 2.5.2 Final goods producers

**Goods sold domestically** Final goods producers purchase intermediate goods and transform them into differentiated final consumption goods. Therefore, the marginal costs of these firms equal the price of intermediate goods. These firms operate in a monopolistic competitive market, where each firm faces a downward-sloping demand function, given below. Furthermore, we assume that each period $t$ final goods producers face an exogenous probability of changing prices given by $(1-\theta^H)$. Following Calvo (1983), we assume that this probability is independent of the last time the firm set prices and the previous price level. Thus, given a price fixed from period $t$, the present discounted value of the profits of firm $z$ is given by:

$$E_t \left\{ \sum_{k=0}^{\infty} \left(\theta^H\right)^k \Lambda_{t+k} \left[ \frac{P_t^{H,o}(z)}{P_{t+k}^H} - MC_{t+k}^H \right] Y_{t,t+k}^H(z) \right\} \tag{30}$$

where $\Lambda_{t+k} = \beta^k \frac{U_{C,t+k}}{U_{C,t}}$ is the stochastic discount factor, $MC_{t+k}^H = MC_{t+k} \frac{P_{t+k}}{P_{t+k}^H}$ is the real marginal cost expressed in units of goods produced domestically, and $Y_{t,t+k}^H(z)$ is the demand for good $z$ in $t+k$ conditioned to a fixed price from period $t$, given by

$$Y_{t,t+k}^H(z) = \left[ \frac{P_t^{H,o}(z)}{P_{t+k}^H} \right]^{-\varepsilon} Y_{t+k}^H$$

Each firm $z$ chooses $P_t^{H,o}(z)$ to maximise (30). The first order condition of this problem is:

$$E_t \left\{ \sum_{k=0}^{\infty} \left(\theta^H\right)^k \Lambda_{t+k} \left[ \frac{P_t^{H,o}(z)}{P_t^H} F_{t,t+k}^H - \mu M C_{t+k}^H \right] \left(F_{t,t+k}^H\right)^{-\varepsilon} Y_{t+k}^H \right\} = 0$$

where $\mu \equiv \frac{\varepsilon}{\varepsilon - 1}$ and $F_{t,t+k}^H \equiv \frac{P_t^H}{P_{t+k}^H}$.

Following Benigno and Woodford (2005), the previous first order condition can be written recursively using two auxiliary variables, $V_t^D$ and $V_t^N$, defined as follows:

$$\frac{P_t^{H,o}(z)}{P_t^H} = \frac{V_t^N}{V_t^D}$$

where

$$V_t^N = \mu U_{C,t} Y_t^H M C_t^H + \theta^H \beta E_t \left[ V_{t+1}^N \left(\Pi_{t+1}^H\right)^{\varepsilon} \right] \tag{31}$$

$$V_t^D = U_{C,t} Y_t^H + \theta^H \beta E_t \left[ V_{t+1}^D \left(\Pi_{t+1}^H\right)^{\varepsilon - 1} \right] \tag{32}$$

Also, since in each period $t$ only a fraction $\left(1 - \theta^H\right)$ of these firms change prices, the gross rate of domestic inflation is determined by the following condition:

$$\theta^H \left(\Pi_t^H\right)^{\varepsilon - 1} = 1 - \left(1 - \theta^H\right) \left( \frac{V_t^N}{V_t^D} \right)^{1-\varepsilon} \tag{33}$$

The equations (31), (32) and (33) determine the supply (Phillips) curve of domestic production.

**Exported goods** We assume that firms producing final goods can discriminate prices between domestic and external markets. Therefore, they can set the price of their exports in foreign currency. Also, when selling abroad they face an environment of monopolistic competition with nominal rigidities, with a probability $1 - \theta^X$ of changing prices.

The problem of retailers selling abroad is very similar to that of firms that sell in the domestic market, which is summarised in the following three equations that determine the supply curve of exporters in foreign currency prices:

$$V_t^{N,X} = \mu \left(Y_t^X U_{C,t}\right) M C_t^X + \theta^X \beta E_t \left[ V_{t+1}^{N,X} \left(\Pi_{t+1}^X\right)^{\varepsilon} \right] \tag{34}$$

$$V_t^{D,X} = \left(Y_t^X U_{C,t}\right) + \theta^X \beta E_t \left[ V_{t+1}^{D,X} \left(\Pi_{t+1}^X\right)^{\varepsilon - 1} \right] \tag{35}$$

$$\theta^X \left(\Pi_t^X\right)^{\varepsilon - 1} = 1 - \left(1 - \theta^X\right) \left( \frac{V_t^{N,X}}{V_t^{D,X}} \right)^{1-\varepsilon} \tag{36}$$

where the real marginal costs of the goods produced for export are given by:

$$\begin{aligned} M C_t^X &= \frac{P_t M C_t}{S_t P_t^X} \\ &= \frac{M C_t}{R E R_t \left(\frac{P_t^X}{P_t^*}\right)} \end{aligned} \tag{37}$$

which depend inversely on the real exchange rate ($RER_t = \frac{S_t P_t^*}{P_t}$) and the relative price of exports to external prices $\left(\frac{P_t^X}{P_t^*}\right)$.

### 2.5.3 Retailers of imported goods

Those firms that sell imported goods buy a homogeneous good in the world market and differentiate it into a final imported good $Y_t^M(z)$. These firms also operate in an environment of monopolistic competition with nominal rigidities, with a probability $1-\theta^M$ of changing prices.

The problem for retailers is very similar to that of producers of final goods. The Phillips curve for importers is given by:

$$V_t^{N,M} = \mu\left(Y_t^M U_{C,t}\right) MC_t^M + \theta^M \beta E_t\left[V_{t+1}^{N,M}\left(\Pi_{t+1}^M\right)^{\varepsilon}\right] \tag{38}$$

$$V_t^{D,M} = \left(Y_t^M U_{C,t}\right) + \theta^M \beta E_t\left[V_{t+1}^{D,M}\left(\Pi_{t+1}^M\right)^{\varepsilon-1}\right] \tag{39}$$

$$\theta^M\left(\Pi_t^M\right)^{\varepsilon-1} = 1-\left(1-\theta^M\right)\left(\frac{V_t^{N,M}}{V_t^{D,M}}\right)^{1-\varepsilon} \tag{40}$$

where the real marginal cost for importers is given by the cost of purchasing the goods abroad $(S_t P_t^*)$ to the price of imports $(P_t^M)$:

$$MC_t^M = \frac{S_t P_t^*}{P_t^M} \tag{41}$$

where $MC_t^M$ also measures the deviations from the law of one price.[12]

## 2.6 Market clearing

Total domestic production is given by:

$$P_t^{def} Y_t = P_t^H Y_t^H + S_t P_t^X Y_t^X \tag{42}$$

After using equations (23) and (24) and the definition of the consumer price index (26), equation (42) can be decomposed in:

$$P_t^{def} Y_t = P_t C_t + S_t P_t^X Y_t^X - P_t^M Y_t^M \tag{43}$$

To identify the gross domestic product (GDP) of this economy, $Y_t$, it is necessary to define the GDP deflator, $P_t^{def}$, which is the weighted sum of the consumer, export and import price indices:

$$P_t^{def} = \phi_C P_t + \phi_X S_t P_t^X - \phi_M P_t^M \tag{44}$$

where $\phi_C, \phi_X$ and $\phi_M$ are steady state values of the ratios of consumption, exports and imports to GDP, respectively. The demand for intermediate goods is obtained by aggregating the

[12] See Galí and Monacelli (2005) for a similar formulation.

production for home consumption and exports:

$$
\begin{aligned}
Y_t^{int}(z) &= Y_t^H(z) + Y_t^X(z) \\
&= \left(\frac{P_t^H(z)}{P_t^H}\right)^{-\varepsilon} Y_t^H + \left(\frac{P_t^X(z)}{P_t^X}\right)^{-\varepsilon} Y_t^X
\end{aligned} \tag{45}
$$

Aggregating (45) with respect to $z$, we obtain:

$$
Y_t^{int} = \frac{1}{n}\int_0^n Y_t^{int}(z)\, dz = \Delta_t^H Y_t^H + \Delta_t^X Y_t^X \tag{46}
$$

where $\Delta_t^H = \frac{1}{n}\int_0^n \left(\frac{P_t^H(z)}{P_t^H}\right)^{-\varepsilon} dz$ and $\Delta_t^X = \frac{1}{n}\int_0^n \left(\frac{P_t^X(z)}{P_t^X}\right)^{-\varepsilon} dz$ are measures of relative price dispersion, which have a null impact on the dynamic in a first order approximation of the model. Similarly, the aggregate demand for labour is:

$$
L_t = \frac{MC_t}{W_t/P_t}\left(\Delta_t^H Y_t^H + \Delta_t^X Y_t^X\right) \tag{47}
$$

After aggregating household's budget constraints, firms' and dealers' profits, and including the equilibrium condition in the financial market that equates household wealth with the stock of domestic bonds, we obtain the aggregate resources constraint of the home economy:

$$
\begin{aligned}
&\Delta B_{t+1}^d + \Delta B_{t+1}^{cb} + \Delta\left(S_{t+1}B_{t+1}^{d,*}\right) + \Delta(S_{t+1}B_{t+1}^{cb,*}) + \frac{\psi}{2}\left(A_t^S - \overline{A}^S\right)^2 = P_t^{def}Y_t - P_tC_t + \ldots \\
&\ldots + i_tB_t^d + i_t^*S_tB_t^{d,*} + i_t^{cb}B_t^{cb} + i_t^{cb,*}S_tB_t^{cb,*} + \Delta S_{t+1}((1+i_t^*)B_t^{d,*} - (1+i_t^{cb,*})B_t^{cb,*}) + REST
\end{aligned} \tag{48}
$$

Equation (48) corresponds to the current account of the home economy. The left-hand side is the change in the net asset position in terms of consumption units. Notice that the current account can be financed by domestic currency assets the total change on the net holdings of domestic assets mirrors the demand of these assets by non-resident investors. The right-hand side is the trade balance, the difference between GDP and consumption which is equal to net exports, and the investment income. The last term, $REST_t \equiv P_t^* S_t Y_t^M \left(\int \left[\frac{P_t^M(z)}{P_t^*}\right]^{1-\varepsilon} - \left[\frac{P_t^M(z)}{P_t^*}\right]^{-\varepsilon} dz\right)$ is negligible and takes into account the monopolistic profits of imported good retail firms.[13]

## 2.7 Foreign Exchange Rate Intervention Channels

Before presenting the results we study the channels through which FX intervention works in this model. Solving forward the modified undercovered interest rate parity condition in (3) we obtain:

$$
s_t = E_t s_{t+1} + i_t^* - i_t - \gamma\sigma^2(b_t^{d,*,}) \tag{49}
$$

$$
= E_t \sum_{j=t}^{t+n}\left[i_j^* - i_j - \gamma\sigma^2(b_j^{d,*})\right] + E_t s_{t+n+1} \tag{50}
$$

[13] A complete set of the log-linearised equations of the model can be found in Appendix 1.B.

