Effectiveness of Sterilized Foreign Exchange Intervention under Imperfect Financial Markets*

Serra Pelin
UC Berkeley

October 25, 2023

Abstract

Emerging market (EM) central banks are known to intervene in the foreign exchange rate market during times of financial risk and currency devaluation. This paper develops an open-economy New Keynesian DSGE model with imperfect financial markets and dollar-denominated debt in EM banking sector to test the effectiveness of sterilized foreign exchange intervention policy. The model finds that such intervention reduces EM long-run inflation, output gap and real exchange rate volatility as well as reducing EM welfare losses. The theoretical results of the model can rationalize the incentives as to why several EMs have turned to such intervention during the U.S. monetary tightening periods as well as in other periods of heightened financial risk in EMs.

*I would like to thank George Hall and Jean-Paul L'Huillier for insightful discussions. A special thank you to Ozge Akinci for sharing relevant materials and insight into international financial markets.

Contents

1 Introduction 3

2 Related Literature 5

3 The Model 6
- 3.1 Households . . . 7
- 3.2 Firms and Price Setting . . . 8
- 3.3 Capital Producers . . . 8
- 3.4 Central Bank . . . 9
- 3.5 Banks . . . 10
- 3.6 Foreign Economy . . . 12
- 3.7 Market Clearing, Balance of Payments . . . 12
- 3.8 Discussion of Assumptions . . . 13

4 Calibration and Results 13
- 4.1 Calibration . . . 13
- 4.2 IRF Plots and Analysis . . . 14

5 Should Central Banks Use Sterilized FX Intervention? 18

6 Further Expansions 20

A Solving Banker's Problem 23

B List of Model Equations 24

C Tables 27

1 Introduction

During the recent U.S. Monetary tightening policy regime between 2016-2019 as well as the post-Covid inflationary period, many emerging markets (EMs), including Argentina, Chile and Turkey, faced heightened volatility in their exchange rates with the dollar. Simultaneously, they faced high spikes in their inflation levels, tracking the pattern of the exchange rate. Alongside an inflation targeting Taylor rule to determine the policy rate, affected countries' policymakers have found it useful to implement a foreign exchange intervention policy to stabilize prices and other domestic variables.

This evidence renews the interest in the foreign effects of U.S. monetary policy actions. Recent works such as Giovanni et al. (2017) and Akinci and Queraltó (2018) have emphasized the role of financial channels involving a deviation from the uncovered interest parity (UIP) fluctuating counter-cyclically, as the global financial markets tighten. Another avenue for explaining the strong linkage between foreign variables and inflation has been the dominant currency paradigm (DCP) suggested by Gopinath et al. (2018) where trade pricing is in dollar terms instead of producer currency pricing (PCP). With these recent developments in mind, there has been an ongoing debate about the appropriate monetary policy response of dollar dependent EMs to U.S. monetary policy shifts.

A central bank can engage in foreign exchange markets by selling (or buying) official dollar reserves in exchange for domestic currency. This process increases the dollar supply and decreases the domestic money supply in the exchange market, thus reducing the exchange rate. If the intervention were to be unsterilized this would conclude the intervention. With unsterilized intervention, the domestic money supply decreases and therefore the intervention indirectly affects monetary policy. In order for the domestic money supply and the nominal interest rate to remain unchanged by intervention, the central bank engages in sterilization, i.e. buying back (or selling) an equivalent amount of government issued bonds only held by domestic institutions.

For example, in response to an exchange rate hike the central bank sells some of its dollar reserves to lower the exchange rate while indirectly increasing the domestic money supply. Simultaneously, the central bank buys back sterilized bonds[1] from domestic banks thus counter-balancing the money supply and keeping nominal interest rates unchanged. Buying back sterilized bonds frees up the domestic banks' budget constraint thus simulating lending to the private sector, and reducing production costs and domestic prices. This can also be viewed as a change in the composition of debt held by the banks.

Textbook open-economy New Keynesian models like that of Galí and Monacelli (2005) argue that monetary policy should focus on domestic objectives and allow the exchange rate to fluctuate freely under the framework of the 'divine coincidence'. This stands in contrast with policies under

[1]Sterilized bonds by definition can only be held by domestic institutions.

which many EM central banks put substantial importance on exchange rate stabilization in order to control domestic variables. Thus, there exists a divergence between the theory and the intervention policy approach implemented by EM policymakers.

The aim of my paper is to close the gap between the policymakers' incentives to engage in intervention policy and the economic theory. More precisely, under what conditions is a sterilized foreign exchange intervention policy an effective measure to control domestic prices?

I will focus specifically on sterilized intervention under imperfect financial markets since sterilization directly affects the domestic banking sector's budget sheet and constraint. Due to a high correlation between inflation and exchange rates, the intervention policy's efficiency will be tested under a dollar dependent economy with dollar-denominated debt, using a two-country medium-scale DSGE model based on the SIGMA model (this model is described in detail in Erceg et al. (2006)) and Akinci and Queraltó (2018). Both papers are taken from the Fed Staff Reports as the goal of this model is to make a policy recommendation.

