**BANCO CENTRAL DE RESERVA DEL PERÚ**

# Foreign exchange intervention and monetary policy design: a market microstructure analysis

Carlos Montoro[1] y Marco Ortiz[2]

[1] Banco Central de Reserva del Perú y Consejo Fiscal
[2] Banco Central de Reserva del Perú

DT. N° 2016-008
Serie de Documentos de Trabajo
Working Paper series
Setiembre 2016

# Foreign exchange intervention and monetary policy design: a market microstructure analysis

Carlos Montoro

Banco Central de Reserva y Consejo Fiscal (BCRP & CF)

Marco Ortiz

Banco Central de Reserva del Peru (BCRP)

August 2016

**Abstract**

In this paper we extend a new Keynesian open economy model to include risk-averse FX dealers and FX intervention by the monetary authority. These 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 preannounced 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; and (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.

*Key words:* Foreign exchange Microestructure, Exchange rate dynamics, Exchange Rate Intervention, Monetary policy, Information Heterogeneity.

*JEL Classification:* E4, E5, F3, G15.

# 1 Introduction

Interventions by central banks in foreign exchange (FX) markets have been common in many countries, and they have become even more frequent in the most recent past, 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. For instance, in Figure 1 we can see that during 2009-12 the amount of FX interventions as a percentage of FX reserves minus gold was between 30% and 100% in some Latin American countries, and considerably more than 100% in Switzerland. Also, 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.

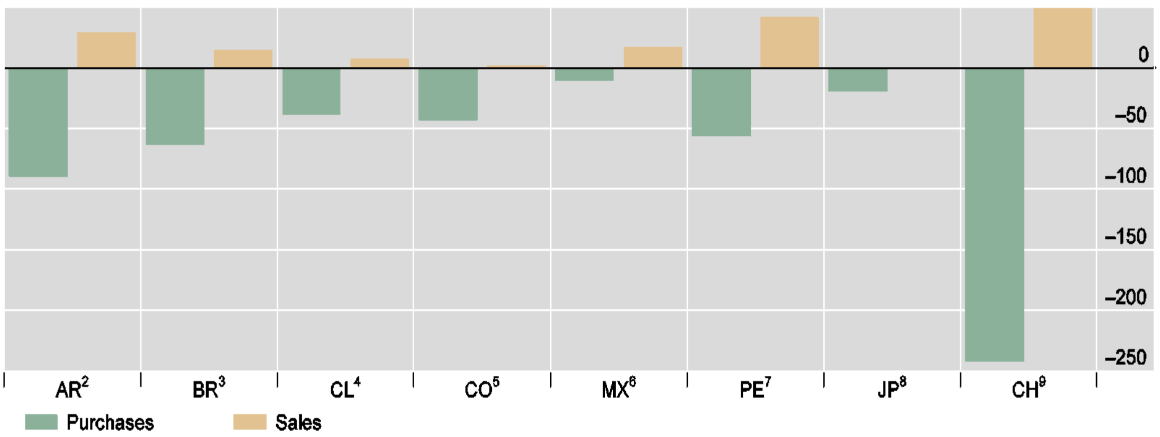
There is substantial empirical evidence that traditional approaches of exchange rate determination (e.g., asset markets) fail to explain exchange rate movements in the short-run, see Meese and Rogoff (1983) and Frankel and Rose (1995) Cogley and Sargent (2005) . This empirical evidence shows that most 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*, 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.

Regarding the effectiveness of FX intervention, the empirical evidence remains inconclusive.

[1] Mihaljek (2005) reports that the typical share of intervention in turnover in EMEs fell from 12% in 2002 to 8% in 2004 as a percentage of the average monthly holdings of FX reserves. 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.

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.

(As a percentage of average foreign exchange reserve minus gold)




AR = Argentina; BR = Brazil; CH = Switzerland; CL = Chile; CO = Colombia; JP = Japan; MX = Mexico; PE = Peru.

[1] The bars correspond to the sum of amounts allocated/transacted in the period. Positive (negative) values indicate a sale (purchase) of US dollars by the central bank, unless otherwise indicated. [2] Spot sales. [3] Swap market auctions; spot market auctions; repo market auctions; trade finance loans and forward market auctions. [4] Reserve accumulation programme and swap auctions. [5] Options for reserve accumulation; options for exchange rate volatility control and direct purchase auctions. [6] USD sales mechanism; auctions with minimum price; auctions without a minimum price; Fed swaps; direct sales and option auctions. [7] Auctions; CDR certificates and CDLD certificates. [8] Interventions by the Japanese Ministry of Finance. [9] Inferred by changes in the foreign currency investments of the Swiss National Bank by currency; adjusted for exchange rate changes.

Sources: National data; BIS calculations.

Figure 1: Intervention in the foreign exchange market: 2009 - 2012[1]

Benes et al. (2015) 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.[2] 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.

[2] 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.

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.

Unlike previous research, we follow a market microstructure approach 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 rate determination through two channels: the portfolio balance effect and a volatility effect. In the former, a sterilised intervention alters the value of the currency because it modifies the ratio between domestic and foreign assets held by the private sector; and according to the latter, central bank interventions have an impact on the volatility of exchange rates and consequently on the extent to which *liquidity* based trades affect the equilibrium exchange rate. 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.[3]

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. (2015). 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 show that intervention rules can have stronger stabilisation power in response to shocks as they exploit the volatility channel.

In the next section we introduce the model, with a special focus on the FX market. In Section 3 we show results from the simulation of the model. In Section 4 we present some robustness exercises. The last section concludes.

[3]The third element mentioned by the author is *information*. We present a model where information across dealers is heterogeneous in a companion paper.

## 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]

In this setup, dealers in the small domestic economy operate the secondary bond market. They receive customer orders for the sale of domestic bonds from households and for the sale of foreign bonds from foreign investors and the central bank. 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]

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 capital flows.[6]

[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 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] 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.

## 2.1 Dealers

In the domestic economy there is a continuum of dealers $\iota$ in the interval $[0,1]$. Each dealer $\iota$ receives $\varpi_t^{\iota}$ and $\varpi_t^{\iota,cb}$ in domestic bond sale and purchase orders from households and the central bank, and $\varpi_t^{\iota*}$ and $\varpi_t^{\iota*,cb}$ in foreign bond sale orders from foreign investors and the central bank, respectively. These orders are exchanged among dealers, that is $\varpi_t^{\iota}+\varpi_t^{\iota,cb}+S_t\left(\varpi_t^{\iota*}+\varpi_t^{\iota*,cb}\right)=B_t^{\iota}+S_tB_t^{\iota*}$, where $B_t^{\iota}$ and $B_t^{\iota*}$ are the ex-post holdings of domestic and foreign bonds by dealer $\iota$, respectively.[7] 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.[8]

Dealers are risk-averse and short-sighted. They select an optimal portfolio allocation in order to maximise the expected utility of their end-of-period returns, where their utility is given by a CARA utility function. The one-period dealer's horizon gives tractability and captures the feature that FX dealers tend to unwind their FX exposure at the end of any trading period, as explained by Vitale (2011). The problem of dealer $\iota$ is:

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

subject to:

$$\varpi_t^{\iota}+\varpi_t^{\iota,cb}+S_t\left(\varpi_t^{\iota*}+\varpi_t^{\iota*,cb}\right)=B_t^{\iota}+S_tB_t^{\iota*} \tag{1}$$

where $E_t$ is the rational expectations operator, $\gamma$ is the coefficient of absolute risk aversion and $\Omega_{t+1}^{\iota}$ is the total investment after returns, given by:

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

where we have made use of the resource constraint of dealers, we have log-linearised the excess of return on investing in foreign bonds and $s_t=\ln S_t$. Since the only non-predetermined variable is $s_{t+1}$, assuming it is normal distributed with time-invariant variance, the first order condition for the dealers is:[9]

$$0=-\gamma\,(i_t^*-i_t+E_ts_{t+1}-s_t)+\gamma^2B_t^{\iota*}\sigma^2$$

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

$$B_t^{\iota*}=\frac{i_t^*-i_t+E_ts_{t+1}-s_t}{\gamma\sigma^2} \tag{2}$$

[7] 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.

[8] Under the present formulation FX transactions carried out for commercial purposes will only affect the exchange rate through their impact in the domestic interest rate though not through variations in the order flow faced by dealers.

[9] Conditions verified to be satisfied ex-post.

According to this expression, the demand for foreign bonds will be larger the higher its return, the lower the risk aversion or the lower the volatility of the exchange rate.

### 2.1.1 FX market equilibrium

Foreign bonds equilibrium in the domestic market should sum FX market orders from foreign investors (capital inflows) and central bank FX intervention, that is:[10]

$$\int_0^1 B_t^{\iota *} d\iota = \int_0^1 \left( \varpi_t^{\iota *} + \varpi_t^{\iota *, cb} \right) d\iota = \varpi_t^* + \varpi_t^{*,cb}.$$

Dealers are passive and unable to rebalance their trading with foreigners. This assumption is in line with Lyons (2006), who explains how the risk that drives the portfolio balance effect is undiversifiable across dealers.[11] Replacing the FX market equilibrium condition in the aggregate demand for foreign bonds yields the following arbitrage condition:

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

Condition (3) determines the exchange rate, and differs from the traditional uncovered interest parity condition because of an endogenous risk premium component. According to it, an increase (decrease) in capital inflows or sales (purchases) of foreign bonds by the central bank appreciates (depreciates) the exchange rate $s_t$, *ceteris paribus*. This effect is larger, the more risk-averse dealers are (larger $\gamma$) or the more volatile the expected depreciation rate is (larger $\sigma^2$).[12]

Equation (3) is useful to understand both mechanisms through which FX intervention can affect the exchange rate. The last term on the right hand side captures the portfolio-balance channel. Given that dealers are risk-averse and hold domestic and foreign assets to diversify risk, FX intervention changes the composition of domestic and foreign asset held by the dealers. This will be possible only if there is a change in the expected relative rate of returns of these assets, which compensates for the change in the risk they bear. In other words, according to the portfolio-balance channel, a sale (purchase) of foreign bonds by the central bank augments (reduces) the ratio between foreign and domestic assets hold by dealers, inducing an appreciation (depreciation) of the domestic currency because dealers require a greater (smaller) risk premium to hold a larger (smaller)

[10] Similar to other foreign variables in the model, holdings of foreign bonds in the domestic market are exogenous (i.e., it is not affected by domestic conditions). This is consistent with the small open economy assumption, meaning that domestic conditions do not affect foreign variables. The second part of this equation is an accounting relationship.

[11] These shocks imply that the market as a whole must hold a position that they would not otherwise hold, which entails an enduring risk premium. See Lyons (2006), Ch. 2.

[12] Sterilised intervention implies that a sale (purchase) of foreign bonds by the central bank is accompanied by purchases (sales) of domestic bonds by the monetary authority, such that the domestic interest rates are in line with the policy target rate. In our model, the central bank directly exchange domestic bonds in their balance for foreign ones. In this sense, interventions will have no impact on the interest rate as households' aggregate savings remain invariant.

The second mechanism at work is the volatility channel. When central banks intervene in the FX markets they can affect the conditional volatility of exchange rates, reducing the impact that shifts in portfolio have over the equilibrium exchange rate.

## 2.2 Monetary authority

The central bank in the domestic economy intervenes in the FX market by selling/buying foreign bonds to/from dealers in exchange for domestic bonds. Each period the central bank negotiates directly with dealers, such that every dealer receives the same amount of sales/purchases of foreign bonds from the central bank. Each period any dealer $\iota$ receives a market order $\varpi_t^{\iota *,cb}$ from the central bank, where $\varpi_t^{\iota *,cb} > 0 \left(\varpi_t^{\iota *,cb} < 0\right)$ when the central bank sells (purchases) foreign bonds in exchange of domestic bonds. The total customer flow of foreign bonds received by dealer $\iota$ equals $\varpi_t^{\iota *} + \varpi_t^{\iota *,cb}$. We assume the central bank can always perform fully sterilised FX interventions, therefore it maintains control over the interest rate regardless of the intervention. Moreover, we further assume the central bank does not have to distribute profits/losses to the households. That is, the monetary authority is not constrained by its balance sheet to perform interventions in the FX market.[13][14]

### 2.2.1 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.[15]

The central bank can have three different FX intervention strategies. First, it can perform pure discretional intervention:

$$\varpi_t^{*cb} = \varepsilon_t^{cb,0} \tag{4}$$

where the central bank intervenes via unanticipated or secret interventions. According to strategy (4), FX intervention by the central bank is not anticipated.[16]

[13]Sterilised intervention implies that a sale (purchase) of foreign currency by the central bank is accompanied by purchases (sales) of domestic bonds by the monetary authority such that the domestic interest rates are in line with the policy target rate. We implicitly assume an asymmetry between the FX market and the domestic currency bond markets. In the latter, capital sales (purchases) by the central bank have no impact on the price of the bond. In this way the bank intermediates between markets with a heterogeneous microstructure.