Log-linearizing the current account equation in (48) we obtain:

$$
\begin{aligned}
b_t^{d,*} &= \beta^{-1} b_{t-1}^{d,*} - rer_t - \frac{\phi_b}{\phi_{b^*}} \left(b_t - \beta^{-1} b_{t-1}\right) - \frac{\phi_{b^{cb}}}{\phi_{b^*}} \left(b_t^{cb} - \beta^{-1} b_{t-1}^{cb}\right) + \dots \\
&\dots - \frac{\phi_{b^{cb,*}}}{\phi_{b^*}} \left(rer_t + b_t^{cb,*} - \beta^{-1} b_{t-1}\right) + \frac{1}{\phi_{b^*}} \left(t_t^{def} + y_t - \phi_C c_t\right) + \frac{\phi_b + \phi_{b^{cb}}}{\beta \phi_{b^*}} \left(i_{t-1} - \pi_t\right) + \dots \\
&\dots + \frac{\phi_{b^*} + \phi_{b^{cb,*}}}{\beta \phi_{b^*}} \left(i_{t-1}^* + rer_t - \pi_t^*\right)
\end{aligned} \tag{51}
$$

where $\phi_x$ is the the steady state value of variable $x$ over the steady state GDP. Substituting (51) into (49):

$$
\begin{aligned}
s_t = E_t \sum_{j=t}^{t+n} \Bigg[ i_j^* - i_j - \gamma\sigma^2 \Bigg\{ & \beta^{-1} b_{j-1}^{d,*} - rer_j - \frac{\phi_b}{\phi_{b^*}} \left(b_j - \beta^{-1} b_{j-1}\right) - \frac{\phi_{b^{cb}}}{\phi_{b^*}} \left(b_j^{cb} - \beta^{-1} b_{j-1}^{cb}\right) + \dots \\
\dots - \frac{\phi_{b^{cb,*}}}{\phi_{b^*}} \left(rer_j + b_j^{cb,*} - \beta^{-1} b_{j-1}\right) &+ \frac{1}{\phi_{b^*}} \left(t_j^{def} + y_j - \phi_C c_j\right) + \frac{\phi_b + \phi_{b^{cb}}}{\beta \phi_{b^*}} \left(i_{j-1} - \pi_j\right) + \dots \\
\dots + \frac{\phi_{b^*} + \phi_{b^{cb,*}}}{\beta \phi_{b^*}} \left(i_{j-1}^* + rer_j - \pi_j^*\right) \Bigg\} \Bigg] &+ E_t s_{t+n+1}
\end{aligned} \tag{52}
$$

Equation (52) shows the channels through which the central bank affects the exchange rate. Besides the path of future interest rates, now the central bank can affect the exchange rate by changing the portfolio of domestic households (*portfolio balance channel*). Also the future path of FX interventions matters for the determination of the spot exchange rate. Thus, a central bank that follows a pattern for intervening in foreign exchange markets would be able to stabilize the exchange rate with a lower amount of sales and purchases (*expectations channel*). Finally, the volatility of the exchange rate affects the price of the risk that financial intermediaries will assign to their different portfolio positions. Thus, in a market with high FX volatility, changes to the portfolio will have a larger impact in the exchange rate (*volatility channel*).

# 3 Results

## 3.1 Calibration

Instead of calibrating the parameters to a particular economy, we set the parameters to values that are standard in the new open economy literature, as shown in Table 1. The discount factor $\beta$ is fixed at 0.9975, which implies a real interest rate of 1% in the steady state. The labour supply elasticity is set at 0.5 implying a relatively inelastic labour supply, though within the values found in empirical studies.[14] The parameter $\gamma$ governing households' risk aversion is fixed at 1, which is the one corresponding to logarithmic utility. The value for the elasticity of substitution between home and foreign goods is a controversial parameter. We follow previous studies in the DSGE literature, which consider values between 0.75 and 1.5.[15] The share of

[14] See Chetty et al. (2011).

[15] See Rabanal and Tuesta (2006). Other authors in the trade literature find values for this elasticity around 5, see Lai and Trefler (2002).

domestic tradable goods in the CPI is set to 0.6, implying a participation of imported final and intermediate goods of 0.4 in the domestic CPI, in line with other studies for small open economies.[16] Regarding price stickiness, we set a higher value for domestic goods over imported and exported ones. For domestic goods, the assumed stickiness implies that firms keep their prices fixed for 4 quarters on average.

The parameter for portfolio adjustment costs is set a 0.01 to ensure that the cost of adjusting the size of the portfolio is small in the baseline calibration. For the central bank reaction function, we fixed a baseline reaction to inflation deviations of 1.5, which means that the central bank reacts more than one for one to inflation expectations, affecting the real interest rate. The coefficient of absolute risk aversion for dealers was set to 500 as in Bacchetta and Wincoop (2006). Finally, The standard deviation of all exogenous processes was set to 0.01 and the autocorrelation coefficient to 0.5.

## 3.2 Model dynamics

In this section we present our results. We first discuss briefly the existence of equilibrium.[17] Once we confirm the existence of an equilibrium, we study the effectiveness of different FX intervention strategies in reducing the macroeconomic volatility. We do this by contrasting the relative volatility of a sample of variables in the absence and under the presence of intervention. Next, we explore the reaction of the economy to external shocks under different intervention strategies through the calculation of impulse-response functions. We close this section studying how FX intervention affects the relative importance of shocks to fundamentals *vis-à-vis* liquidity based trading.

### 3.2.1 Rational expectations (RE) equilibria

As shown in Section 2, the risk premium-adjusted uncovered interest parity condition (equation 3) depends, among other things, on the conditional variance of the change in the exchange rate. This, is an endogenous outcome of the RE equilibrium of the model. Solving for the RE equilibria entails solving for a fixed point problem in the conditional variance of the change in the exchange rate. In Figure 3, we plot the mappings of the conjectured and the implied conditional variance of the depreciation rate for different parametrisations of the FX intervention reaction function. Intersections with the 45-degree straight line correspond to fixed points for the conditional variance of the depreciation rate.

As shown in the left-hand panels, the volatility of the exchange rate increases with the conjectured variance given that the portfolio channel is amplified as this parameter increases. However, the rate at which the actual volatility increases diminishes as the portfolio balance

[16] See Castillo et al. (2009).

[17] As in Vitale (2011), when solving for the equilibrium variance of the exchange rate, we are unable to rely on a theorem of existence, nor exclude the presence of multiple equilibria.

channel becomes larger. This result contrasts the ones obtained in partial equilibrium models (see Vitale (2006)) or models that do not consider the interaction between current account flows and portfolio flows (Montoro and Ortiz (2016)). To explain this result we have to observe how the economy stabilizes after a portfolio shock. When capitals withdraw domestic agents lose foreign assets as non-residents exchange their domestic currency assets for foreign currency ones. This triggers a depreciation and activates the trade balance channel. As exports increase the holdings of foreign assets by domestic agents revert. Thus, the portfolio channel increases the stabilization properties of the trade balance channel. The variance of the exchange rate reported by the model increases less than one to one with the conjectured variance. To our knowledge, this mechanism is absent in previous work studying the existence of equilibria in models with a portfolio balance channel.[18] Under both rules of FX intervention there is only a unique and stable equilibrium. Also, the intensity of FX intervention reduces the RE equilibrium variance of the exchange rate change.[19]

The RE equilibrium variance of the exchange rate change also affects the direct impact of FX intervention and capital flows on the exchange rate, as shown in equation (3). Therefore, a more intensive FX intervention strategy also reduces the effectiveness of non-systematic interventions as the reduction in variance dampens the impact of interventions on the exchange rate.

### 3.2.2 FX intervention and foreign financial shocks

In Figures 4 and 5 we compare the dynamic effects of external financial shocks under discretion, the $\Delta s_t$ rule and the case with no intervention.[20] Overall, the effectiveness of intervention is confirmed. In the presence of external financial shocks such as portfolio outflows or a hike in foreign interest rates, FX intervention under rules helps stabilizing the exchange rate, and consequently it also stabilizes both GDP and inflation. This shows the expectation channel at work; given that it is common knowledge that the central bank will enter the FX market to prevent large fluctuations in the exchange rate, the amount of intervention necessary to reduce fluctuations is smaller because of its impact on expected future exchange rate fluctuations. This means that the FX sales and purchases by the central bank necessary to stabilise the exchange rate will be much higher under discretion because it does not influence expectations as in the case of an intervention rule.[21]

In Figures 4 we show the reaction to a portfolio or non-fundamental capital flow shock. These outflows generate an depreciation of the exchange rate via the portfolio channel. In the

[18] A slope lower (higher) than one of the mapping of the conjectured and the implied conditional variance of the depreciation rate, evaluated at the intersection with the 45-degree straight line, indicates a stable (unstable) equilibrium.