The key takeaways from the model are as follows: (1) Intervention policy is able to reduce EM welfare losses along with reducing output gap, inflation and real exchange rate volatility, thus deviating from the divine coincidence. On the objective of controlling domestic prices the answer is more nuanced: (2) when it comes to CPI-inflation the intervention doesn't change the behavior of the model. This echoes previous findings on the effectiveness of sterilized intervention. (3) Regarding PPI-inflation, the intervention policy is effective in reducing volatility in the short run.[2](4) The intervention comes at a cost of reduced net exports for the emerging economy since the benefit of currency depreciation to exports is muted. (5) It is important to note that after intervention, there is a permanent change in central bank foreign reserve levels. Consecutive intervention episodes can cause a depletion of foreign reserves. (6) There is an unexpected spill-back effect to U.S. CPI-inflation where intervention further deflates the dollar from an initial U.S. monetary tightening as well as increasing U.S. welfare losses.

The model can be extended to incorporate dollar exposure in export pricing as described by Gopinath et al. (2018) to allow the emerging economy to be more dependent on exchange rate fluctuations in trade and pricing. This could change the results regarding CPI-inflation mentioned above as well as trade behavior.

Motivation from Data

During the recent U.S. monetary tightening between 2016-2019 as well as the post-Covid inflationary period, many emerging economies faced currency depreciation against the dollar while also facing continued increases in inflation. Some of these countries, such as Argentina, Chile, and Turkey, have repeatedly engaged in foreign exchange intervention. This suggests that when there

[2]Producers are an important part of the economy since they directly affect the returns of the banking sector and thus the international credit market.

exists a strong relationship between exchange rates and inflation countries have found value in exchange rate stabilization in the form of selling reserves.

Table C.1 shows correlations between central bank foreign reserve holdings and domestic CPI inflation for 75 EMs. For 65% of listed EMs, central bank foreign reserve holdings are inversely related to domestic CPI-inflation, suggesting the use of exchange rate intervention policy for the purpose of inflation control. This inverse correlation is especially strong (larger than 0.50) for Albania, Bangladesh, Costa Rica, El Salvador, Ghana, Indonesia, South Korea, Lebanon, Moldova, Nicaragua, Romania, Russia, Seychelles, and Turkey, all of which are known for intervening in their foreign exchange market with the exception of El Salvador where dollar is the official currency.

This strong relationship between foreign reserve holdings and domestic inflation makes it worth analyzing the effectiveness of intervention policies especially given the financial liabilities EMs are exposed to the U.S.[3].

The rest of the paper is outlined as follows. Section 2 is a discussion on the related literature to this paper. Section 3 describes the quantitative model in detail, Section 4 discusses the calibration of the model and analyzes impulse response functions. Section 5 examines sterilized intervention from a welfare maximizing optimal policy. Section 6 introduces future expansions of the model.

2 Related Literature

This paper aims to develop an open economy New Keynesian macroeconomic model for policy analysis such as Galí and Monacelli (2005), and Erceg et al. (2006), and Akinci and Queraltó (2018). Additionally, the model is related to Gertler and Kiyotaki (2010) where the presence of financial market frictions and institutions allows to consider a Foreign Exchange Intervention as an "unconventional" policy instrument.

More specifically, the model developed in this paper is based on Akinci and Queraltó (2018) where there are financial market frictions and dollar-denominated debt leading to an endogenous uncovered interest parity (UIP) deviation and strong monetary spillovers from the U.S. to an EM. Deviation from the UIP is defined as "the premium of the local safe rate over the expected dollar rate" (Akinci and Queraltó (2018)). This setup creates excess volatility in exchange rate dynamics compared to a setting when the UIP holds all the time. Additionally, dollar-denominated liabilities undesirably expose the borrowers' (i.e. domestic banks) balance sheet to exchange rate fluctuations thus adding further volatility to the credit market.

Departing from Akinci and Queraltó (2018) on how a central bank responds to international variables, the model allows for a separate policy instrument of sterilized intervention instead of adjusting the Taylor rule based on exchange rate movements. This is also in line with the findings

[3]Other channels that can cause the inverse relationship between domestic inflation and central bank foreign reserves are not considered.

of Galí and Monacelli (2005) suggesting that targeting international variables in a Taylor rule is not welfare maximizing. With this construction, intervention policy directly impacts the bank's budget sheet through the size of sterilized bonds.