[14]The balance sheet of the central bank is the following: $S_t R_t^{cb} = B_t^{cb} + NW_t^{cb}$, where $R_t^{cb}$, $B_t^{cb}$ and $NW_t^{cb}$ are the central bank's reserves in foreign bonds, liabilities in domestic bonds and net worth, respectively. The first two components evolve according to: $R_t^{cb} = (1 + i_t^*) R_{t-1}^{cb} - \varpi_t^{*,cb}$ and $B_t^{cb} = (1 + i_t) B_{t-1}^{cb} - \varpi_t^{cb}$. Also, profits are given by: $P_t \Gamma_t^{cb} = \left[\frac{S_t(1+i_t^*)}{S_{t-1}} - 1\right] S_{t-1} R_{t-1}^{cb} - i_t B_{t-1}^{cb} - \left(S_t \omega_t^{*,cb} - \omega_t^{cb}\right)$

[15]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.

[16]We contrast (comparable) discretional interventions with rule based interventions in order to gauge the impact of rules on expectations. 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.

As a second case, the central bank can perform rule based intervention taking into account the changes in the exchange rate. We call this strategy "the $\Delta s$ rule".

$$\varpi_t^{*cb} = \phi_{\Delta s} \Delta s_t + \varepsilon_t^{cb,1} \tag{5}$$

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.

Finally, 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".

$$\varpi_t^{*cb} = \phi_{rer} rer_t + \varepsilon_t^{cb,2} \tag{6}$$

where $rer_t$ captures deviations of the real exchange rate with respect to its steady state. In the same vein as the previous case, under this rule the central bank sells (purchases) foreign bonds when the exchange rates depreciates (appreciates) in real terms from its long-run value. The $\Delta s$ rule is expressed in nominal terms and takes into account only the change in the exchange rate, whilst the $RER$ rule takes into account the deviations in the level of the exchange rate in real terms. The difference between both rules is similar to that between inflation targeting and price level targeting for the case of shocks to the price level. Intuitively, under the $\Delta s$ rule shocks to the exchange rate are accommodated, while under the $RER$ rule, they are reversed.

We explicitly leave out a rule according to which intervention responds to *liquidity* trading, even though we acknowledge this type of rule will be the most effective against these shocks. The reason is twofold: (1) in practice it is difficult for central banks to determine which type of capital flows are affecting the exchange rate - fundamental or *liquidity* trading - and (2) the rules under study are in line with the goals some central banks claim to address through their FX intervention policies.[17]

#### 2.2.2 Monetary policy

The central bank implements monetary policy by setting the nominal interest rate according to a Taylor-type feedback rule that depends on CPI inflation. The generic form of the interest rate rule that the central bank uses is given by:

$$\frac{(1+i_t)}{(1+\bar{i})} = \left(\frac{\Pi_t}{\overline{\Pi}}\right)^{\varphi_\pi} \exp\left(\varepsilon_t^{MON}\right) \tag{7}$$

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 $N \sim \left(0, \sigma_i^2\right)$.

[17] We address this and other problems related to informational asymmetry in a companion paper.

## 2.3 Households

### 2.3.1 Preferences

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. 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:

$$\mathcal{U}_t = E_t \left[ \sum_{s=0}^{\infty} \beta^{t+s} U \left( C_{t+s}^j, L_{t+s}^j, \right) \right], \tag{8}$$

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:

$$U\left(C_t, L_t\right) = \frac{C_t^{1-\gamma_c}}{1-\gamma_c} - \frac{L_t^{1+\chi}}{1+\chi}, \quad \text{if } \gamma_c \neq 1. \tag{9}$$

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

$$U\left(C_t, L_t\right) = \ln C_t - \frac{L_t^{1+\chi}}{1+\chi} \tag{10}$$

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

$$C_t \equiv \left[ \left(\gamma^H\right)^{1/\varepsilon_H} \left(C_t^H\right)^{\frac{\varepsilon_H - 1}{\varepsilon_H}} + \left(1-\gamma^H\right)^{1/\varepsilon_H} \left(C_t^M\right)^{\frac{\varepsilon_H - 1}{\varepsilon_H}} \right]^{\frac{\varepsilon_H}{\varepsilon_H - 1}}, \tag{11}$$

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:

$$C_t^H \equiv \left[ \left(\frac{1}{n}\right)^{\frac{1}{\varepsilon}} \int_0^n C_t^H(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}}, C_t^M \equiv \left[ \left(\frac{1}{1-n}\right)^{\frac{1}{\varepsilon}} \int_n^1 C_t^M(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{12}$$

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:

$$C_t^H(z) = \frac{1}{n} \gamma^H \left(\frac{P_t^H(z)}{P_t^H}\right)^{-\varepsilon} \left(\frac{P_t^H}{P_t}\right)^{-\varepsilon_H} C_t, \tag{13}$$

$$C_t^M(z) = \frac{1}{1-n} \left(1-\gamma^H\right) \left(\frac{P_t^M(z)}{P_t^M}\right)^{-\varepsilon} \left(\frac{P_t^M}{P_t}\right)^{-\varepsilon_H} C_t \tag{14}$$

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:

$$P_t \equiv \left[ \gamma^H \left( P_t^H \right)^{1-\varepsilon_H} + \left( 1 - \gamma^H \right) \left( P_t^M \right)^{1-\varepsilon_H} \right]^{\frac{1}{1-\varepsilon_H}} \tag{15}$$

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:

$$P_t^H \equiv \left[ \frac{1}{n} \int_0^n P_t^H(z)^{1-\varepsilon} dz \right]^{\frac{1}{1-\varepsilon}}, \; P_t^M \equiv \left[ \frac{1}{1-n} \int_n^1 P_t^M(z)^{1-\varepsilon} dz \right]^{\frac{1}{1-\varepsilon}} \tag{16}$$

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.

### 2.3.2 Households' budget constraint

For simplicity, we assume domestic households save only in bonds.[18] The budget constraint of the domestic household $(j)$ in units of home currency is given by:

$$\varpi_t^j = (1 + i_{t-1}) \varpi_{t-1}^j - \frac{\psi}{2} \left( \varpi_t^j - \overline{\varpi} \right)^2 + W_t L_t^j - P_t C_t^j + P_t \Gamma_t^j \tag{17}$$

where $\varpi_t^j$ is wealth in domestic assets, $W_t$ is the nominal wage, $i_t$ is the domestic nominal interest rate, and $\Gamma_t^j$ are nominal profits distributed from firms and dealers in the home economy to the household $j$. 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.[19] Households maximise (8) subject to (17).

### 2.3.3 Consumption decisions and the supply of labour

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

$$U_{C,t} = \beta E_t \left\{ U_{C,t+1} \left[ \frac{1 + i_t}{1 + \psi \left( \varpi_t^j - \overline{\varpi} \right)} \right] \frac{P_t}{P_{t+1}} \right\} \tag{18}$$

where we have eliminated the index $j$ for the assumption of representative agent. $U_{C,t}$ denotes the marginal utility for consumption. Equation (18) corresponds to the Euler equation that determines the optimal path of consumption for households in the home economy, by equalising

[18] This way the only portfolio decision is made by dealers, which simplifies the analysis.

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

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:

$$-\frac{U_{L,t}}{U_{C,t}} = \frac{W_t}{P_t} \tag{19}$$

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 (19).

## 2.4 Foreign economy

The consumption basket of the foreign economy is similar to that of the domestic economy, and is given by:

$$C_t^* \equiv \left[ \left(\gamma^F\right)^{1/\varepsilon_F} \left(C_t^X\right)^{\frac{\varepsilon_F - 1}{\varepsilon_F}} + \left(1-\gamma^F\right)^{1/\varepsilon_F} \left(C_t^F\right)^{\frac{\varepsilon_F - 1}{\varepsilon_F}} \right]^{\frac{\varepsilon_F}{\varepsilon_F - 1}} \tag{20}$$

where $\varepsilon_F$ is the elasticity of substitution between domestic $(C_t^X)$ and foreign goods $(C_t^F)$, respectively, and $\gamma^F$ is the share of domestically produced goods in the consumption basket of the foreign economy. Also, $C_t^X$ and $C_t^F$ are indices of consumption across the continuum of differentiated goods produced similar to $C_t^H$ and $C_t^M$ defined in equations (12). The demands for each type of good is given by:

$$C_t^X(z) = \frac{1}{n}\gamma^F \left(\frac{P_t^X(z)}{P_t^X}\right)^{-\varepsilon} \left(\frac{P_t^X}{P_t^*}\right)^{-\varepsilon_H} C_t^* \tag{21}$$

$$C_t^F(z) = \frac{1}{1-n}\left(1-\gamma^F\right) \left(\frac{P_t^F(z)}{P_t^F}\right)^{-\varepsilon} \left(\frac{P_t^F}{P_t^*}\right)^{-\varepsilon_H} C_t^* \tag{22}$$

where $P_t^X$ and $P_t^F$ correspond to the price indices of exports and the goods produced abroad, respectively. $P_t^*$ is the consumer price index of the foreign economy:

$$P_t^* \equiv \left[\gamma^F \left(P_t^X\right)^{1-\varepsilon_F} + \left(1-\gamma^F\right)\left(P_t^F\right)^{1-\varepsilon_F}\right]^{\frac{1}{1-\varepsilon_F}} \tag{23}$$

### 2.4.1 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:

$$Y_t^H = \gamma \left( \frac{P_t^H}{P_t} \right)^{-\varepsilon_H} C_t \tag{24}$$

$$M_t = (1-\gamma) \left( \frac{P_t^M}{P_t} \right)^{-\varepsilon_H} C_t \tag{25}$$

$$X_t = (1-\gamma^*) \left( \frac{P_t^X}{P_t^*} \right)^{-\varepsilon_F} C_t^* \tag{26}$$

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

$$P_t \equiv \left[ \gamma \left( P_t^H \right)^{1-\varepsilon_H} + (1-\gamma) \left( P_t^M \right)^{1-\varepsilon_H} \right]^{\frac{1}{1-\varepsilon_H}} \tag{27}$$

$$P_t^* = P_t^F \tag{28}$$

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:

$$Y_t^{int}(z) = A_t L_t(z) \tag{29}$$

$L_t(z)$ 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:

$$MC_t(z) = \frac{W_t/P_t}{A_t} \tag{30}$$

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:

$$E_t\left\{\sum_{k=0}^{\infty}\left(\theta^H\right)^k\Lambda_{t+k}\left[\frac{P_t^{H,o}(z)}{P_{t+k}^H}-MC_{t+k}^H\right]Y_{t,t+k}^H(z)\right\} \tag{31}$$

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 (31). The first order condition of this problem is:

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

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

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

$$V_t^D=U_{C,t}Y_t^H+\theta^H\beta E_t\left[V_{t+1}^D\left(\Pi_{t+1}^H\right)^{\varepsilon-1}\right] \tag{33}$$

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:

$$\theta^H\left(\Pi_t^H\right)^{\varepsilon-1}=1-\left(1-\theta^H\right)\left(\frac{V_t^N}{V_t^D}\right)^{1-\varepsilon} \tag{34}$$

The equations (32), (33) and (34) 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:

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

$$V_t^{D,X} = \left(Y_t^X U_{C,t}\right) + \theta^X \beta E_t\left[V_{t+1}^{D,X}\left(\Pi_{t+1}^X\right)^{\varepsilon-1}\right] \tag{36}$$

$$\theta^X\left(\Pi_t^X\right)^{\varepsilon-1} = 1-\left(1-\theta^X\right)\left(\frac{V_t^{N,X}}{V_t^{D,X}}\right)^{1-\varepsilon} \tag{37}$$

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

$$\begin{aligned} MC_t^X &= \frac{P_t MC_t}{S_t P_t^X} \\ &= \frac{MC_t}{RER_t\left(\frac{P_t^X}{P_t^*}\right)} \end{aligned} \tag{38}$$

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:

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

$$V_t^{D,M} = \left(Y_t^M U_{C,t}\right) + \theta^M \beta E_t\left[V_{t+1}^{D,M}\left(\Pi_{t+1}^M\right)^{\varepsilon-1}\right] \tag{40}$$

$$\theta^M\left(\Pi_t^M\right)^{\varepsilon-1} = 1-\left(1-\theta^M\right)\left(\frac{V_t^{N,M}}{V_t^{D,M}}\right)^{1-\varepsilon} \tag{41}$$