[19] This is a novel result, in stark contrast with the findings of Vitale (2011). We consider the author's setup different to ours as in his model, central bank FX interventions are always informative and can potentially increase information dispersion across agents.

[20] The case of the $RER$ rule is presented in figures 7, 8 and 9 in Appendix 1.A.

[21] An implicit key assumption for this result is that dealers do not have an strategic behaviour when setting the purchase and sale orders.

case where the central bank intervenes through rules or discretion, the effects of these shocks are dampened, stabilising the economy. For the case of a foreign interest rate shock, in Figure 5 we show how interventions can ease the pressure on the exchange rate.

## 3.3 FX intervention and monetary policy

### 3.3.1 Targeting exchange rate variations

Up to now we have shown that FX interventions can be effective as a mechanism to cope with the effects of external financial shocks. Now we study the interactions of FX policy and monetary policy. Figure 10 contrasts the interactions between monetary and FX policy. Our results shows that exchange rate stabilization reduces the effectiveness of monetary policy. Without FX intervention, interest rate hikes generate an appreciation of the domestic currency and a contraction in foreign demand for domestic goods, as foreign goods become relatively cheaper. However, when the central bank seeks to stabilize the exchange rate via FX interventions, this channel is curbed. This result is key in the design of an FX intervention policy as a rule that¿ stabilizes the exchange rate such as the one in equation (8), curtails the capacity of the central bank to stabilize the economy when other shocks hit the economy. In order to study this interaction in more detail we perform simulations for simple intervention and monetary policy rules. [22] The loss function we use is:

$$\mathcal{L}^{cb} = \sigma_y^2 + 2 \times \sigma_\pi^2$$

where, $\sigma_y$ and $\sigma_\pi$ represent the unconditional standard deviations for the output gap and the inflation rate, respectively.

Our simulations confirm the previous result that FX intervention reduces the equilibrium volatility of the exchange rate. Nonetheless, this result depends on the intensity of the monetary policy reaction to inflation as the effectiveness of the FX intervention rule to reign in macroeconomic volatility wanes when the central bank is more hawkish (higher $\varphi_\pi$). Under the $\Delta s$ rule, the interest becomes less effective as a stabilization instrument. For this reason, the central bank needs to react more to domestic shocks, which in turn cause a more volatile interest rate. Given that the domestic interest rate affects the determination of the exchange rate, as the central bank tries to reduce FX volatility through interventions in the FX market, a larger interest rate shifts do the exact opposite, increasing the volatility of the exchange rate. Thus, an intervention strategy focused on the changes of the exchange rate can become ineffective. Therefore, an FX intervention rule that does not distinguish the source of the shocks to the exchange rate can actually be destabilizing. The outcome will depend on the frequency

[22] As De Paoli (2009) shows, in a small open economy model the central bank loss function will be in terms of output, the real exchange rate and locally produced goods inflation rate. We acknowledge that our present setup has additional frictions. Specifically: (1) agents do not consider the government's portfolio as part of theirs; and (2) dealers' behaviour is myopic. Thus, we acknowledge these exercises do not analyse optimal policy in a strict way.

of shocks hitting the economy. If portfolio and foreign interest rate shocks are more frequent than domestic ones, the $\Delta s$ rule can stabilize the economy, while the opposite occurs if the case non-financial shocks. This is in line with Montoro and Ortiz (2016), where FX intervention was effective reducing macro volatility when the only shocks affecting the economy were portfolio and foreign interest rate shocks, while the contrary occurred for the other shocks.

#### 3.3.2 Targeting portfolio shocks

Now we assume the central bank is capable to identify portfolio shocks and act to exactly offset them. This assumption, reflected in equation (9), means that the central bank will react selling foreign currency in the exact amount as the one demanded by foreign carry-traders. We use the same loss function as in the previous case. Figure 11 presents the results. A central bank reacting directly to offset portfolio shocks can turn off these shocks to the economy, reducing the overall volatility of the economy. Thus, when these shocks are more prevalent in the economy, the gains arising from intervention in FX markets become more important. Moreover, our robustness results show that when these shocks are the primary driver of exchange rate dynamics, an FX rule targeting the exchange rate volatility will be preferable over no intervention.

We consider this a novel result. FX intervention effectiveness depends on the strategy followed by the central bank and the underlying shocks to the economy. A central bank reacting to *non-fundamental* shocks, will be able to stabilize the economy effectively.[23] When shocks are originated in the FX market and do not have major effects on the rest of endogenous variables, the central bank can offset them. When shocks originated in other markets affect the exchange rate, reacting to them will deteriorate the effectiveness of monetary policy, which could in turn render both monetary and exchange rate policies ineffective.

To further explore this result we simulate the model and compare how different FX intervention strategies work assuming a single source of volatility at the time. [24] For comparison, relative variances are normalised with respect to the no intervention case.

The results in Table 2 confirm that the effectiveness of intervention strategies depend on the underlying shock affecting the economy. As in Montoro and Ortiz (2016), FX intervention are relatively more effective dealing with financial shocks such as capital flows or foreign interest rate shocks, vis-a-vis shocks to foreign inflation or output. For instance, the volatility of exports and output generated by foreign interest rate and capital flow shocks is reduced under FX intervention regimes. However, the use of FX interventions to smooth the nominal exchange rate amplifies the volatility of inflation and output generated by foreign inflation shocks. Similarly, the use of a real exchange rate misalignment rule increases the volatility of exports under the presence of foreign output shocks.

[23] Vitale (2006) makes the case for considering these shocks fundamental too as they convey information to the economy.

[24] Exercises are simulated using the conditional variance of the depreciation rate in equilibrium in equation 3.

Regarding an FX intervention strategy based on the reaction to non-fundamental capital flows, the central bank can completely offset these shocks. Clearly, these results must be taken with caution for several reasons: First, as stated before, we are not modelling any type of strategic interaction between the central bank and FX market participants. Second, the behaviour of carry traders has been assumed exogenous, when investors react to the FX policy of the central bank. Third, we assume perfect information across market participants when the literature shows that central banks operate in a partial information setup and in some cases FX dealers can exploit informational advantages. Finally, we assume the central bank intervention is credible, while the level of foreign reserves constitutes a constraint. The capacity of the central bank to affect expectations depends in the credibility market participants have on it following its intervention rule. As Basu et al. (2018) show, a non-negativity constraint in reserves can affect the capacity of the central bank to commit to a path of foreign exchange interventions. For tractability, we abstract from these issues, as the channels through which FX interventions affect the exchange rate are robust to changes in these assumptions.

# 4 Conclusions

In this paper, we present a model to analyse the interaction between monetary policy and FX intervention by central banks, which also includes microstructure fundamentals in the determination of the exchange rate. We introduce a portfolio decision of risk-averse dealers, which adds an endogenous risk premium to the traditional uncovered interest rate condition. In this model, FX intervention affects the exchange rate through both a portfolio-balance and and a volatility channel.

Our results illustrate that FX intervention has strong interactions with monetary policy. Albeit, FX intervention rules can be more powerful in stabilising the economy as they exploit the expectations channel, intervening to smooth exchange rate misalignments can mute the monetary transmission mechanism through exchange rates, reducing the impact on aggregate demand and prices. When we analyse the response to foreign financial shocks, we show that FX intervention rules have some advantages as a stabilisation tool over discretionary interventions, though we many central banks argue against pre-announcing rules given the strategic interaction with FX market participants. Also, considerations regarding zero lower bond on reserves are absent from our analysis.

We show that there are important trade-offs in the use of FX intervention as a exchange rate stabilization device, as it weakens monetary policy. Alternatively, when the central bank is capable of identifying portfolio shocks from other shocks affecting the exchange rate, FX intervention is an effective tool to stabilize the economy. As it is frequently the case, the effectiveness of the central bank will depend on the nature of the shock and its ability to identify it in a timely manner. Likewise, rules reacting to the exchange rate, without taking into consideration the shock behind its movement, will be more effective when the prevalent shocks are financial ones; while in economies where the contrary occurs, FX intervention will be ineffective. Thus, exchange rate stabilization policies would be more effective in small open economies subject to large portfolio shocks and with a lower degree of financial development, understood as lower risk tolerance by intermediaries.

Additionally, we show an important interaction between the current account and the portfolio channel. Although a higher volatility of the exchange rate amplifies the impact of foreign financial shocks, capital flows generated from shifts in the trade balance act as an stabilizing mechanism. Finally, we consider that the comovement of the exchange rate and interests rates stemming from portfolio shocks can help solving the exchange rate determination puzzle, as the portfolio balance channel allows for an additional explanation of exchange rate dynamics in small open economy NK-DSGE setup.

In terms of policy, the design of a FX intervention policy needs to consider more information than previously thought and relying on broad recipes for exchange rate stabilization could generate more instability, the exact opposite result to the one intended with the policy.