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 ($P_t^M$):

$$MC_t^M = \frac{S_t P_t^*}{P_t^M} \tag{42}$$

where $MC_t^M$ also measures the deviations from the law of one price.[20]

## 2.6 Market clearing

Total domestic production is given by:

$$P_t^{def} Y_t = P_t^H Y_t^H + S_t P_t^X Y_t^X \tag{43}$$

After using equations (24) and (25) and the definition of the consumer price index (27), equation (43) can be decomposed in:

$$P_t^{def} Y_t = P_t C_t + S_t P_t^X Y_t^X - P_t^M Y_t^M \tag{44}$$

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:

$$P_t^{def} = \phi_C P_t + \phi_X S_t P_t^X - \phi_M P_t^M \tag{45}$$

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 production for home consumption and exports:

$$\begin{aligned} Y_t^{int}(z) &= Y_t^H(z) + Y_t^X(z) \\ &= \left(\frac{P_t^H(z)}{P_t^H}\right)^{-\varepsilon} Y_t^H + \left(\frac{P_t^X(z)}{P_t^X}\right)^{-\varepsilon} Y_t^X \end{aligned} \tag{46}$$

Aggregating (46) with respect to $z$, we obtain:

$$Y_t^{int} = \frac{1}{n}\int_0^n Y_t^{int}(z)\, dz = \Delta_t^H Y_t^H + \Delta_t^X Y_t^X \tag{47}$$

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:

$$L_t = \frac{MC_t}{W_t/P_t}\left(\Delta_t^H Y_t^H + \Delta_t^X Y_t^X\right) \tag{48}$$

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:

$$\begin{aligned} \frac{B_t}{P_t} - \frac{B_{t-1}}{P_{t-1}} + \frac{\psi}{2}\left(\frac{B_t}{P_t} - \frac{\overline{B}}{P}\right)^2 &= \frac{P_t^{def}}{P_t} Y_t - C_t \\ &+ \left\{\frac{(1+i_{t-1})}{\Pi_t} - 1\right\}\frac{B_{t-1}}{P_{t-1}} + REST_t \end{aligned} \tag{49}$$

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

Equation (49) 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. 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, $REST_t \equiv \frac{P_t^M}{P_t} Y_t^M \left(1 - \Delta_t^M MC_t^M\right)$ is negligible and takes into account the monopolistic profits of retail firms.[21]

# 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.[22] 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.[23] The share of 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.[24] 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.

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 |

[21] A complete set of the log-linearised equations of the model can be found in Appendix 1.B.
[22] See Chetty et al. (2011).
[23] See Rabanal and Tuesta (2006). Other authors in the trade literature find values for this elasticity around 5, see Lai and Trefler (2002).
[24] See Castillo et al. (2009).

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. In the benchmark case, we calibrate the FX intervention reaction to exchange rate changes and real exchange rate misalignments to 0.5 for the $\Delta s$ rule and 0.3 for the $RER$ rule, and analyse how results change with those parameters.

### 3.2 Model dynamics

In this section we present our results. We first discuss briefly the existence of equilibrium.[25] 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 the interest rate *vis-à-vis* liquidity based trading. We present robustness exercises to the parameters defining the pass-through of exchange rates to prices $(\varepsilon, \varepsilon_F)$ and domestic price rigidity ($\theta_H$ in Section 4.

#### 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 2, we plot the mappings of the conjectured and the implied conditional variance of the depreciation rate for different parameterisations 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, there are two RE equilibria in the case of no FX intervention, corresponding to a low-variance stable equilibrium and a high-variance unstable equilibrium.[26] This type of multiple equilibria is similar to the one found by Bacchetta and Wincoop (2006) in a model without FX intervention. However, as shown in the centre and

[25] 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.

[26] 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.

right-hand panels, FX intervention helps to rule out the second unstable equilibrium. 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.[27]

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 its effectiveness as the reduction in variance dampens the impact of interventions on the exchange rate.

#### 3.2.2 Transmission of external shocks

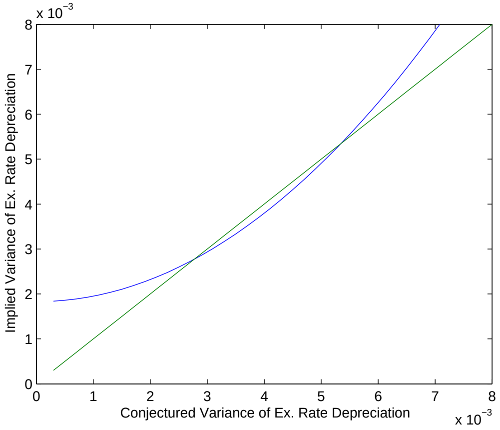
In Table 2 we present unconditional relative variances of some main macroeconomic variables assuming only one source of volatility at the time for different FX intervention regimes.[28] For comparison, relative variances are normalised with respect to the no intervention case.

As shown, not surprisingly, FX intervention reduces the volatility of the change of the exchange rate in all cases. However, this exercise highlights some trade-offs in the use of FX intervention. In particular, the effects of FX intervention on the volatility of other macroeconomic variables will depend on the source of the shock. FX intervention helps to isolate domestic macroeconomic variables from financial external shocks, but amplifies fluctuations in some domestic variables from nominal and real external shocks.

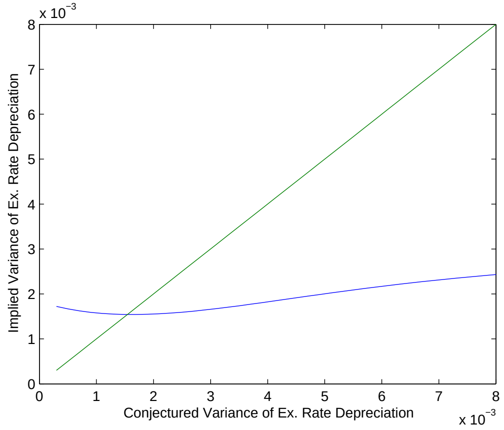
For instance, the volatility of consumption, exports, output and inflation generated by foreign interest rate and capital flow shocks is reduced under both types of FX intervention regimes. However, the use of FX interventions to smooth the nominal exchange rate amplifies the volatility of inflation and output generated by foreign inflation shocks. Similarly, the use of a real exchange rate misalignment rule increases the volatility of consumption, exports, output and inflation generated by foreign output shocks. In this case, FX intervention prevents the adjustment of the real exchange rate as a macroeconomic stabiliser.

[27]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.

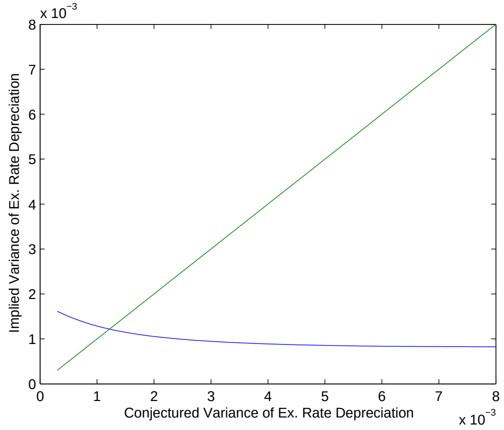
[28]Exercises are simulated using the conditional variance of the depreciation rate in equilibrium in equation 3.



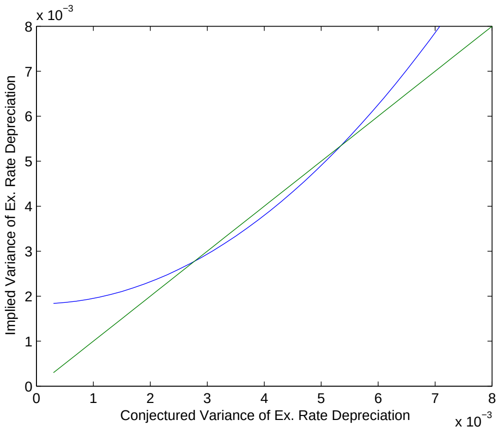

(a) $\Delta s$ rule ($\varphi_{\Delta s} = 0$)



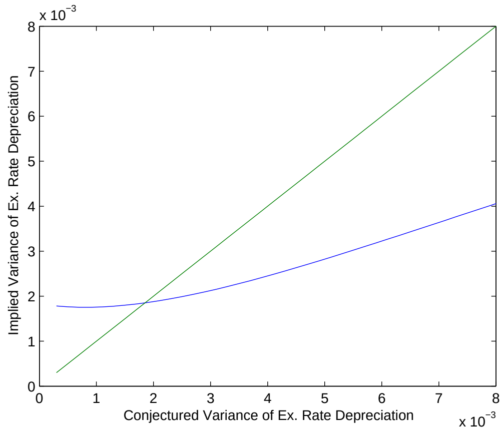

(b) $\Delta s$ rule ($\varphi_{\Delta s} = 0.25$)



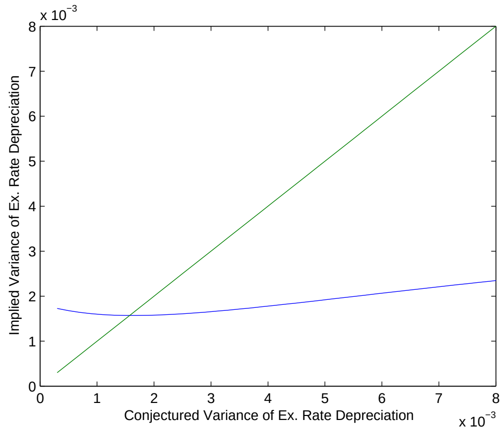

(c) $\Delta s$ rule ($\varphi_{\Delta s} = 0.50$)




(d) $RER$ rule ($\varphi_{rer} = 0$)




(e) $RER$ rule ($\varphi_{rer} = 0.25$)




(f) $RER$ rule ($\varphi_{rer} = 0.50$)

Figure 2: Existence of equilibria under FX intervention rules

Simulations involved 61 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.

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* ($\varepsilon_{i^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.31 | 0.69 | 0.48 | 0.92 | 0.44 | 0.12 | 0.41 |
| $\varphi_{\Delta s} = 0.50$ | 0.10 | 0.56 | 0.26 | 0.89 | 0.21 | 0.03 | 0.17 |
| $\varphi_{rer} = 0.25$ | 0.76 | 0.90 | 0.84 | 0.97 | 0.86 | 0.66 | 0.84 |
| $\varphi_{rer} = 0.50$ | 0.64 | 0.85 | 0.75 | 0.96 | 0.78 | 0.49 | 0.74 |
| | | | *Capital flows shock* ($\varepsilon^{\omega^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.25 | 0.23 | 0.31 | 0.28 | 0.34 | 0.32 | 0.31 |
| $\varphi_{\Delta s} = 0.50$ | 0.15 | 0.13 | 0.21 | 0.17 | 0.24 | 0.21 | 0.21 |
| $\varphi_{rer} = 0.25$ | 0.38 | 0.38 | 0.40 | 0.38 | 0.42 | 0.39 | 0.40 |
| $\varphi_{rer} = 0.50$ | 0.24 | 0.23 | 0.25 | 0.24 | 0.27 | 0.25 | 0.26 |
| | | | *Foreign inflation shock* ($\varepsilon^{\pi^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.90 | 0.78 | 0.99 | 0.92 | 1.08 | 1.02 | 1.06 |
| $\varphi_{\Delta s} = 0.50$ | 0.84 | 0.67 | 0.96 | 0.85 | 1.13 | 1.01 | 1.08 |
| $\varphi_{rer} = 0.25$ | 0.76 | 0.74 | 0.77 | 0.75 | 0.81 | 0.78 | 0.80 |
| $\varphi_{rer} = 0.50$ | 0.63 | 0.62 | 0.66 | 0.63 | 0.71 | 0.66 | 0.69 |
| | | | *Foreign output shock* ($\varepsilon^{y^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.28 | 0.93 | 0.89 | 0.99 | 0.72 | 0.92 | 0.63 |
| $\varphi_{\Delta s} = 0.50$ | 1.42 | 0.85 | 0.85 | 0.98 | 0.59 | 0.89 | 0.46 |
| $\varphi_{rer} = 0.25$ | 0.72 | 0.73 | 1.10 | 1.02 | 1.15 | 1.09 | 1.18 |
| $\varphi_{rer} = 0.50$ | 0.59 | 0.62 | 1.15 | 1.02 | 1.24 | 1.14 | 1.30 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

In Figures 3, 4 and 5 we compare the dynamic effects of external shocks under discretion, the $\Delta s_t$ rule and the case with no intervention.[29] Overall, the effectiveness of intervention rules is confirmed. In other words, given that it is known 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. 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.