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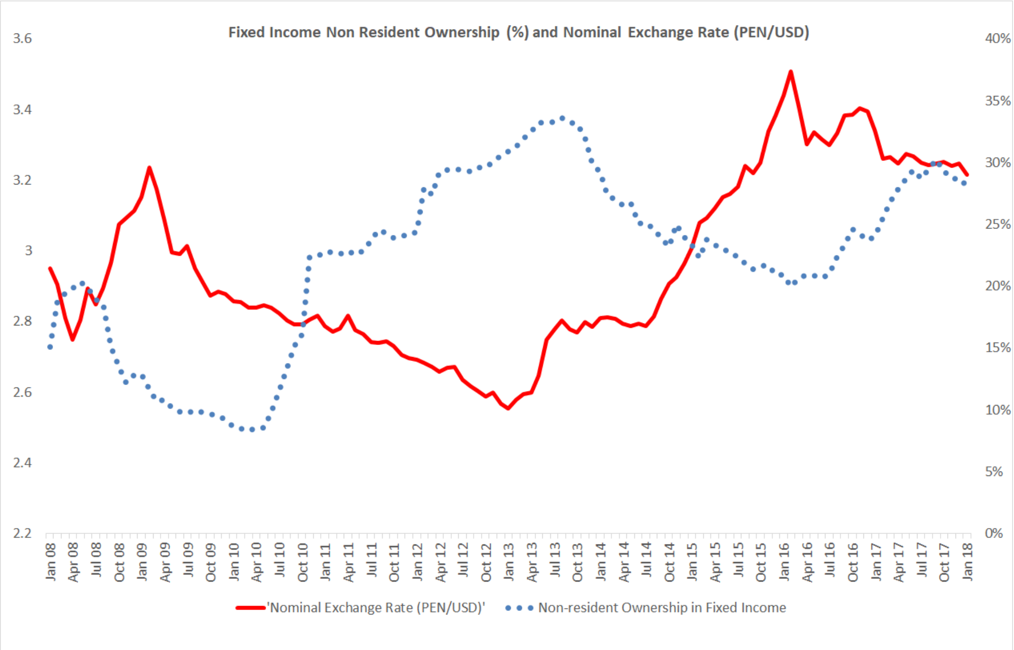
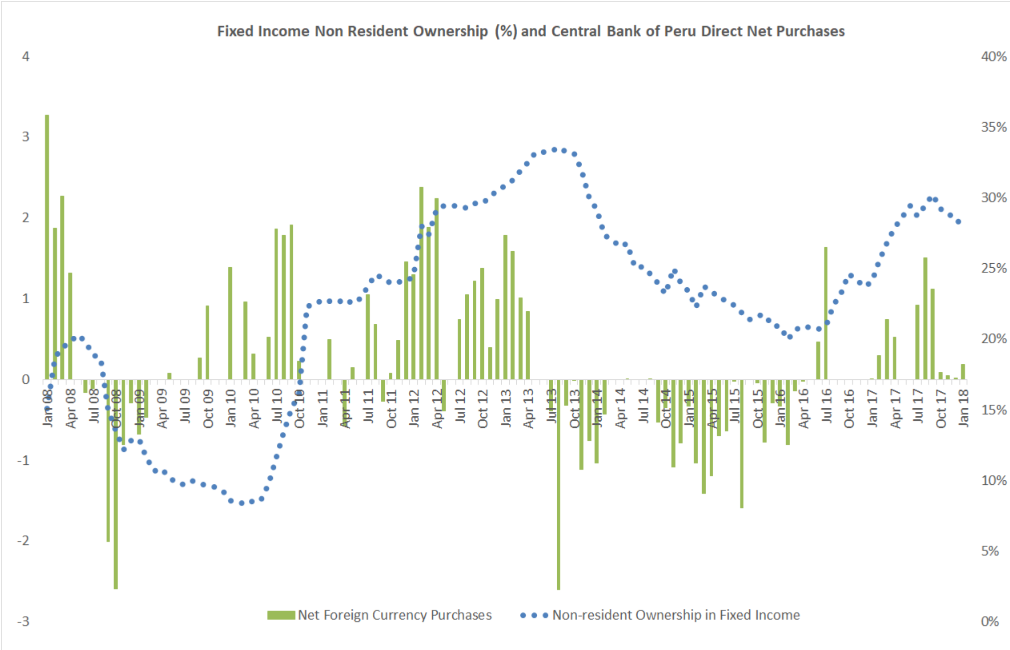
## 1.A Figures and Tables

Figure 1: Foreign Ownership of Fixed Income Instruments in Peru and Exchange Rate




*Source: Central Reserve Bank of Peru (BCRP).*

Figure 2: Foreign Ownership of Fixed Income Instruments in Peru and Exchange Rate