In Figures 3 we show the reaction to a portfolio or capital flow shock. These inflows generate an appreciation of the exchange rate, that under no intervention affects the whole economy. In the 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 4 we show how interventions can ease the pressure of capital outflows on the exchange rate. It is interesting to see how interventions have similar effects when reacting to capital flow and interest rate shocks. Finally, in Figure 5 we show the reaction to a foreign inflation shock. In this case, as in the previous ones, interventions provide a channel to counter the impact of external shocks on the economy. Foreign inflation will generate an exchange rate appreciation and a current account deficit. An active central bank is capable of reversing these effects through foreign exchange interventions, since the combination of a low nominal depreciation under the exchange rate smoothing rule with higher foreign inflation can generate a depreciation of the real exchange rate.

[29] The case of the $RER$ rule is presented in figures 8, 9 and 10 in Appendix 1.A.

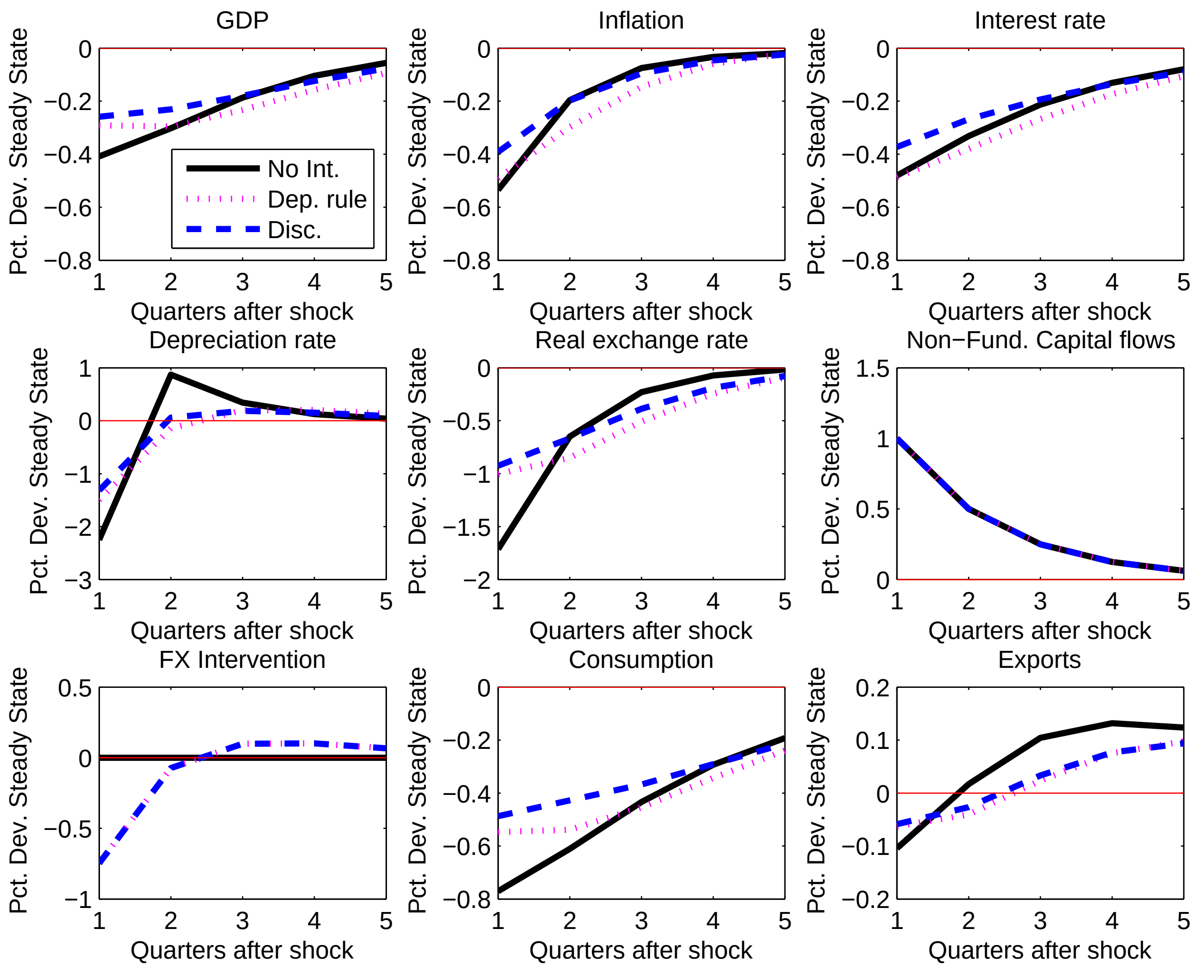



Figure 3: Reaction to a 1% portfolio shock - $\Delta s_t$ rule.

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

### 3.2.3 Contribution of shocks and FX intervention

Up to now we have shown the effectiveness of FX interventions by the central bank as a mechanism to cope with the effects of external shocks. To show this we have kept the variance of the exchange rate constant across regimes, as a way to make results comparable. However, as shown by Figure 2, intervention rules reduce the equilibrium value of the exchange rate volatility. This is key to understanding an additional effect of interventions. The impact of portfolio shocks on the exchange rate value is a function of the risk dealers bear for holding more foreign currency in their portfolio. Hence, a lower volatility will reduce the risk and consequently the premia they charge for these holdings. This makes interventions less effective when dealing with most external shocks, as shown by Table 2, while improving the resilience of the economy to portfolio or capital flow shocks. Specifically, when we assume the only shocks in the economy are given by the portfolio capital flows shocks, the volatility of the real exchange

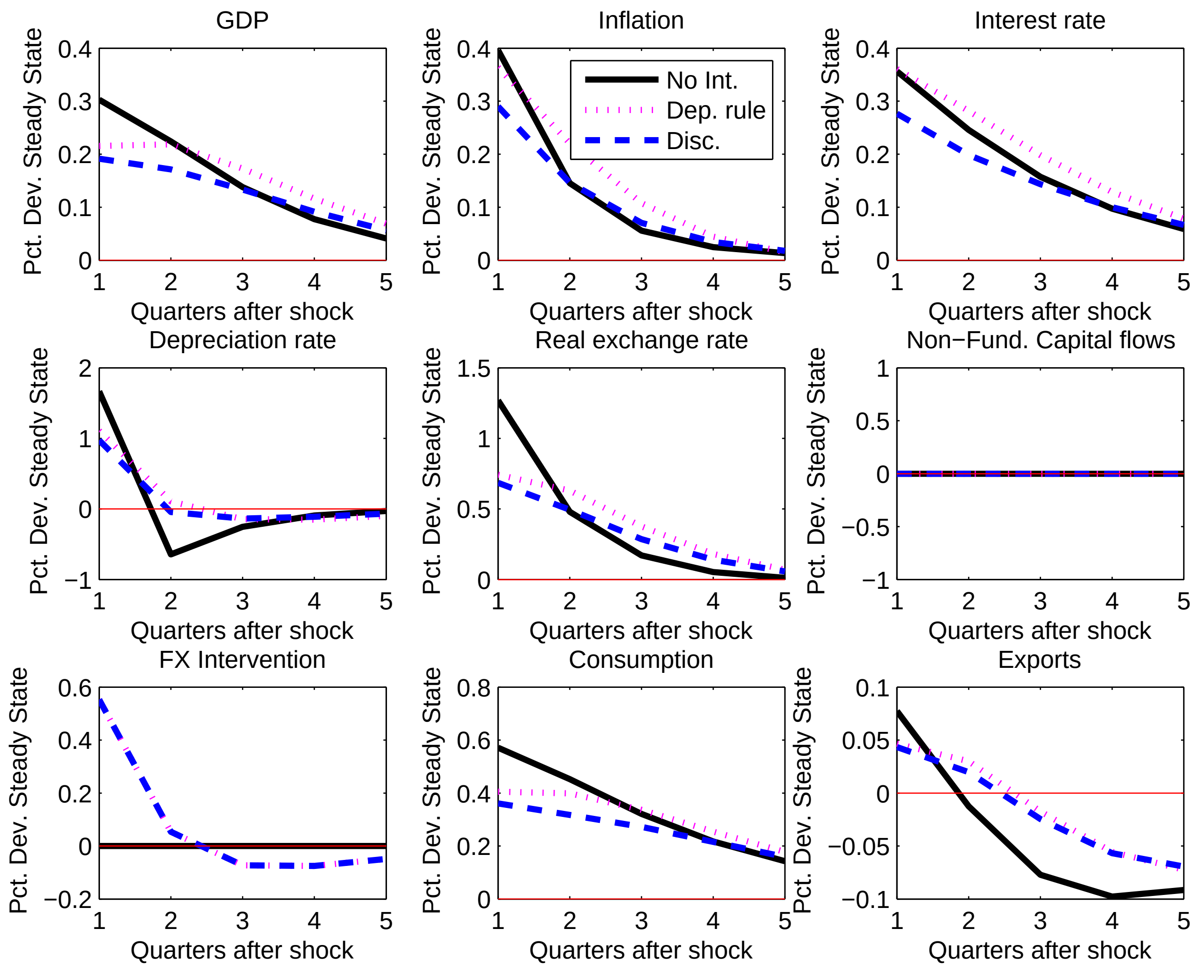



Figure 4: Reaction to a 1% foreign interest rate shock - $\Delta s_t$ rule.

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

rate and the change of the exchange rate fall up to 85 and 87 percent respectively, in comparison to the no intervention case. This implies that through FX interventions, it is possible to reduce significantly the response of the exchange rate to portfolio shocks.[30]

Thus, our simulations show that intervention rules that reduce the volatility of the exchange rate affect as well the relative importance that shocks have in explaining this variance. In Figure 6 we show the variance decomposition of the exchange rate variation under different shocks. Our result is robust to the intensity of intervention, when the central bank intervenes in the FX market through rules, capital flows shocks explain a smaller fraction of the fluctuations of the change of the exchange rate, while the effect of others, such as foreign interest rate shocks, become relatively more important.

[30]Since discretional interventions work in a similar way as these portfolio shocks, the ability of the central bank to affect the exchange rate through discretional sales or purchases, diminishes as well.

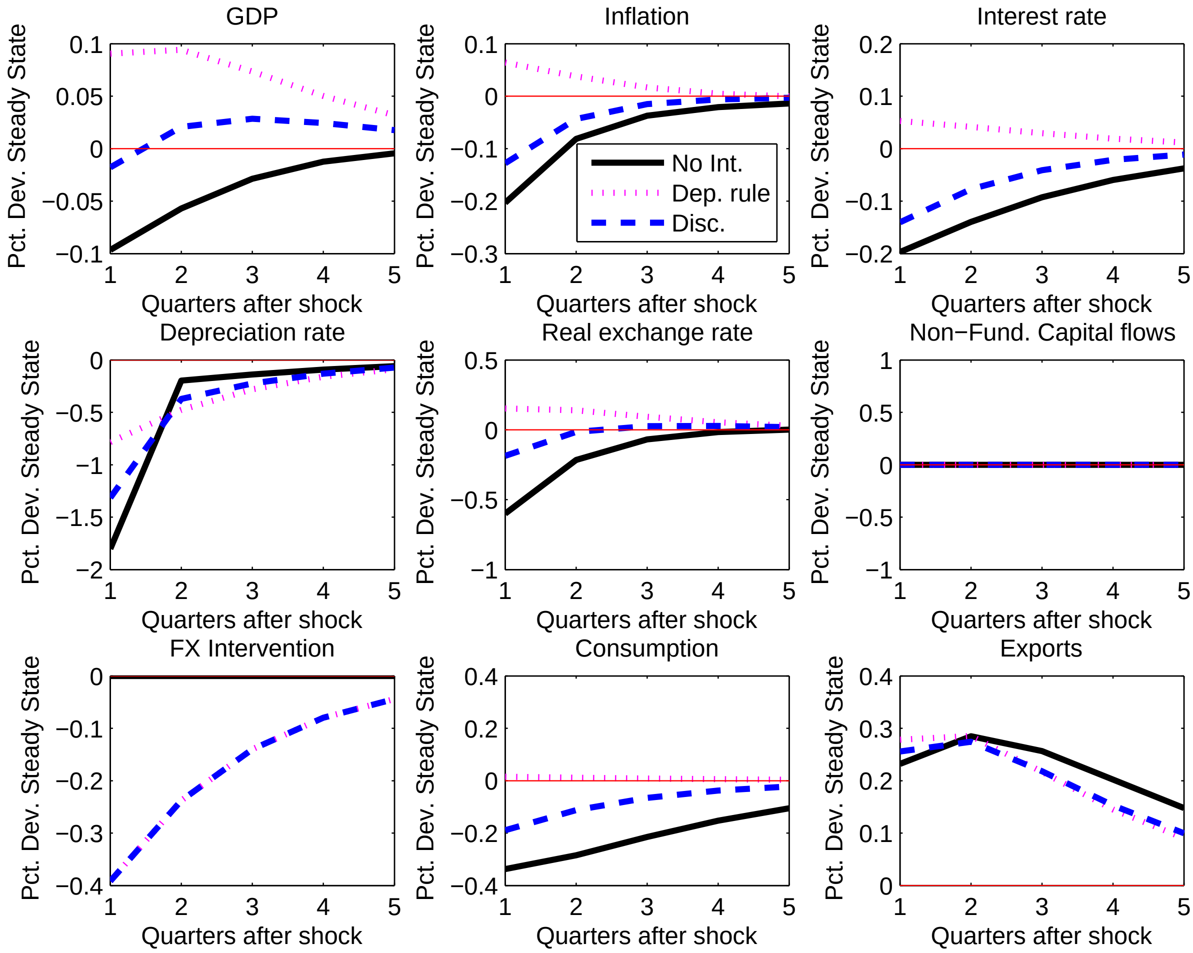
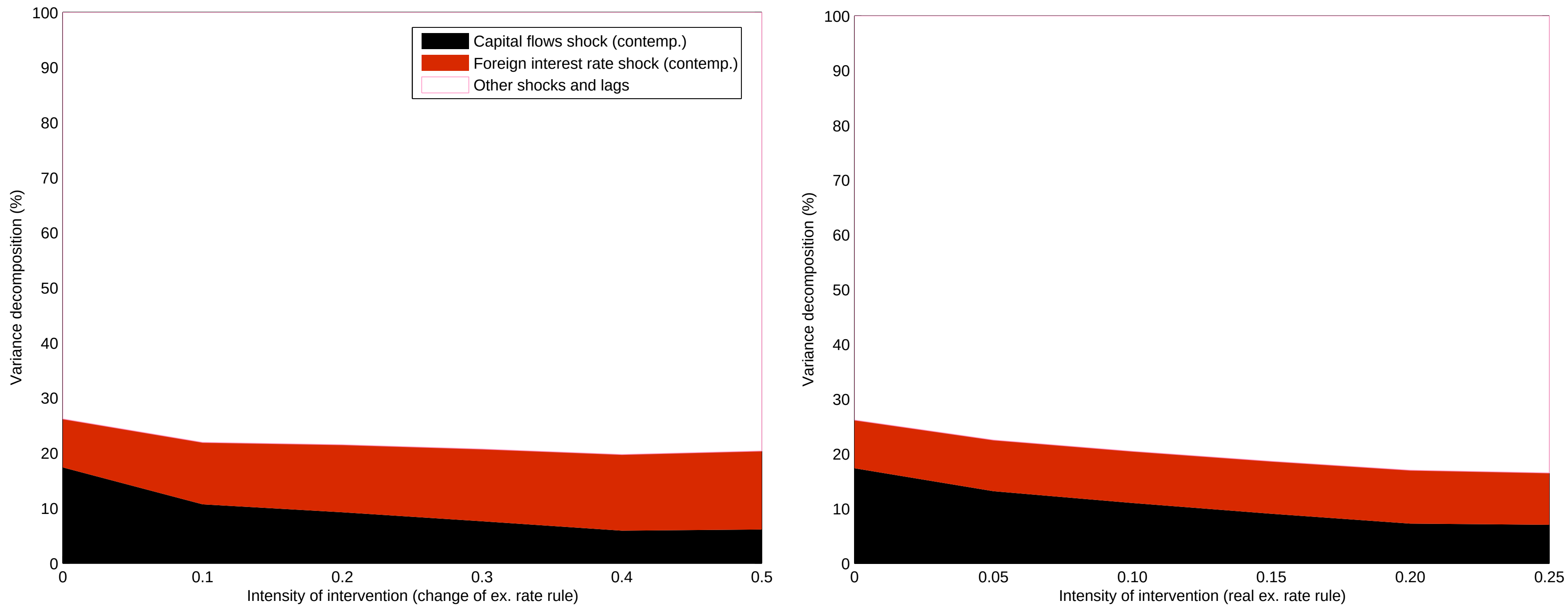



Figure 5: Reaction to a 1% foreign inflation rate shock - $\Delta s_t$ rule.

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




(a) $\Delta s$ rule

(b) $RER$ rule

Figure 6: Variance decomposition of the exchange rate changes ($\Delta s_t$)

Graphs report the average R2 statistic of regressions of the change of the exchange rate over the specified series and a constant. The sample in each simulation is of 2500 observation (first 500 points dropped). Regressions are done on all 9 shocks of the model for their contemporaneous value and 5 lags. Sum of R2 statistics is normalized to 1.)

# 4 Robustness

We perform robustness exercises to several parameters related to the transmission mechanism of FX interventions into prices. Results are presented in Appendix 1.A. Results are robust to the assumed degree of elasticity between home and foreign goods ($\varepsilon$), as Tables 3 and 4 show. Tables 5 and 6 show results for changes in the elasticity of substitution between foreign and exports goods, ($\varepsilon_F$). This parameter has strong effects on the capacity of the central bank to reduce the relative volatility of consumption and production in the face of financial shocks. This result is not surprising since a lower elasticity of substitution means that shocks to the exchange rate will have a smaller impact on the quantities exported, but a higher impact on the country's income. As we observe, interventions are more effective reducing the volatility of consumption but less effective in the case of exports. The opposite occurs in the case of a high $\varepsilon_F$.

Tables 7 and 8 show results for the case of low and high domestic good price rigidity, respectively. We observe that price rigidity increases the effectiveness of FX intervention rules in isolating the economy from foreign interest rate shocks. Under low domestic good price rigidity, intervention rules imply a volatility of consumption between 43% and 96% of the no intervention benchmark. When price rigidity is high ($\theta_H = 0.95$), the relative volatility of consumption with intervention rules is between 12% and 64% of the no intervention benchmark. However, this result does not hold when the economy is hit by capital flows shocks. In this case, a central bank aiming to smooth the exchange rate can actually increase the volatility of variables such as consumption and production. The presence of high price stickiness, combined with a sluggish exchange rate - due to an active FX intervention policy - slows down corrections of the real exchange rate, increasing both consumption and GDP volatility.

# 5 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. Intervening to smooth real exchange rate misalignments can mute the monetary transmission mechanism through exchange rates, reducing the impact on aggregate demand and prices, while intervening to smooth nominal exchange rate fluctuations can amplify the impact. Also, FX intervention rules can be more powerful in stabilising the economy as they exploit the expectations channel. When we analyse the response to foreign shocks, we show that FX intervention rules have some advantages as a stabilisation tool, because they anchor expectations about future exchange rates. Therefore, the amount of FX intervention needed to stabilise the exchange rate under rules is much smaller than under discretion. We also show that there are some trade-offs in the use of FX intervention. 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.

## References

Adolfson, M., S. Laséen, J. Lindé, and M. Villani (2008, August). Evaluating an estimated new Keynesian small open economy model. *Journal of Economic Dynamics and Control 32*(8), 2690–2721.

Amato, J. D., A. Filardo, G. Galati, G. von Peter, and F. Zhu (2005, June). Research on exchange rates and monetary policy: an overview. BIS Working Papers 178, Bank for International Settlements.

Bacchetta, P. and E. V. Wincoop (2006, June). Can information heterogeneity explain the exchange rate determination puzzle? *American Economic Review 96*(3), 552–576.

Benes, J., A. Berg, R. Portillo, and D. Vavra (2015, February). Modeling Sterilized Interventions and Balance Sheet Effects of Monetary Policy in a New-Keynesian Framework. *Open Economies Review 26*(1), 81–108.

Benigno, P. and M. Woodford (2005, December). Inflation stabilization and welfare: The case of a distorted steady state. *Journal of the European Economic Association 3*(6), 1185–1236.

Calvo, G. A. (1983, September). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics 12*(3), 383–398.

Castillo, P., C. Montoro, and V. Tuesta (2009, March). A dynamic stochastic general equilibrium model with dollarization for the peruvian economy. Working Papers 2009-003, Banco Central de Reserva del Perú.

Chamon, M., J. D. Ostry, and A. R. Ghosh (2012). Two targets, two instruments: Monetary and exchange rate policies in emerging market economies. IMF Staff Discussion Notes 12/01, International Monetary Fund.

Chari, V. V., P. J. Kehoe, and E. R. McGrattan (2002, July). Can sticky price models generate volatile and persistent real exchange rates? *Review of Economic Studies 69*(3), 533–63.

Chetty, R., A. Guren, D. Manoli, and A. Weber (2011, May). Are micro and macro labor supply elasticities consistent? a review of evidence on the intensive and extensive margins. *American Economic Review 101*(3), 471–75.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005, February). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1), 1–45.

Cogley, T. and T. J. Sargent (2005, April). The conquest of US inflation: Learning and robustness to model uncertainty. *Review of Economic Dynamics 8*(2), 528–563.

Devereux, M. B., P. R. Lane, and J. Xu (2006, April). Exchange rates and monetary policy in emerging market economies. *Economic Journal 116*(511), 478–506.

Filardo, A., G. Ma, and D. Mihaljek (2011). Exchange rate and monetary policy frameworks in emes. In B. for International Settlements (Ed.), *Capital flows, commodity price movements and foreign exchange intervention*, Volume 57 of *BIS Papers chapters*, pp. 37–63. Bank for International Settlements.

Frankel, J. A. and A. K. Rose (1995). Empirical research on nominal exchange rates. In G. M. Grossman and K. Rogoff (Eds.), *Handbook of International Economics*, Volume 3 of *Handbook of International Economics*, Chapter 33, pp. 1689–1729. Elsevier.

Galí, J. and T. Monacelli (2005, July). Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies 72*(3), 707–734.

Kamil, H. (2008, April). Is central bank intervention effective under inflation targeting regimes? the case of colombia. IMF Working Papers 08/88, International Monetary Fund.

Lai, H. and D. Trefler (2002, September). The gains from trade with monopolistic competition: Specification, estimation, and mis-specification. NBER Working Papers 9169, National Bureau of Economic Research, Inc.

Lyons, R. K. (2006). *The Microstructure Approach to Exchange Rates*. Number 026262205x in MIT Press Books. The MIT Press.

Meese, R. and K. Rogoff (1983, September). The out-of-sample failure of empirical exchange rate models: Sampling error or misspecification? In *Exchange Rates and International Macroeconomics*, NBER Chapters, pp. 67–112. National Bureau of Economic Research, Inc.

Menkhoff, L. (2012, April). Foreign Exchange Intervention in Emerging Markets: A Survey of Empirical Studies. Hannover Economic Papers (HEP) dp-498, Leibniz Universität Hannover, Wirtschaftswissenschaftliche Fakultät.

Mihaljek, D. (2005). Survey of central banks views on effects of intervention. In B. for International Settlements (Ed.), *Foreign exchange market intervention in emerging markets: motives, techniques and implications*, Volume 24 of *BIS Papers chapters*, pp. 82–96. Bank for International Settlements.

Obstfeld, M. and K. Rogoff (1995, June). Exchange rate dynamics redux. *Journal of Political Economy 103*(3), 624–60.

Rabanal, P. and V. Tuesta (2006, November). Euro-dollar real exchange rate dynamics in an estimated two-country model: What is important and what is not. CEPR Discussion Papers 5957, C.E.P.R. Discussion Papers.

Schmitt-Grohe, S. and M. Uribe (2003, October). Closing small open economy models. *Journal of International Economics 61*(1), 163–185.

Sutherland, A. (2005, March). Incomplete pass-through and the welfare effects of exchange rate variability. *Journal of International Economics 65*(2), 375–399.

Vargas, H., A. González, and D. Rodríguez (2013). Foreign exchange intervention in colombia. Borradores de Economía 010465, Banco de la República.

Vitale, P. (2011, January). The impact of fx intervention on fx markets: a market microstructure analysis. *International Journal of Finance & Economics 16*(1), 41–62.