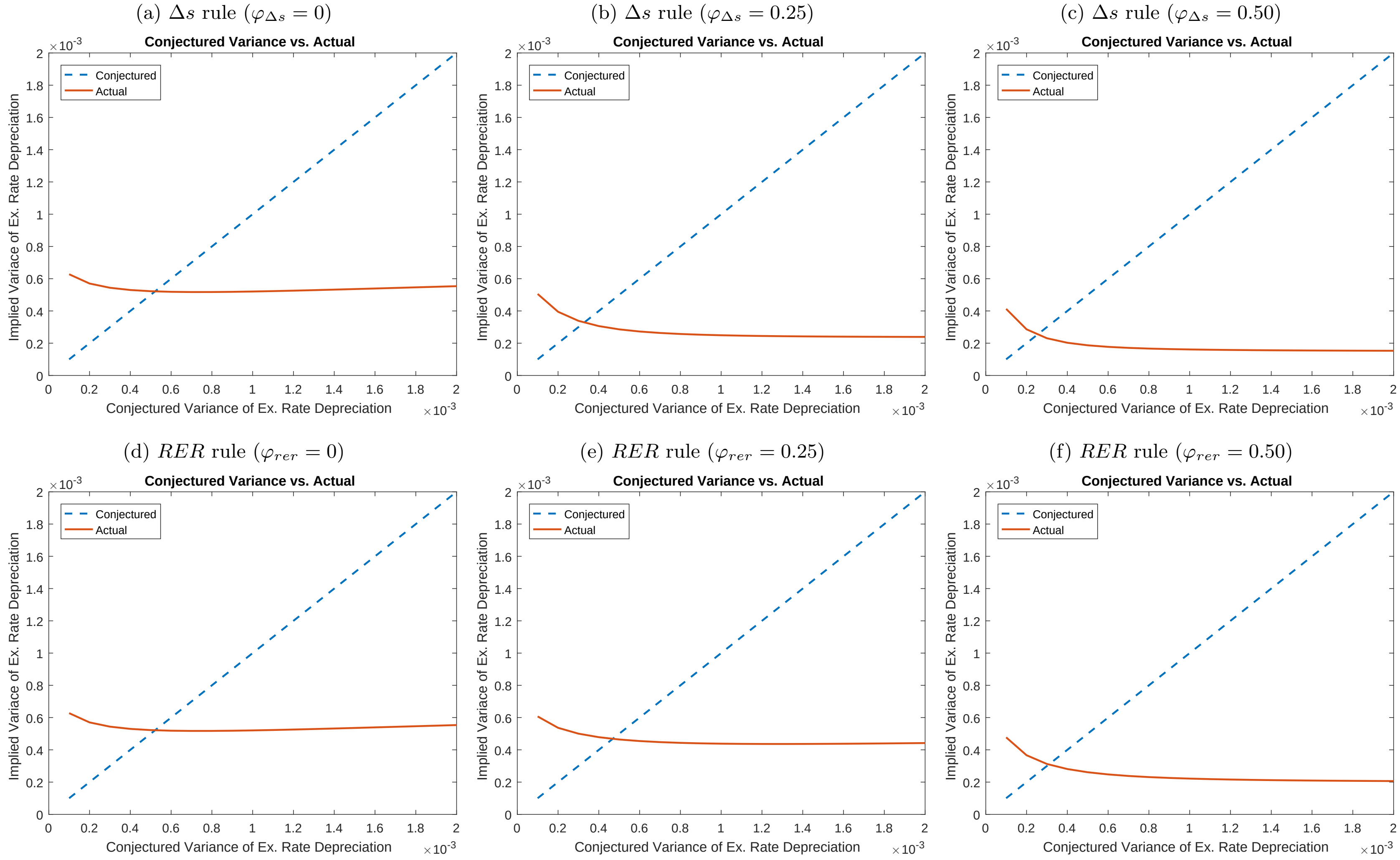



*Source: Central Reserve Bank of Peru (BCRP).*

Table 1: **Baseline Calibration**

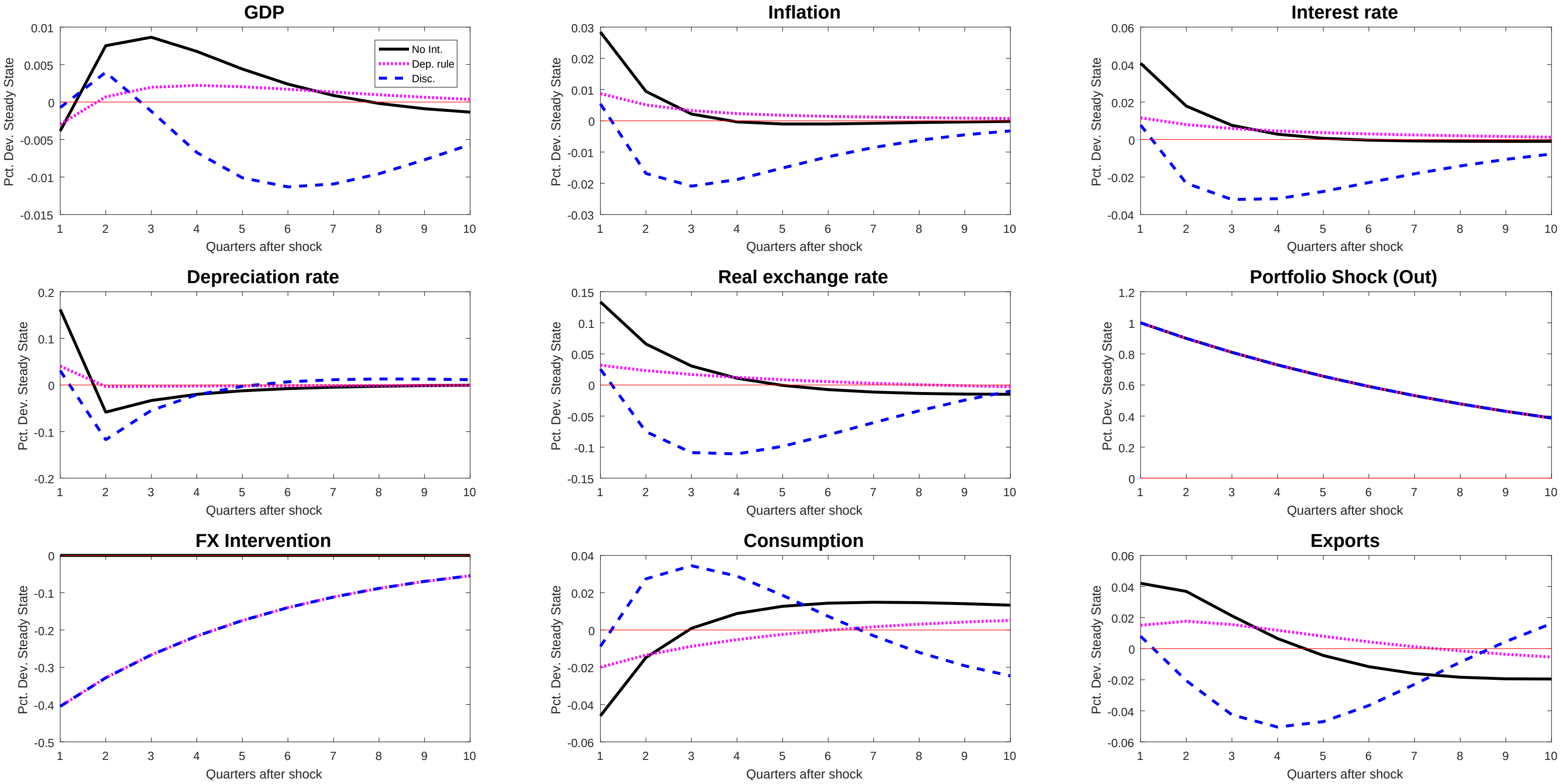
| *Parameter* | *Value* | *Description* |
|---|---|---|
| $\beta$ | 0.9975 | Consumers time-preference parameter. |
| $\chi$ | 0.5 | Labour supply elasticity. |
| $\gamma_c$ | 1 | Risk aversion parameter. |
| $\varepsilon$ | 0.75 | Elast. of subst. btw. home and foreign goods. |
| $\varepsilon_F$ | 0.75 | Elast. of subst. btw. exports and foreign goods. |
| $\psi$ | 0.6 | Share of domestic tradables in domestic consumption. |
| $\theta_H$ | 0.75 | Domestic goods price rigidity. |
| $\theta_M$ | 0.5 | Imported goods price rigidity. |
| $\theta_X$ | 0.5 | Exported goods price rigidity. |
| $\psi_b$ | 0.01 | Portfolio adjustment costs. |
| $\varphi_\pi$ | 1.5 | Taylor rule reaction to inflation deviations. |
| $\gamma$ | 500 | Absolute risk aversion parameter (dealers) |
| $\phi_\varpi$ | 0.5 | Net asset position over GDP ratio |
| $\phi_C$ | 0.68 | Consumption over GDP ratio |
| $\sigma_x$ | 0.01 | S.D. of all shocks x |
| $\rho_x$ | 0.5 | AR(1) coefficient for all exogenous processes |
| $\phi_{b^d}$ | 0.1 | Households domestic bonds over GDP ratio |
| $\phi_{b^{cb}}$ | 0.1 | Central Bank outstanding bonds over GDP ratio |
| $\phi_{b^{c,*}}$ | 0.2 | Non-resident domestic bonds holdings over GDP ratio |

Figure 3: Existence of equilibria under FX intervention rules



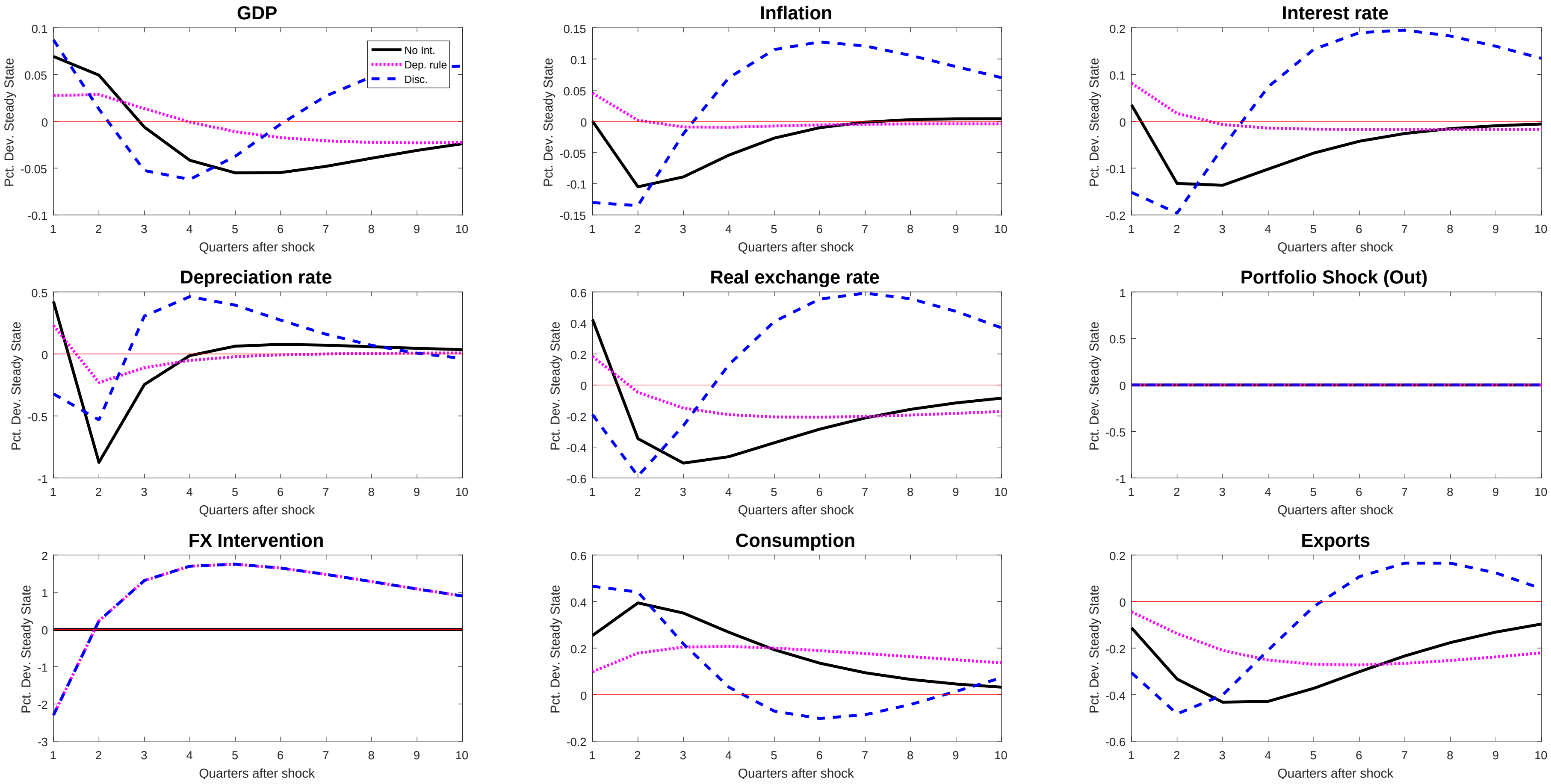

Simulations involved 11 values for the conjectured variances of the change of the exchange rate. When the intervention parameter under both rules is zero, we replicate the values for the pure discretional intervention case.

Figure 4: Reaction to a 1% portfolio shock - $\Delta s_t$ rule.



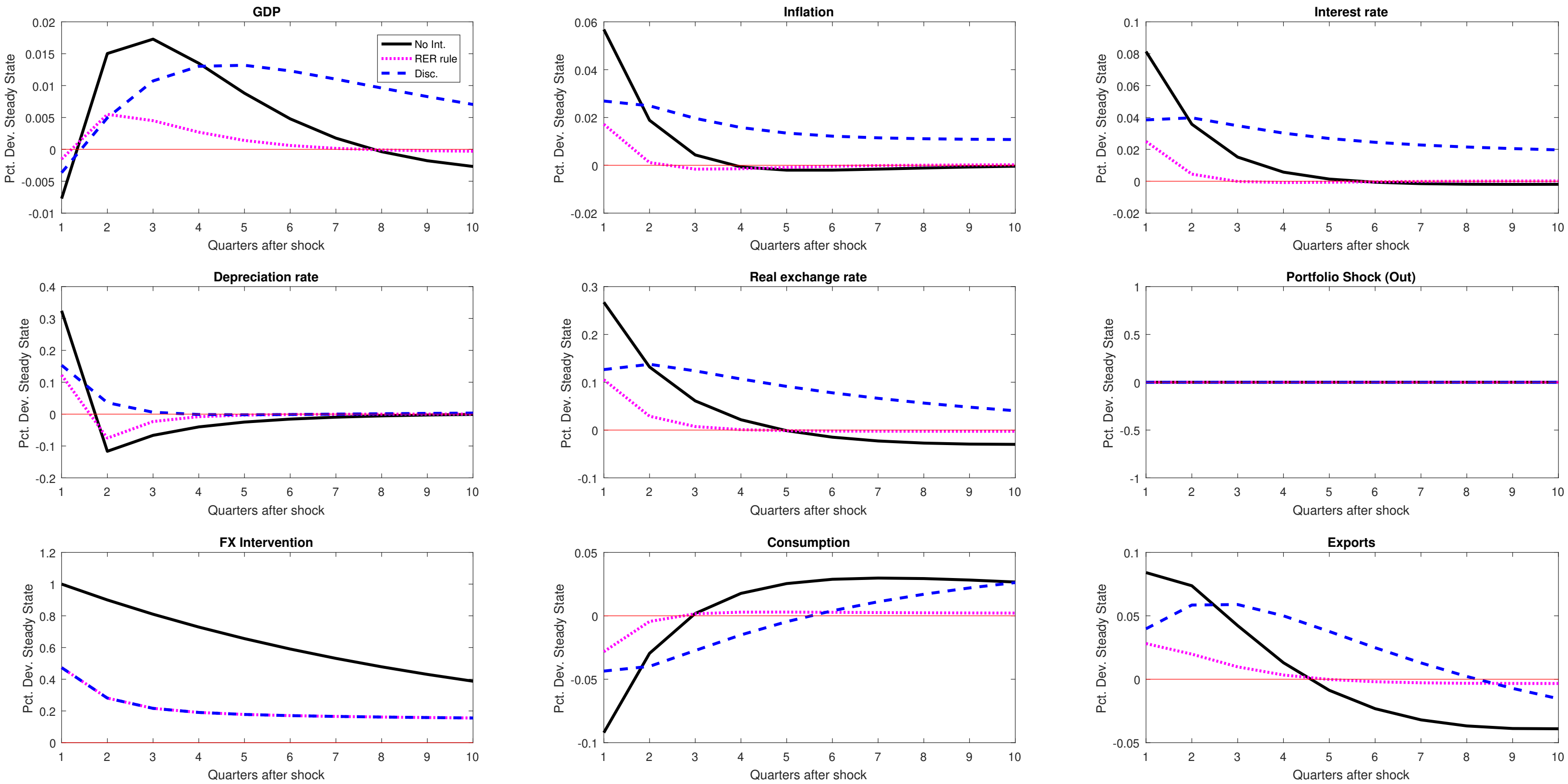

*Note: Intervention under discretion normalised to the implied intervention path under rules.*

Figure 5: Reaction to a 1% foreign interest rate shock - $\Delta s_t$ rule.