## 1.A Figures and tables

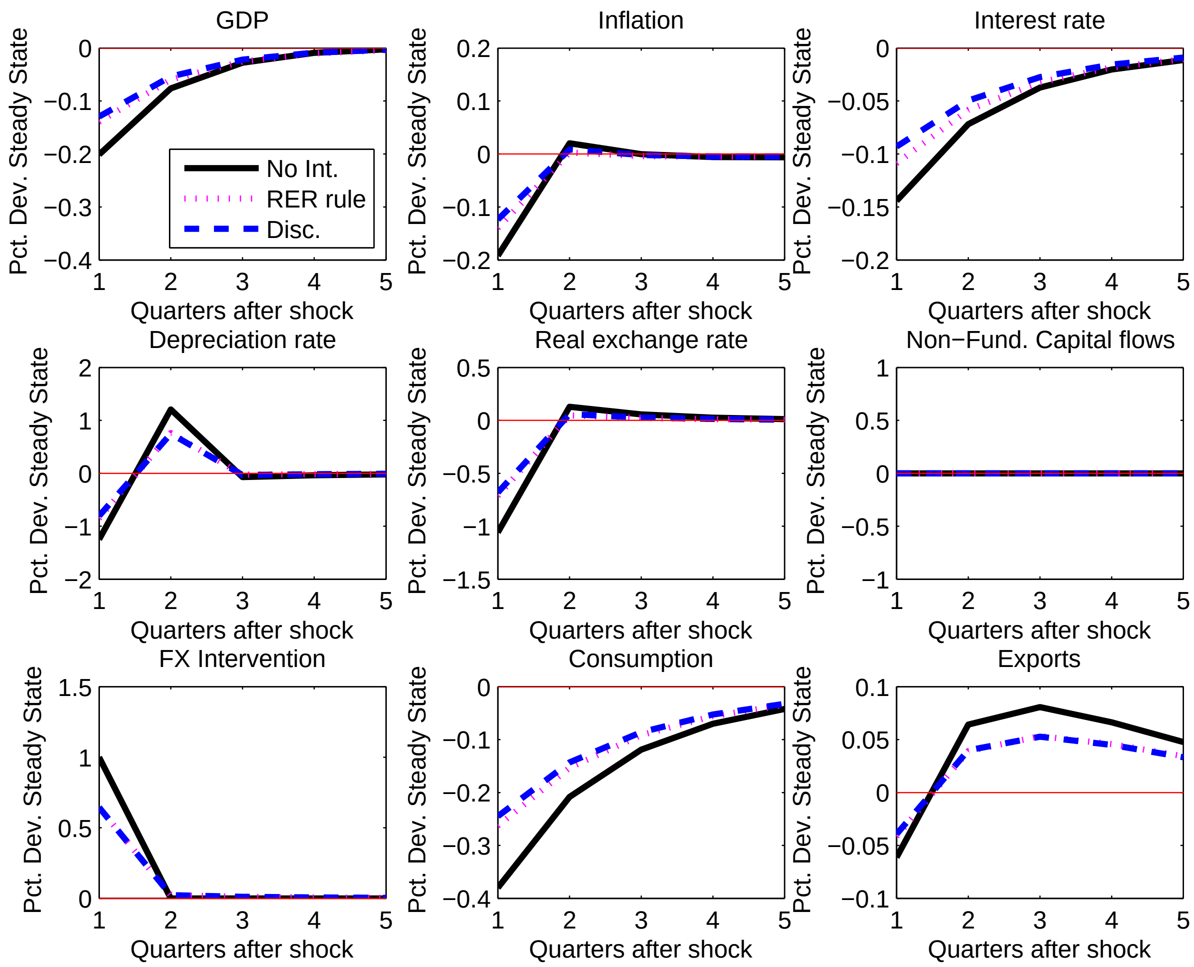



Figure 7: Reaction to a 1% FX intervention shock - *RER* rule.

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

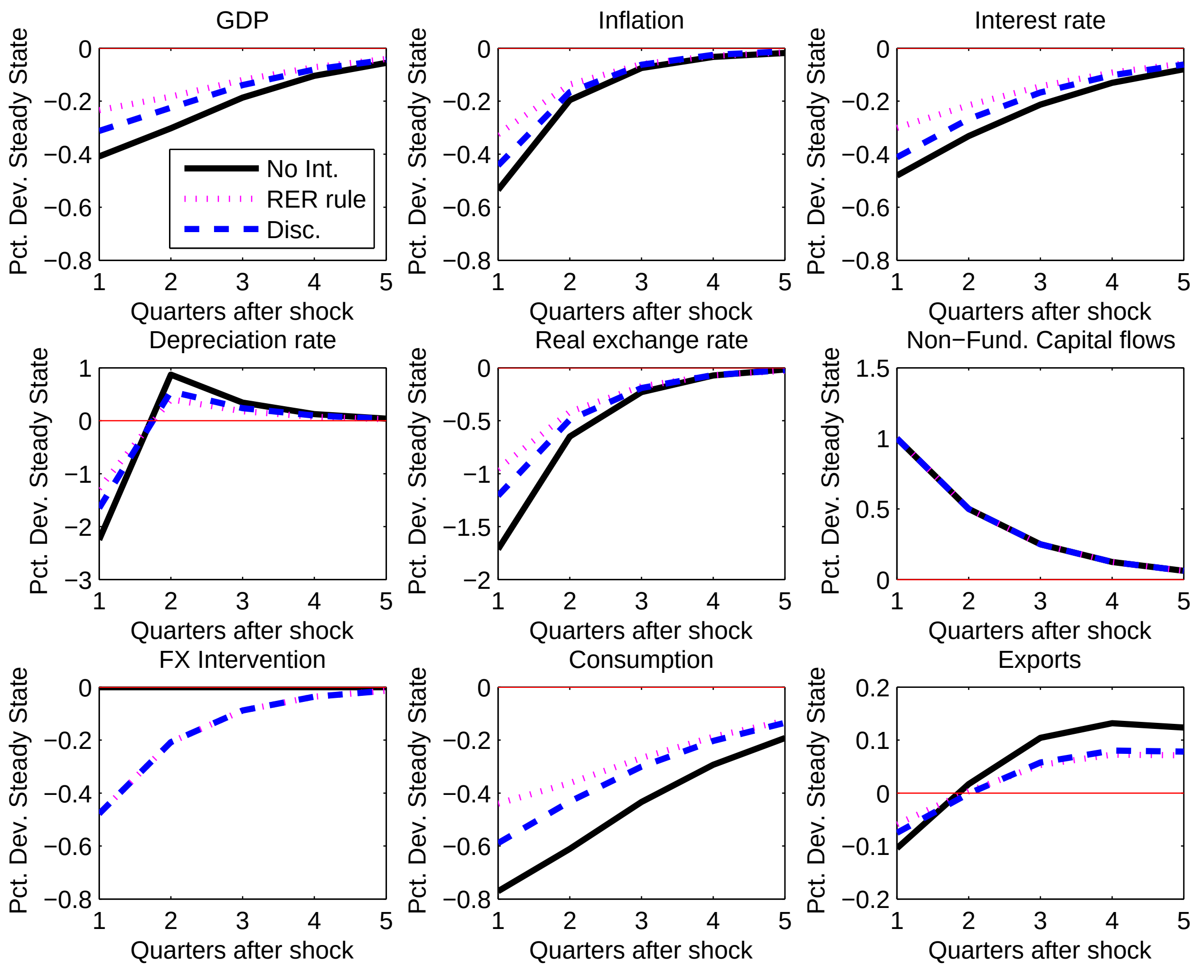



Figure 8: Reaction to a 1% portfolio shock - *RER* rule

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

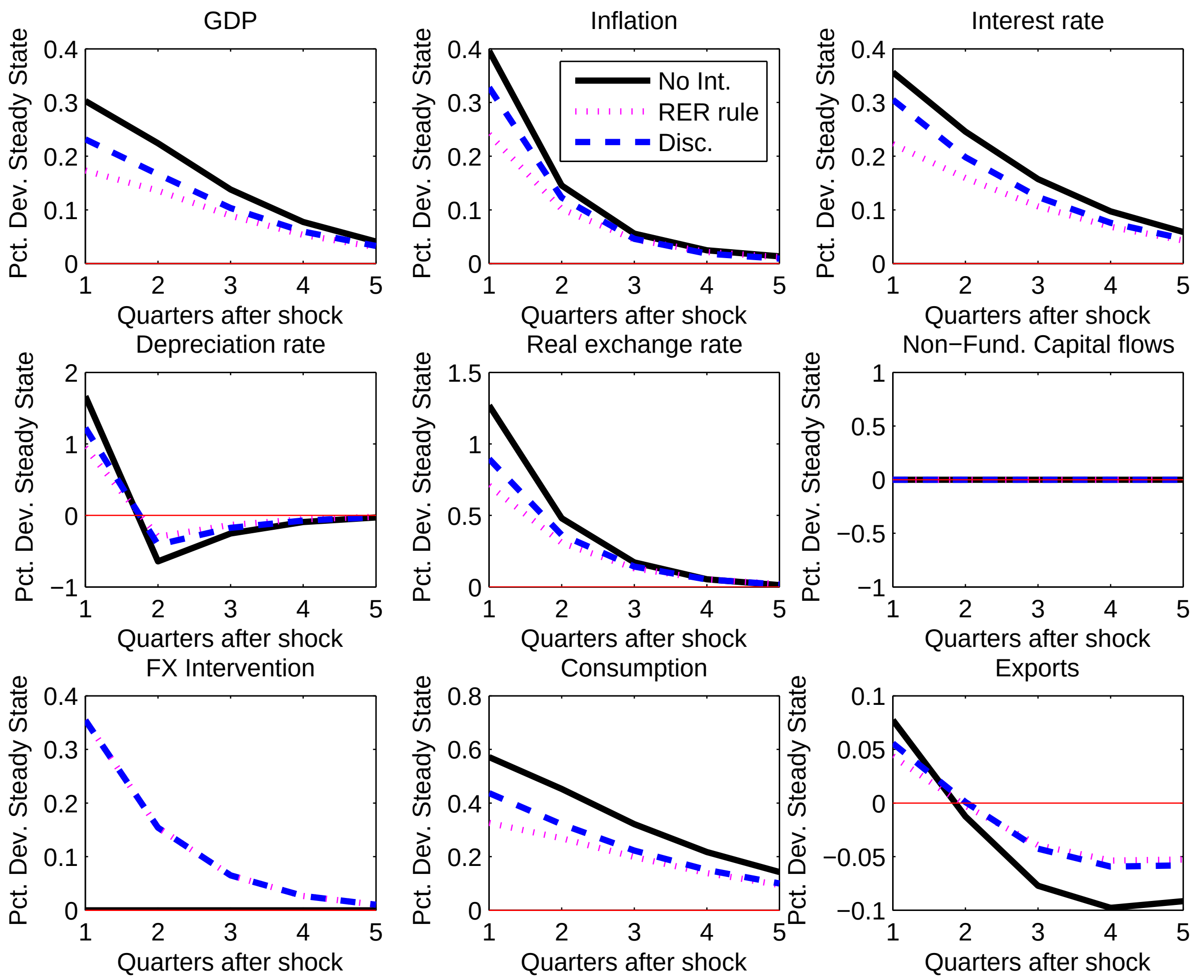



Figure 9: Reaction to a 1% foreign interest rate shock - *RER* rule.