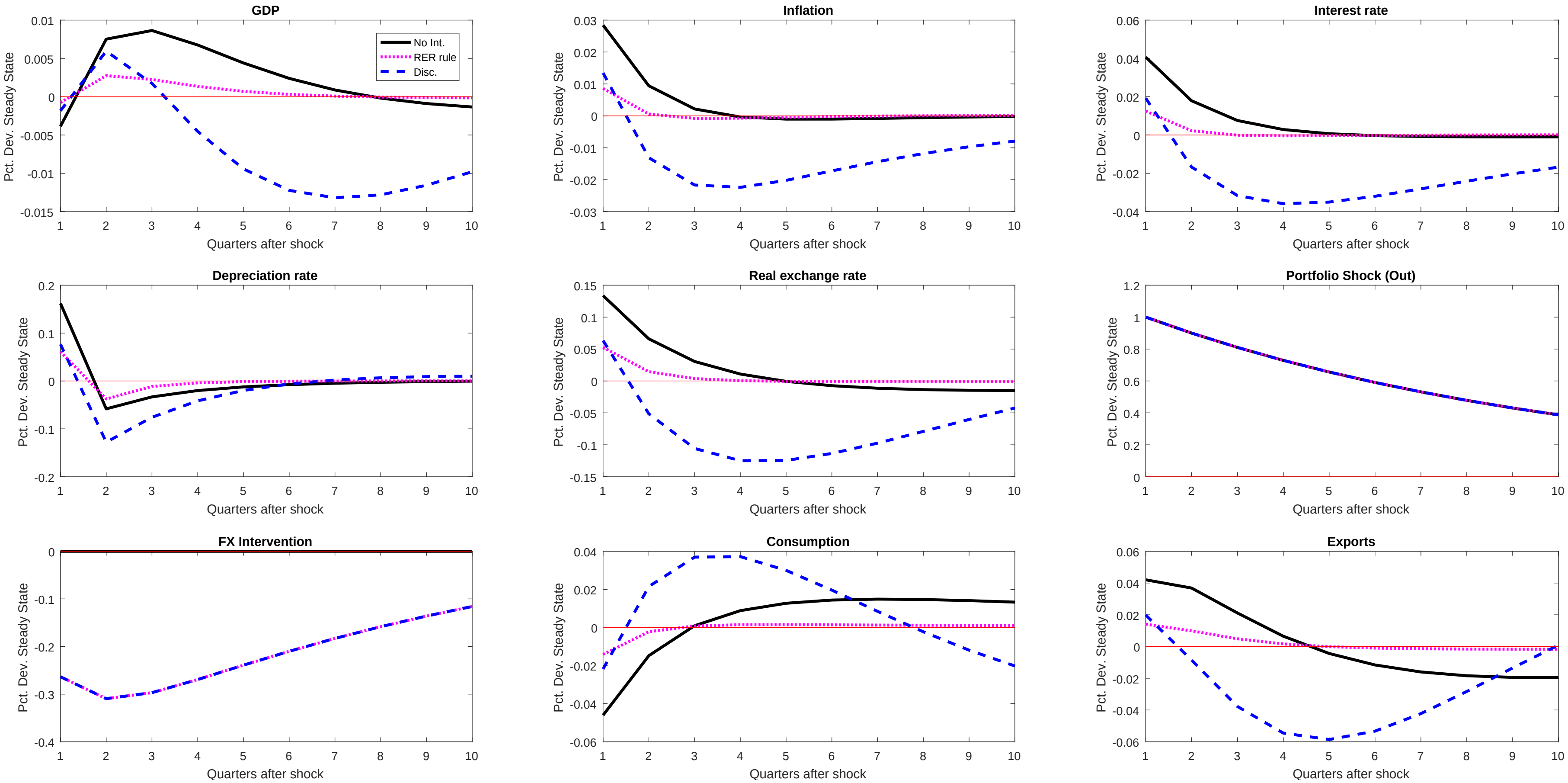

*Note: Intervention under discretion normalised to the implied intervention path under rules.*

Figure 6: Reaction to a 1% FX intervention shock - *RER* rule.



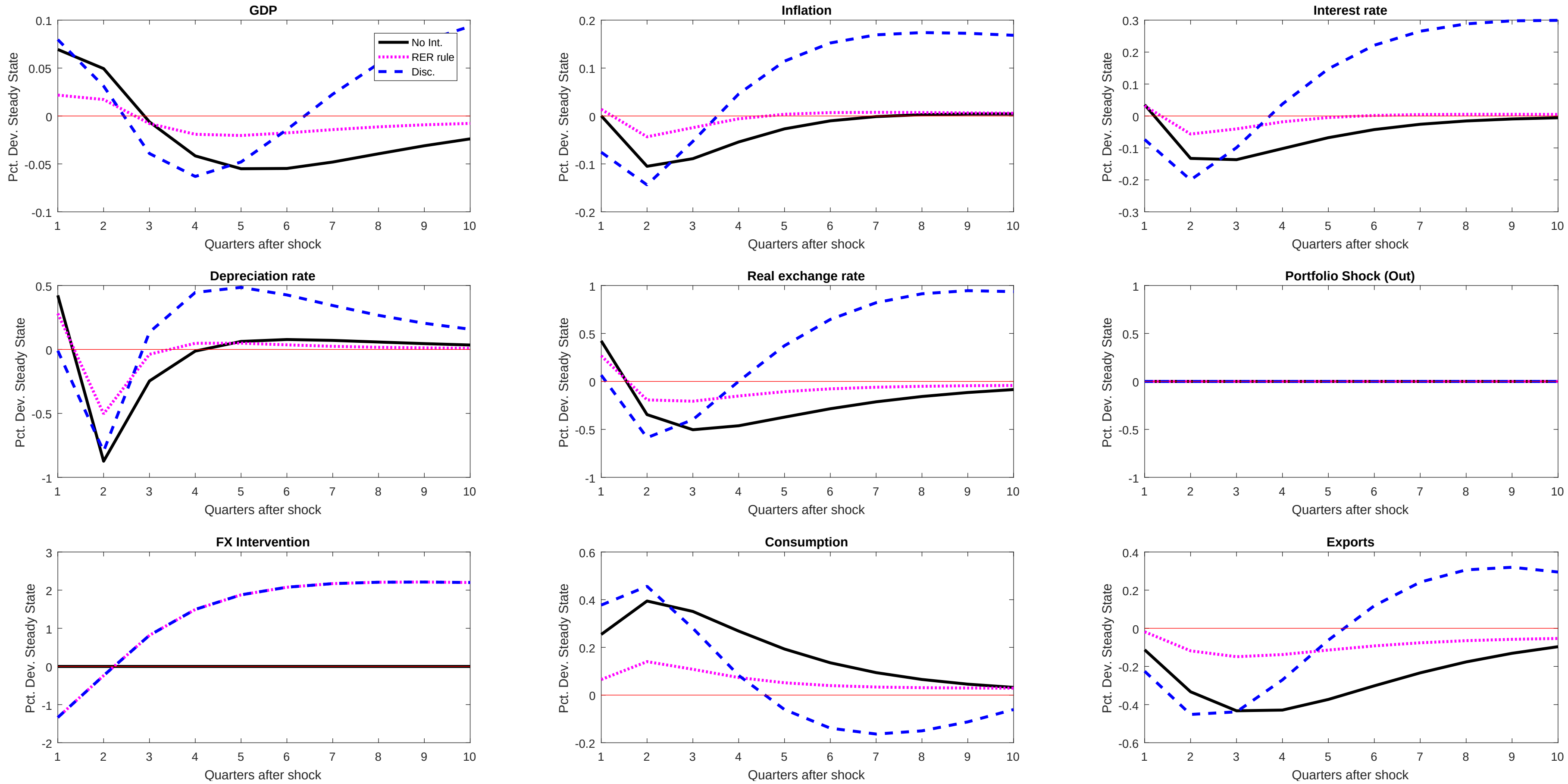

*Note: Intervention under discretion normalised to the implied intervention path under rules.*