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

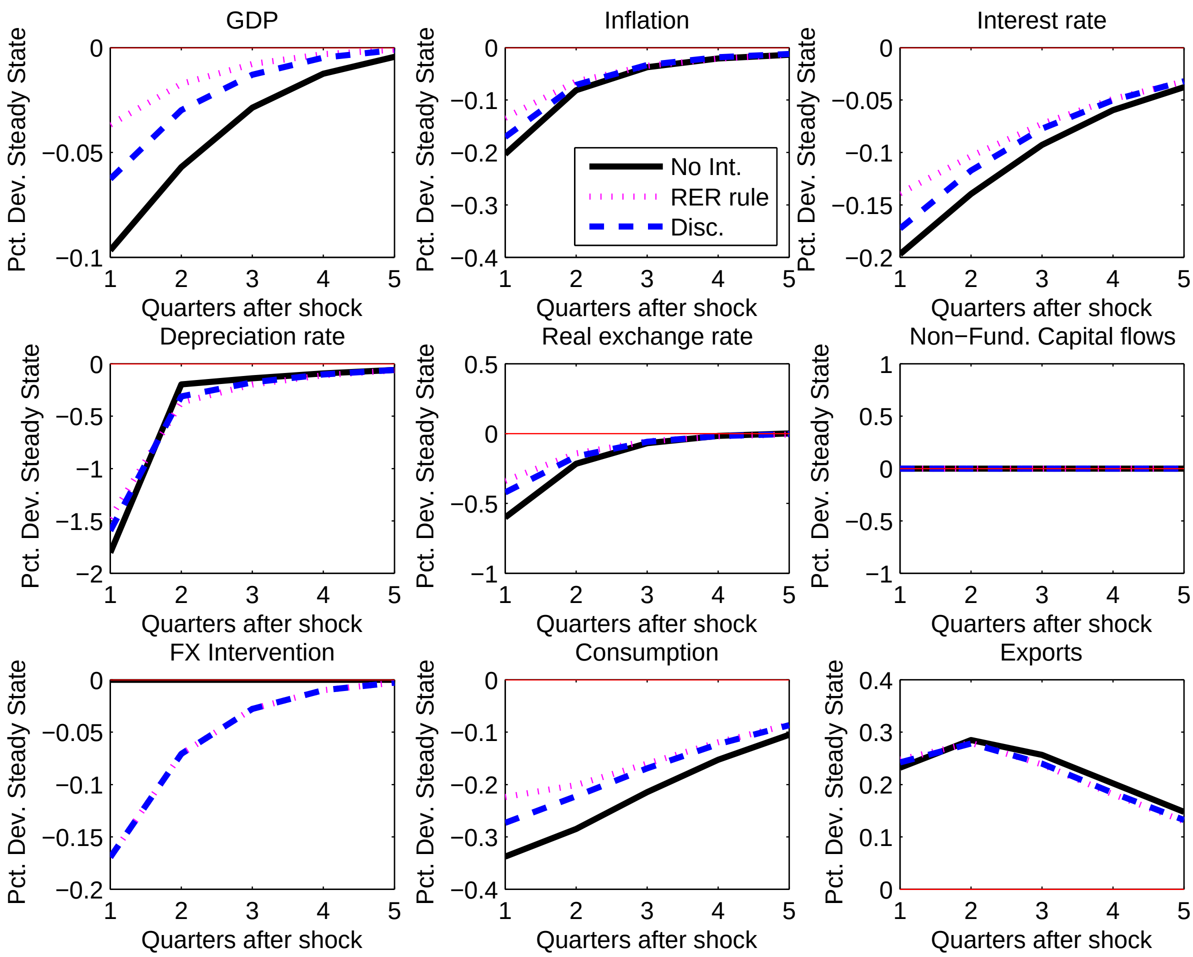



Figure 10: Reaction to a 1% foreign inflation rate shock - $RER$ rule.

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

Table 3: **Macroeconomic volatility (No intervention $\equiv 1$), Low elasticity of subs. btw. home and foreign goods ($\varepsilon = 0.4$.)**

| *Endogenous variable* | *RER* | *Δ Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| | | | *Foreign interest rate shock* ($\varepsilon_{i^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.32 | 0.69 | 0.5 | 0.98 | 0.46 | 0.09 | 0.42 |
| $\varphi_{\Delta s} = 0.50$ | 0.07 | 0.53 | 0.24 | 0.99 | 0.18 | 0.12 | 0.14 |
| $\varphi_{rer} = 0.25$ | 0.66 | 0.86 | 0.77 | 0.98 | 0.8 | 0.49 | 0.76 |
| $\varphi_{rer} = 0.50$ | 0.55 | 0.81 | 0.69 | 0.98 | 0.72 | 0.33 | 0.67 |
| | | | *Capital flows shock* ($\varepsilon^{\omega^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.21 | 0.19 | 0.25 | 0.22 | 0.28 | 0.26 | 0.26 |
| $\varphi_{\Delta s} = 0.50$ | 0.15 | 0.12 | 0.2 | 0.15 | 0.24 | 0.21 | 0.21 |
| $\varphi_{rer} = 0.25$ | 0.23 | 0.22 | 0.24 | 0.22 | 0.26 | 0.24 | 0.24 |
| $\varphi_{rer} = 0.50$ | 0.12 | 0.11 | 0.12 | 0.11 | 0.14 | 0.12 | 0.13 |
| | | | *Foreign inflation shock* ($\varepsilon^{\pi^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.93 | 0.79 | 0.98 | 0.96 | 1.11 | 1.03 | 1.08 |
| $\varphi_{\Delta s} = 0.50$ | 0.87 | 0.67 | 0.95 | 0.93 | 1.2 | 1.02 | 1.13 |
| $\varphi_{rer} = 0.25$ | 0.66 | 0.64 | 0.67 | 0.64 | 0.71 | 0.67 | 0.7 |
| $\varphi_{rer} = 0.50$ | 0.54 | 0.52 | 0.55 | 0.52 | 0.61 | 0.56 | 0.58 |
| | | | *Foreign output shock* ($\varepsilon^{y^*}$) | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.34 | 0.96 | 0.91 | 0.99 | 0.72 | 0.91 | 0.64 |
| $\varphi_{\Delta s} = 0.50$ | 1.55 | 0.88 | 0.86 | 1 | 0.56 | 0.88 | 0.44 |
| $\varphi_{rer} = 0.25$ | 0.6 | 0.63 | 1.13 | 1.03 | 1.22 | 1.13 | 1.28 |
| $\varphi_{rer} = 0.50$ | 0.47 | 0.54 | 1.19 | 1.04 | 1.32 | 1.18 | 1.4 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

Table 4: **Macroeconomic Volatility (No intervention $\equiv 1$), High elasticity of subs. btw. home and foreign goods ($\varepsilon = 1.5$.)**

| *Endogenous variable* | *RER* | *$\Delta$ Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| *Foreign interest rate shock ($\varepsilon_{i^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.31 | 0.69 | 0.46 | 0.84 | 0.42 | 0.15 | 0.4 |
| $\varphi_{\Delta s} = 0.50$ | 0.14 | 0.59 | 0.28 | 0.78 | 0.23 | 0.02 | 0.21 |
| $\varphi_{rer} = 0.25$ | 0.68 | 0.87 | 0.78 | 0.94 | 0.8 | 0.59 | 0.78 |
| $\varphi_{rer} = 0.50$ | 0.57 | 0.83 | 0.69 | 0.92 | 0.72 | 0.45 | 0.69 |
| *Capital flows shock ($\varepsilon^{\omega^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.31 | 0.28 | 0.4 | 0.37 | 0.43 | 0.4 | 0.39 |
| $\varphi_{\Delta s} = 0.50$ | 0.16 | 0.14 | 0.22 | 0.2 | 0.25 | 0.22 | 0.22 |
| $\varphi_{rer} = 0.25$ | 0.35 | 0.34 | 0.37 | 0.37 | 0.4 | 0.37 | 0.38 |
| $\varphi_{rer} = 0.50$ | 0.18 | 0.17 | 0.2 | 0.19 | 0.22 | 0.19 | 0.2 |
| *Foreign inflation shock ($\varepsilon^{\pi^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.87 | 0.77 | 0.98 | 0.96 | 1.04 | 0.99 | 1.02 |
| $\varphi_{\Delta s} = 0.50$ | 0.81 | 0.68 | 0.96 | 0.94 | 1.06 | 0.98 | 1.03 |
| $\varphi_{rer} = 0.25$ | 0.68 | 0.66 | 0.71 | 0.72 | 0.76 | 0.71 | 0.74 |
| $\varphi_{rer} = 0.50$ | 0.57 | 0.55 | 0.6 | 0.61 | 0.66 | 0.6 | 0.64 |
| *Foreign output shock ($\varepsilon^{y^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.22 | 0.89 | 0.88 | 1 | 0.72 | 0.92 | 0.62 |
| $\varphi_{\Delta s} = 0.50$ | 1.3 | 0.83 | 0.84 | 1 | 0.61 | 0.9 | 0.49 |
| $\varphi_{rer} = 0.25$ | 0.65 | 0.67 | 1.14 | 1.01 | 1.2 | 1.12 | 1.25 |
| $\varphi_{rer} = 0.50$ | 0.53 | 0.58 | 1.2 | 1.01 | 1.29 | 1.17 | 1.37 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

Table 5: **Macroeconomic volatility (No intervention $\equiv 1$), Low elasticity of subs. btw. exports and foreign goods ($\varepsilon_F = 0.4$.)**

| *Endogenous variable* | *RER* | *Δ Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| *Foreign interest rate shock* ($\varepsilon_{i^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.43 | 0.7 | 0.3 | 0.95 | 0.34 | 0.7 | 0.42 |
| $\varphi_{\Delta s} = 0.50$ | 0.17 | 0.54 | 0.04 | 0.94 | 0.05 | 0.26 | 0.13 |
| $\varphi_{rer} = 0.25$ | 0.65 | 0.82 | 0.53 | 0.98 | 0.51 | 0.59 | 0.6 |
| $\varphi_{rer} = 0.50$ | 0.53 | 0.76 | 0.38 | 0.97 | 0.36 | 0.75 | 0.46 |
| *Capital flows shock* ($\varepsilon^{\omega^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.21 | 0.19 | 0.26 | 0.21 | 0.31 | 0.26 | 0.26 |
| $\varphi_{\Delta s} = 0.50$ | 0.14 | 0.12 | 0.21 | 0.14 | 0.28 | 0.2 | 0.22 |
| $\varphi_{rer} = 0.25$ | 0.22 | 0.22 | 0.23 | 0.22 | 0.24 | 0.23 | 0.23 |
| $\varphi_{rer} = 0.50$ | 0.11 | 0.11 | 0.12 | 0.11 | 0.13 | 0.12 | 0.12 |
| *Foreign inflation shock* ($\varepsilon^{\pi^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.9 | 0.78 | 1 | 0.88 | 1.15 | 1.02 | 1.09 |
| $\varphi_{\Delta s} = 0.50$ | 0.82 | 0.65 | 0.97 | 0.77 | 1.25 | 1 | 1.14 |
| $\varphi_{rer} = 0.25$ | 0.65 | 0.64 | 0.67 | 0.64 | 0.7 | 0.67 | 0.68 |
| $\varphi_{rer} = 0.50$ | 0.53 | 0.52 | 0.55 | 0.52 | 0.59 | 0.55 | 0.57 |
| *Foreign output shock* ($\varepsilon^{y^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.32 | 0.96 | 0.91 | 0.99 | 0.79 | 0.94 | 0.69 |
| $\varphi_{\Delta s} = 0.50$ | 1.51 | 0.88 | 0.86 | 0.99 | 0.65 | 0.91 | 0.49 |
| $\varphi_{rer} = 0.25$ | 0.65 | 0.65 | 1.08 | 1.02 | 1.09 | 1.07 | 1.13 |
| $\varphi_{rer} = 0.50$ | 0.53 | 0.55 | 1.11 | 1.03 | 1.14 | 1.1 | 1.2 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

Table 6: **Macroeconomic volatility (No intervention $\equiv 1$), High elasticity of subs. btw. exports and foreign goods ($\varepsilon_F = 1.5$.)**

| *Endogenous variable* | *RER* | *$\Delta$ Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| *Foreign interest rate shock ($\varepsilon_{i^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.32 | 0.68 | 0.6 | 0.9 | 0.46 | 0.28 | 0.39 |
| $\varphi_{\Delta s} = 0.50$ | 0.3 | 0.53 | 0.39 | 0.84 | 0.21 | 0.04 | 0.15 |
| $\varphi_{rer} = 0.25$ | 0.72 | 0.97 | 0.99 | 0.97 | 1.19 | 1 | 1.19 |
| $\varphi_{rer} = 0.50$ | 0.61 | 0.96 | 0.98 | 0.96 | 1.26 | 0.98 | 1.26 |
| *Capital flows shock ($\varepsilon^{\omega^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.32 | 0.29 | 0.39 | 0.36 | 0.37 | 0.4 | 0.37 |
| $\varphi_{\Delta s} = 0.50$ | 0.22 | 0.18 | 0.31 | 0.27 | 0.3 | 0.32 | 0.3 |
| $\varphi_{rer} = 0.25$ | 0.35 | 0.35 | 0.39 | 0.37 | 0.46 | 0.39 | 0.41 |
| $\varphi_{rer} = 0.50$ | 0.18 | 0.18 | 0.21 | 0.19 | 0.26 | 0.21 | 0.23 |
| *Foreign inflation shock ($\varepsilon^{\pi^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.91 | 0.79 | 0.98 | 0.94 | 0.99 | 1.02 | 1.01 |
| $\varphi_{\Delta s} = 0.50$ | 0.84 | 0.67 | 0.96 | 0.88 | 1 | 1.02 | 1.02 |
| $\varphi_{rer} = 0.25$ | 0.69 | 0.67 | 0.72 | 0.7 | 0.83 | 0.73 | 0.8 |
| $\varphi_{rer} = 0.50$ | 0.57 | 0.55 | 0.62 | 0.59 | 0.75 | 0.62 | 0.71 |
| *Foreign output shock ($\varepsilon^{y^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.2 | 0.87 | 0.89 | 0.99 | 0.63 | 0.91 | 0.57 |
| $\varphi_{\Delta s} = 0.50$ | 1.29 | 0.76 | 0.85 | 0.98 | 0.46 | 0.88 | 0.38 |
| $\varphi_{rer} = 0.25$ | 0.63 | 0.69 | 1.25 | 1.03 | 1.53 | 1.25 | 1.61 |
| $\varphi_{rer} = 0.50$ | 0.51 | 0.62 | 1.35 | 1.04 | 1.79 | 1.36 | 1.93 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

Table 7: **Macroeconomic volatility (No intervention $\equiv 1$), Low domestic good price rigidity ($\theta_H = 0.25$.)**

| *Endogenous variable* | *RER* | *Δ Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| *Foreign interest rate shock* ($\varepsilon_{i^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.35 | 0.76 | 0.62 | 0.95 | 0.39 | 1.1 | 0.37 |
| $\varphi_{\Delta s} = 0.50$ | 0.14 | 0.64 | 0.43 | 0.92 | 0.16 | 1.17 | 0.15 |
| $\varphi_{rer} = 0.25$ | 0.84 | 0.99 | 0.96 | 0.98 | 1.06 | 1 | 1.07 |
| $\varphi_{rer} = 0.50$ | 0.71 | 0.98 | 0.93 | 0.96 | 1.12 | 1 | 1.13 |
| *Capital flows shock* ($\varepsilon^{\omega^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.48 | 0.46 | 0.57 | 0.56 | 0.54 | 0.54 | 0.53 |
| $\varphi_{\Delta s} = 0.50$ | 0.31 | 0.28 | 0.4 | 0.39 | 0.37 | 0.36 | 0.36 |
| $\varphi_{rer} = 0.25$ | 0.65 | 0.65 | 0.72 | 0.7 | 0.79 | 0.67 | 0.79 |
| $\varphi_{rer} = 0.50$ | 0.55 | 0.55 | 0.66 | 0.63 | 0.79 | 0.57 | 0.79 |
| *Foreign inflation shock* ($\varepsilon^{\pi^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.8 | 0.76 | 0.88 | 0.87 | 0.82 | 0.88 | 0.81 |
| $\varphi_{\Delta s} = 0.50$ | 0.69 | 0.65 | 0.81 | 0.8 | 0.73 | 0.81 | 0.72 |
| $\varphi_{rer} = 0.25$ | 0.83 | 0.86 | 0.91 | 0.91 | 0.98 | 0.86 | 0.99 |
| $\varphi_{rer} = 0.50$ | 0.7 | 0.75 | 0.83 | 0.82 | 0.96 | 0.74 | 0.96 |
| *Foreign output shock* ($\varepsilon^{y^*}$) | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.03 | 0.83 | 0.98 | 0.98 | 0.69 | 1.02 | 0.59 |
| $\varphi_{\Delta s} = 0.50$ | 1.04 | 0.73 | 0.99 | 0.97 | 0.57 | 1.03 | 0.43 |
| $\varphi_{rer} = 0.25$ | 0.85 | 0.88 | 1.17 | 1.07 | 1.62 | 1.06 | 1.68 |
| $\varphi_{rer} = 0.50$ | 0.74 | 0.86 | 1.34 | 1.13 | 2.35 | 1.11 | 2.55 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

Table 8: **Macroeconomic volatility (No intervention $\equiv 1$), High domestic good price rigidity ($\theta_H = 0.95$.)**

| *Endogenous variable* | *RER* | *$\Delta$ Ex. Rate* | *Consumption* | *Exports* | *Int. Rate* | *Production* | *Inflation* |
|---|---|---|---|---|---|---|---|
| *Foreign interest rate shock ($\varepsilon_{i^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.23 | 0.55 | 0.37 | 0.88 | 0.44 | 0.16 | 0.26 |
| $\varphi_{\Delta s} = 0.50$ | 0.03 | 0.4 | 0.12 | 0.85 | 0.14 | 0 | 0.04 |
| $\varphi_{rer} = 0.25$ | 0.55 | 0.76 | 0.64 | 0.95 | 0.66 | 0.48 | 0.56 |
| $\varphi_{rer} = 0.50$ | 0.41 | 0.68 | 0.52 | 0.93 | 0.54 | 0.32 | 0.42 |
| *Capital flows shock ($\varepsilon^{\omega^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 0.72 | 0.56 | 1.05 | 0.66 | 1.44 | 1.09 | 0.89 |
| $\varphi_{\Delta s} = 0.50$ | 0.41 | 0.27 | 0.71 | 0.33 | 1.23 | 0.75 | 0.56 |
| $\varphi_{rer} = 0.25$ | 0.35 | 0.34 | 0.36 | 0.34 | 0.38 | 0.36 | 0.35 |
| $\varphi_{rer} = 0.50$ | 0.18 | 0.18 | 0.19 | 0.18 | 0.2 | 0.19 | 0.18 |
| *Foreign inflation shock ($\varepsilon^{\pi^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 1.27 | 0.89 | 1.48 | 0.92 | 2.03 | 1.58 | 1.45 |
| $\varphi_{\Delta s} = 0.50$ | 1.5 | 0.85 | 1.84 | 0.84 | 3.17 | 2.04 | 1.78 |
| $\varphi_{rer} = 0.25$ | 0.55 | 0.53 | 0.57 | 0.52 | 0.61 | 0.57 | 0.56 |
| $\varphi_{rer} = 0.50$ | 0.41 | 0.39 | 0.43 | 0.39 | 0.47 | 0.43 | 0.42 |
| *Foreign output shock ($\varepsilon^{y^*}$)* | | | | | | | |
| $\varphi_{\Delta s} = 0.25$ | 2.55 | 1.47 | 0.98 | 1 | 0.96 | 0.98 | 0.8 |
| $\varphi_{\Delta s} = 0.50$ | 3.97 | 1.74 | 0.97 | 1 | 0.93 | 0.97 | 0.7 |
| $\varphi_{rer} = 0.25$ | 0.5 | 0.52 | 1.01 | 1 | 1.01 | 1.01 | 1.06 |
| $\varphi_{rer} = 0.50$ | 0.36 | 0.41 | 1.01 | 1 | 1.01 | 1.01 | 1.09 |

**Note:** The table shows normalised unconditional relative variances of the model assuming the only source of volatility is the shock in the table heading. We have considered changes in variance produced by intervention rules themselves, and how these affect the overall volatility of the economy.

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

### Aggregate demand

Aggregate demand ($y_t$)

$$y_t = \phi_C(c_t) + \phi_X(x_t) - \phi_M(m_t) + g_t \tag{50}$$

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

$$t_t^{def} = \phi_X(rer_t + t_t^X) - \phi_M t_t^M \tag{51}$$

Real exchange rate ($rer_t$)

$$rer_t = rer_{t-1} + \Delta s_t + \pi_t^* - \pi_t \tag{52}$$

Euler equation ($\lambda_t$)

$$\lambda_t = \hat{\imath}_t + E_t(\lambda_{t+1} - \pi_{t+1}) - \psi_b b_t \tag{53}$$

Marginal utility ($\lambda_t$)

$$\lambda_t = -\gamma_c c_t \tag{54}$$

Exports ($x_t$)

$$x_t = -\varepsilon_F(t_t^X) + y_t^*; \tag{55}$$

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

$$t_t^X = t_{t-1}^X + \pi_t^X - \pi_t^*; \tag{56}$$

Imports ($m_t$)

$$m_t = -\varepsilon(t_t^M) + c_t; \tag{57}$$

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

$$t_t^M = t_{t-1}^M + \pi_t^M - \pi_t; \tag{58}$$

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

$$y_t^H = -\varepsilon(t_t^H) + c_t; \tag{59}$$

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

$$t_t^H = -\left(\frac{1-\psi}{\psi}\right) t_t^M \tag{60}$$

### Aggregate supply

Total CPI ($\pi_t$):

$$\pi_t = \psi \pi_t^H + (1-\psi)\,\pi_t^M + \mu_t \tag{61}$$

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

$$\pi_t^H = \kappa_H \left(mc_t - t_t^H\right) + \beta E_t \pi_{t+1}^H \tag{62}$$

Real marginal costs ($mc_t$)

$$mc_t = wp_t - a_t; \tag{63}$$

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

$$\pi_t^M = \kappa_M mc_t^M + \beta E_t \pi_{t+1}^M \tag{64}$$

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

$$mc_t^M = rer_t - t_t^M \tag{65}$$

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

$$\pi_t^X = \kappa_X mc_t^X + \beta E_t \pi_{t+1}^X \tag{66}$$

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

$$mc_t^X = mc_t - rer_t - t_t^X \tag{67}$$

## Labour market

Labour demand ($l_t$)

$$l_t = y_t - a_t; \tag{68}$$

Labour supply ($wp_t$)

$$wp_t = \gamma_c c_t + \chi l_t \tag{69}$$

## FX markets and current account

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

$$\overline{E}_t \Delta s_{t+1} = \hat{\imath}_t - \hat{\imath}_t^* + \gamma \sigma^2 \left( \varpi_t^* + \varpi_t^{*,cb} \right) \tag{70}$$

Current account ($b_t$)

$$\phi_\varpi \left(b_t - \beta^{-1} b_{t-1}\right) = t_t^{def} + y_t - \phi_C c_t + \frac{\phi_\varpi}{\beta} \left(i_{t-1} - \pi_t\right) \tag{71}$$

## Monetary policy

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

$$\hat{\imath}_t = \varphi_\pi(\pi_t) + \varepsilon_t^{int} \tag{72}$$

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

$$\varpi_t^{*,cb} = \varphi_{\Delta s} \Delta s_t + \varphi_{rer} rer_t + \varepsilon_t^{cb} \tag{73}$$

## Foreign economy

Foreign output ($y_t^*$):

$$y_t^* = \rho_{y^*} y_{t-1}^* + \varepsilon_t^{y^*} \tag{74}$$

Foreign inflation ($\pi_t^*$):

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \varepsilon_t^{\pi^*} \tag{75}$$

Foreign interest rates ($i_t^*$):

$$i_t^* = \rho_{i^*} i_{t-1}^* + \varepsilon_t^{i^*} \tag{76}$$

Capital inflows-order flows ($\varpi_t^*$)

$$\varpi_t^* = \rho_{\varpi^*} \varpi_{t-1}^* + \varepsilon_t^{\varpi^*} \tag{77}$$

## Domestic shocks

Productivity shocks ($a_t$):

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \tag{78}$$

Demand shocks ($g_t$):

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g \tag{79}$$

Mark-up shocks ($\mu_t$):

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_t^\mu \tag{80}$$

Thus we have in total 31 equations, 24 from the original model and seven auxiliary equations. We have included two exogenous shock processes - demand ($g_t$) and mark-up/inflation ($\mu_t$) shocks - to perform additional analysis. The variables in the model are: $a_t$, $y_t$, $c_t$, $x_t$, $m_t$, $y_t^*$, $y_t^H$, $l_t$, $\lambda_t$, $\varpi_t^*$, $mc_t$, $mc_t^X$, $mc_t^M$, $t_t^{def}$, $t_t^X$, $t_t^M$, $t_t^H$, $\pi_t$, $\pi_t^H$, $\pi_t^X$, $\pi_t^M$, $\pi_t^*$, $rer_t$, $\Delta s_t$, $i_t$, $i_t^*$, $wp_t$, $b_t$, $\varpi_t^{*,cb}$, $g_t$, $\mu_t$. The minimum state variable (MSV) set is composed of 12 variables: $a_t$, $y_t^*$, $b_t$, $\varpi_t^*$, $t_t^X$, $t_t^M$, $\pi_t^*$, $rer_t$, $i_t$, $i_t^*$, $g_t$, $\mu_t$.

The nine shocks comprise four foreign economy shocks ($\varepsilon_t^{y^*}, \varepsilon_t^{\pi^*}, \varepsilon_t^{i^*}, \varepsilon_t^{\varpi^*}$), three domestic economy shocks ($\varepsilon_t^a, \varepsilon_t^g, \varepsilon_t^\mu$) and two policy shocks $\left(\varepsilon_t^{int}, \varepsilon_t^{cb}\right)$