Figure 7: Reaction to a 1% portfolio shock - *RER* rule



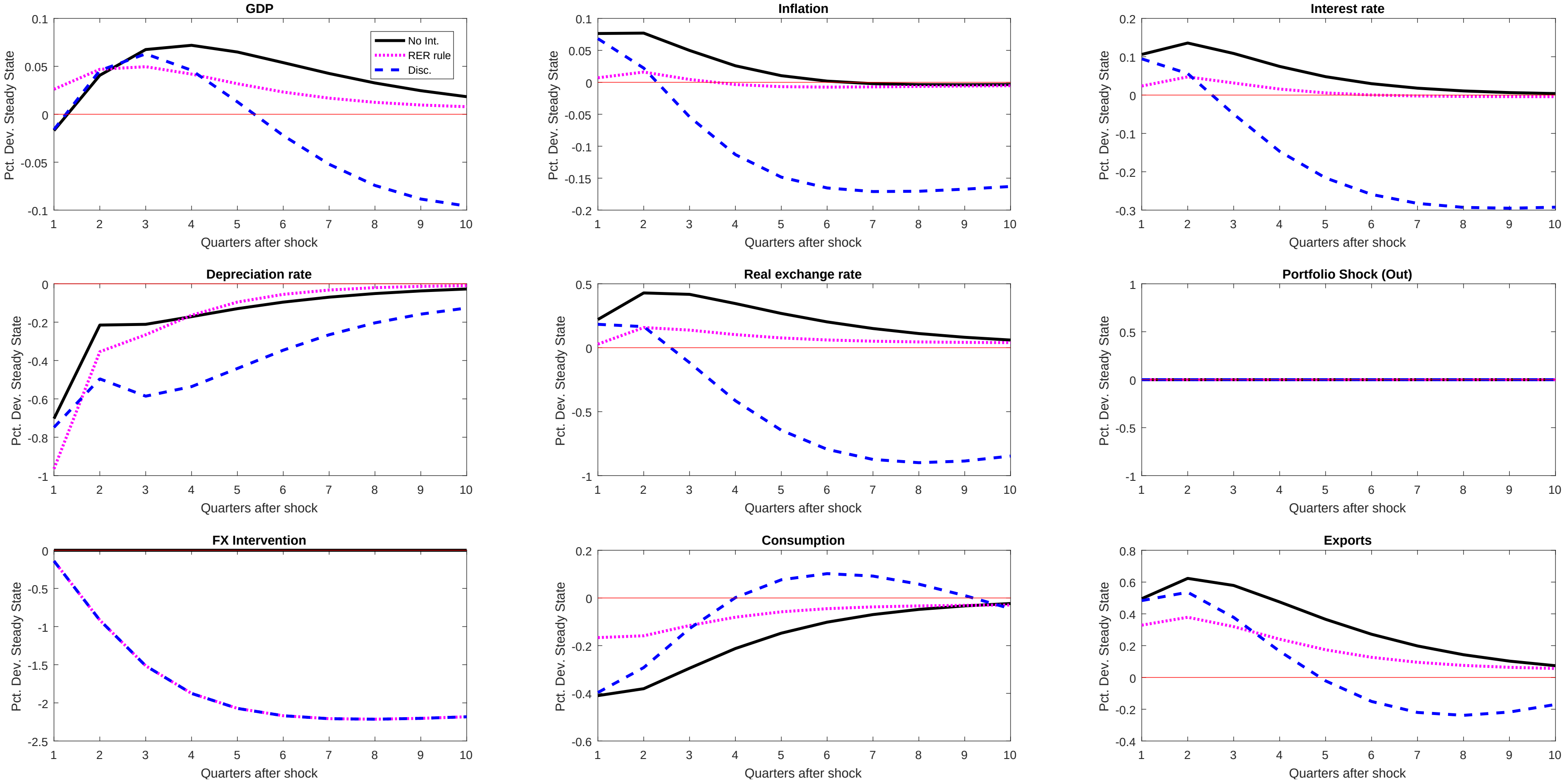

*Note: Intervention under discretion normalised to the implied intervention path under rules.*

Figure 8: Reaction to a 1% foreign interest rate shock - $RER$ rule.




*Note: Intervention under discretion normalised to the implied intervention path under rules.*

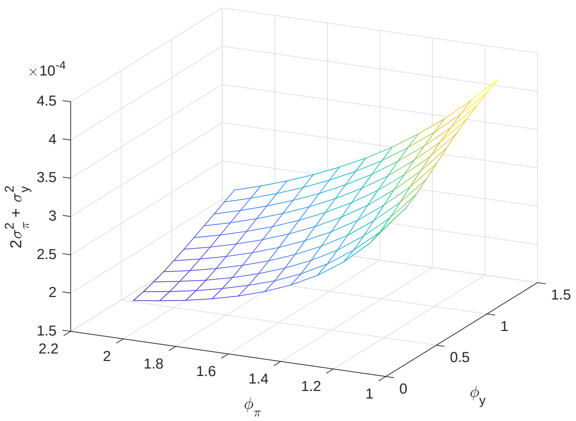
Figure 9: Reaction to a 1% foreign inflation rate shock - *RER* rule.



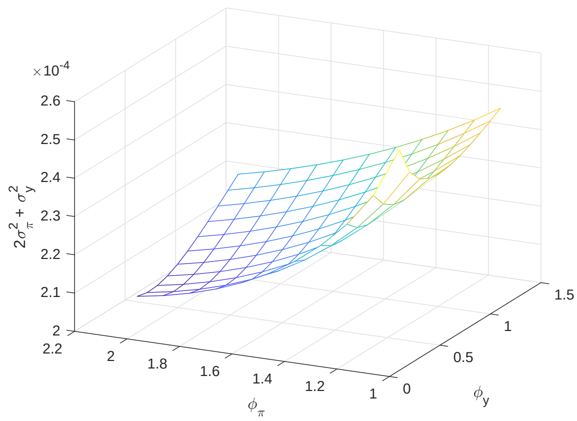

*Note: Intervention under discretion normalised to the implied intervention path under rules.*

Figure 10: Monetary and FX policy interaction

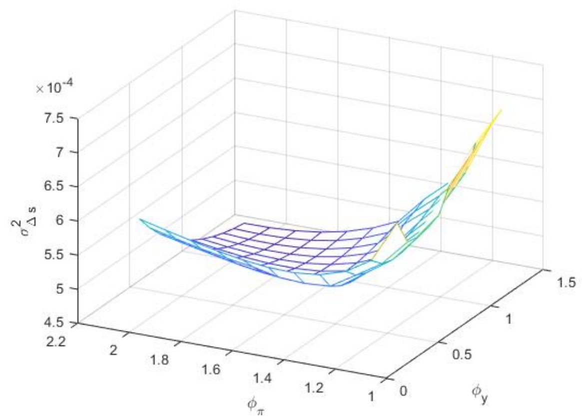
(a) No intervention



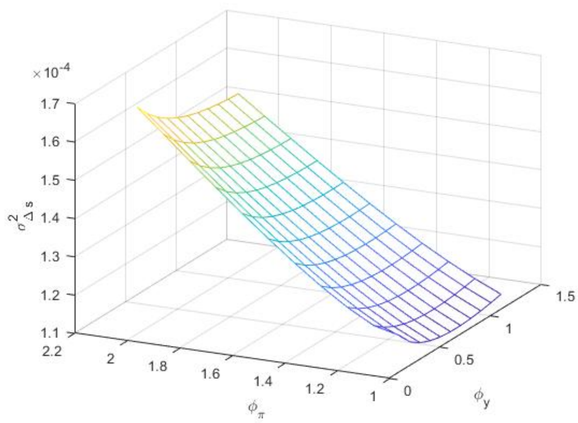

(b) $\Delta s$ rule ($\varphi_{\Delta s} = 10$)




(c) Exchange rate variance (No Intervention)



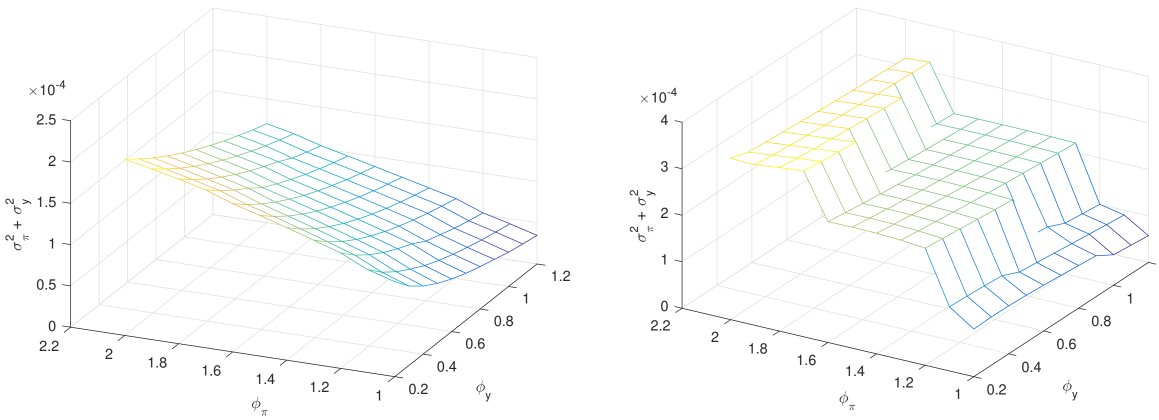

(d) Exchange rate variance ($\Delta s$ rule)




*Note: Upper panel shows the value of an ad hoc loss function for the Central Bank of the form $\mathcal{L} = 2 \times \sigma_\pi^2 + \sigma_y^2$ for different values of parameters in the monetary policy function ruling the central bank's reaction to inflation ($\phi_\pi$) and the output gap ($\phi_y$). Lower panel shows the equilibrium variance of the exchange rate ($\sigma^2_{\Delta s}$) for each combination of the Taylor rule parameters depicted in the respective upper figure.*

Figure 11: Gains for FX Intervention to Portfolio Shocks

(a) Difference in Loss Function (b) Difference in Ex. Rate Volatility




*Note: Left panel shows the difference in the value of an ad hoc loss function for the Central Bank of the form $\mathcal{L} = 2 \times \sigma_\pi^2 + \sigma_y^2$ for different values of parameters in the monetary policy function ruling the central bank's reaction to inflation ($\phi_\pi$) and the output gap ($\phi_y$). The difference is the subtraction of the loss under FX intervention from the loss under no intervention. Right panel shows the difference of equilibrium variances of the exchange rate ($\sigma_{\Delta s}^2$) for each combination of the Taylor rule parameters depicted in the respective upper figure.*

Table 2: **Macroeconomic volatility under FX Intervention Rules (No intervention $\equiv 1$)**

| *Endogenous variable* | *RER* | $\Delta$ *Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| | | | *Foreign interest rate shock* ($\varepsilon_{i^*}$) | | | | |
| $\varphi_{rer} = 1$ | 0.65 | 0.67 | 0.65 | 0.68 | 0.52 | 0.61 | 0.54 |
| $\varphi_{\Delta s} = 10$ | 0.32 | 0.07 | 0.75 | 0.80 | 0.13 | 0.35 | 0.07 |
| | | | *Portfolio flow shock* ($\varepsilon^{\omega^*}$) | | | | |
| $\varphi_{rer} = 1$ | 0.62 | 0.64 | 0.55 | 0.54 | 0.59 | 0.56 | 0.60 |
| $\varphi_{\Delta s} = 10$ | 0.07 | 0.04 | 0.15 | 0.17 | 0.12 | 0.12 | 0.11 |
| $\varphi_{b^{*,c}} = 1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | *Foreign inflation shock* ($\varepsilon^{\pi^*}$) | | | | |
| $\varphi_{rer} = 1$ | 0.62 | 1.18 | 0.73 | 0.82 | 0.53 | 0.79 | 0.48 |
| $\varphi_{\Delta s} = 10$ | 5.40 | 0.25 | 7.49 | 4.27 | 7.76 | 3.34 | 8.91 |
| | | | *Foreign output shock* ($\varepsilon^{y^*}$) | | | | |
| $\varphi_{rer} = 1$ | 0.61 | 0.59 | 0.57 | 1.31 | 0.34 | 0.90 | 0.54 |
| $\varphi_{\Delta s} = 10$ | 0.32 | 0.05 | 1.49 | 2.45 | 0.14 | 1.06 | 0.11 |
| | | | *Domestic demand shock* ($\varepsilon^{g}$) | | | | |
| $\varphi_{rer} = 1$ | 0.63 | 0.62 | 0.57 | 0.70 | 0.35 | 0.89 | 0.56 |
| $\varphi_{\Delta s} = 10$ | 0.35 | 0.07 | 1.44 | 1.08 | 0.15 | 1.03 | 0.11 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading under different FX intervention strategies. The volatility resulting from no intervention is normalized to 1. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy. The strategy reacting to portfolio flow shocks ($\varphi_{b^{*,c}}$) is only considered when these shocks are present in the model.

## 1.B The log-linear version of the model

### Aggregate demand

Aggregate demand ($y_t$)

$$y_t = \phi_C(c_t) + \phi_X(x_t) - \phi_M(m_t) + g_t \tag{53}$$

GDP deflator $\left(t_t^{def}\right)$

$$t_t^{def} = \phi_X(rer_t + t_t^X) - \phi_M t_t^M \tag{54}$$

Real exchange rate ($rer_t$)

$$rer_t = rer_{t-1} + \Delta s_t + \pi_t^* - \pi_t \tag{55}$$

Euler equation ($\lambda_t$)

$$\lambda_t = \hat{\imath}_t + E_t(\lambda_{t+1} - \pi_{t+1}) - \psi_b b_t \tag{56}$$

Marginal utility ($\lambda_t$)

$$\lambda_t = -\gamma_c c_t \tag{57}$$

Exports ($x_t$)

$$x_t = -\varepsilon_F(t_t^X) + y_t^*; \tag{58}$$

Relative price of exports $\left(t_t^X\right)$

$$t_t^X = t_{t-1}^X + \pi_t^X - \pi_t^*; \tag{59}$$

Imports ($m_t$)

$$m_t = -\varepsilon(t_t^M) + c_t; \tag{60}$$

Relative price of imports $\left(t_t^M\right)$

$$t_t^M = t_{t-1}^M + \pi_t^M - \pi_t; \tag{61}$$

Home produced goods demand $\left(y_t^H\right)$

$$y_t^H = -\varepsilon(t_t^H) + c_t; \tag{62}$$

Relative price of home produced goods $\left(t_t^H\right)$

$$t_t^H = -\left(\frac{1-\psi}{\psi}\right) t_t^M \tag{63}$$

### Aggregate supply

Total CPI ($\pi_t$):

$$\pi_t = \psi \pi_t^H + (1-\psi)\,\pi_t^M + \mu_t \tag{64}$$

Phillips curve for home-produced goods ($\pi_t^H$):

$$\pi_t^H = \kappa_H\left(mc_t - t_t^H\right) + \beta E_t \pi_{t+1}^H \tag{65}$$

Real marginal costs ($mc_t$)

$$mc_t = wp_t - a_t; \tag{66}$$

Phillips curve for imported goods ($\pi_t^M$):

$$\pi_t^M = \kappa_M mc_t^M + \beta E_t \pi_{t+1}^M \tag{67}$$

Marginal costs for imports $\left(mc_t^M\right)$

$$mc_t^M = rer_t - t_t^M \tag{68}$$

Phillips curve for exports ($\pi_t^X$)

$$\pi_t^X = \kappa_X mc_t^X + \beta E_t \pi_{t+1}^X \tag{69}$$

Marginal costs for exports $\left(mc_t^X\right)$

$$mc_t^X = mc_t - rer_t - t_t^X \tag{70}$$

## Labour market

Labour demand ($l_t$)

$$l_t = y_t - a_t; \tag{71}$$

Labour supply ($wp_t$)

$$wp_t = \gamma_c c_t + \chi l_t \tag{72}$$

## Capital markets and current account

Risk premium-adjusted UIP ($\Delta s_t$)

$$\overline{E}_t \Delta s_{t+1} = \hat{\imath}_t - \hat{\imath}_t^* + \gamma \sigma^2 \left(b_t^*\right) \tag{73}$$

Dealers real profits ($\Gamma_t^d$)

$$\Gamma_t^d = (1/\beta)\left[\phi_b(i_{t-1} - \pi_t) + \phi_{b^*}(i_{t-1}^* + rer_t - \pi_t^*) - (\phi_b + \phi_{b^*})(i_{t-1} - \pi_t)\right] \tag{74}$$

Foreign carry traders balance sheet ($b_t^c$)

$$\phi_{b^c} b_t^c + \phi_{b^{c,*}} b_t^{c,*} = 0; \tag{75}$$

Equilibrium of domestic bonds market ($b_t^d$)

$$\phi_b b_t + \phi_{b^{cb}} b_t^{cb} + \phi_{b^c} b_t^c = 0 \tag{76}$$

Current account ($cca_t$)

$$\begin{aligned} cca_t = {} & \phi_b \left(b_t - \beta^{-1} b_{t-1}\right) + \phi_{b^{cb}} \left(b_t^{cb} - \beta^{-1} b_{t-1}^{cb}\right) + \phi_{b^*}\left(rer_t + b_t^* - \beta^{-1} b_{t-1}^*\right) + \ldots \\ & \ldots + \phi_{b^{cb,*}}\left(rer_t + b_t^{cb,*} - \beta^{-1} b_{t-1}^{*,cb}\right) \end{aligned} \tag{77}$$

$$cca_t = t_t^{def} + y_t - \phi_C c_t + \frac{\phi_b + \phi_{b^{cb}}}{\beta}\left(i_{t-1} - \pi_t\right) + \frac{\phi_{b^*} + \phi_{b^{cb,*}}}{\beta}\left(i_{t-1}^* + rer_t - \pi_t^*\right) \tag{78}$$

### Monetary policy

Interest rate ($\hat{\imath}_t$)

$$\hat{\imath}_t = \varphi_\pi(\pi_t) + \varepsilon_t^{int} \tag{79}$$

FX intervention $\left(b_t^{*,cb}\right)$

$$b_t^{cb,*} = -\varphi_{\Delta s}\Delta s_t + -\varphi_{rer} rer_t + \rho_{cb,*} b_{t-1}^{cb,*} + \varepsilon_t^{cb} \tag{80}$$

Central bank's profits ($\Gamma_t^{cb}$)

$$\begin{aligned} &\phi_{b^{cb}}(b_t^{cb} - (1/\beta)b_{t-1}^{cb}) + \phi_{b^{cb,*}}(b_t^{cb,*} + rer_t - (1/\beta)b_{t-1}^{cb,*}) + \Gamma_t^{cb} = \ldots \\ &\qquad \ldots = (1/\beta)\left(\phi_{b^{cb}}(i_{t-1} - \pi_t) + \phi_{b^{cb,*}}(i_{t-1}^* + rer_t - \pi_t^*)\right) \end{aligned} \tag{81}$$

Central bank's sterilized intervention ($b_t^{cb}$)

$$\phi_{b^{cb}} b_t^{cb} + \phi_{b^{cb,*}} b_t^{cb,*} = 0; \tag{82}$$

### Foreign economy

Foreign output ($y_t^*$):

$$y_t^* = \rho_{y^*} y_{t-1}^* + \varepsilon_t^{y^*} \tag{83}$$

Foreign inflation ($\pi_t^*$):

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \varepsilon_t^{\pi^*} \tag{84}$$

Foreign interest rates ($i_t^*$):

$$i_t^* = \rho_{i^*} i_{t-1}^* + \varepsilon_t^{i^*} \tag{85}$$

Portfolio shocks $\left(b_t^{*,c}\right)$

$$b_t^{c,*} = \rho_{b^{cb,*}} b_{t-1}^{c,*} + \varepsilon_t^{b^{c,*}} \tag{86}$$

### Domestic shocks

Productivity shocks ($a_t$):

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \tag{87}$$

Demand shocks ($g_t$):

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g \tag{88}$$

Mark-up shocks ($\mu_t$):

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_t^\mu \tag{89}$$