Literature on foreign exchange intervention policy mostly suggests that there are approximately no real effects from a sterilized intervention and considers such policy useless and irrelevant (Backus and Kehoe (1988)). Backus and Kehoe (1988) quantitatively establish that the changes in the composition of debt do not affect equilibrium prices in the portfolio balance sheet approach. Yet there is a new wave of literature trying to explain when intervention policy could be useful. Chang (2018) builds an intervention model with financial frictions similar to this paper. Chang (2018) finds that when financial constraints are occasionally binding under frictions, such interventions could be effective since it frees up bank resources. In this model I assume such constraints to be always binding. Departing from Chang (2018), the model has dollar-denominated debt and an endogenous UIP deviation, thus building on top of the U.S. monetary spillover literature mentioned above, instead of a technology shock perspective that Chang implements.

Other recent intervention policy models include Alla et al. (2017) where they argue 'the divine coincidence' may not hold and international capital markets can give rationale for sterilized intervention leading to credible effects for inflation targeting regimes. Their framework uses exogenous shocks to foreign risk premium thus creating deviations from the 'divine coincidence'. In this paper, I also show how the divine coincidence does not hold with the endogenous UIP deviations instead of exogenous shocks.

Additionally, there is other literature such as Gopinath et al. (2018) that investigates real effects of exchange rate movements on domestic variables and price levels under a dominant currency paradigm (DCP). A future extension of this model could include such a pricing scheme to amplify the dollar dependency of the model and the sizable effects of the exchange rate on domestic prices.

3 The Model

This section describes the baseline quantitative model in detail. The model is based on the framework of a two-country open-economy New Keynesian model similar to previous medium-scale models like Akinci and Queraltó (2018) as well as the SIGMA model (Erceg et al. (2006)) both published in the Fed Staff reports. Following Akinci and Queraltó (2018) the model implements imperfect financial markets with dollar-denominated debt leading to "endogenous fluctuations in the domestic borrowing spread and in the UIP deviation" (Akinci and Queraltó (2018)). This allows for the endogenous UIP deviation to fluctuate with the exchange value of domestic currency. Departing from this literature, the banking side also holds assets in the form of sterilized bonds thus altering the bank's debt ratio in response to an exchange rate fluctuation.

A standard nominal price stickiness is implemented Calvo style, as well as adjustment costs in investment. These features, following previous literature, help generate empirically realistic effects of a U.S. monetary policy shock.

There are two countries in the model: Home (any EM) and Foreign (the U.S.) economy.

3.1 Households

Consider the Home country consumption bundle defined as follows:

$$C = \left[\omega^{\frac{1}{\theta}} C_H^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} C_F^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \theta > 0 \tag{1}$$

where C_H and C_F refer to the Home consumption of Home produced good and Foreign produced good respectively, with $\theta > 0$ being the elasticity of intratemporal substitution and $\omega \in (0, 1)$, the weight given to Home produced good in aggregator C.

The associated consumption based price of C is:

$$P = \left[\omega P_H^{1-\theta} + (1-\omega) P_F^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{2}$$

where P_H is the price of Home-produced good expressed in Home currency and P_F is the price of Foreign-produced good expressed in Home currency.

The law of one price holds for the same goods: $P_H = EP_H^*$ and $P_F = EP_F^*$, where E is the nominal exchange rate (price of Foreign currency in terms of Home currency), P_H^* is the price of Home-produced good expressed in Foreign currency, and P_F^* is the price of Foreign-produced good expressed in Foreign currency. Notice $P \neq EP^*$, where P^* is the associated consumption based price with C^*. Unless $\omega = \omega^*$, the purchasing power parity (PPP) doesn't hold due to the differences in preferences of agents across countries. To measure deviations from PPP define the real exchange rate (RER) $\mathcal{Q} \equiv P^*/P$. Also define the terms of trade (ToT) for the home country $\mathcal{T} \equiv P_F/P_H$.

The representative household solves:

$$\max_{\{C_{t+j}, D_{t+j}, W_{t+j}, L_{t+j},\}_{j=0}^{\infty}} \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \beta_j \frac{C_t^{1-\sigma}}{1-\sigma} - \chi_0 \frac{L_t^{1+\chi}}{1+\chi} \right\} \tag{3}$$

subject to

$$P_t C_t + P_t D_t + B_t \leq W_t L_t + P_t R_t D_{t-1} + R_t^n B_{t-1} \tag{4}$$

where L_t is the amount of labor the household devotes with the associated wage W_t, D_t is deposits made to the bank, and B_t is the riskless one-period bond. R_t^n is the nominal interest rate and R_t is the real interest rate.

3.2 Firms and Price Setting

Following Akinci and Queraltó (2018), a continuum of retail firms produce domestic output using intermediate goods as inputs. Final output Y_t is a CES composite of retailers' output:

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{1}{1+\theta_p}} di \right)^{1+\theta_p} \tag{5}$$

where Y_{it} is output by retailer $i \in [0, 1]$. For the price set by home retailer i, P_{Hit}, the price level of domestic final output is $P_{Ht} = \left(\int_0^1 P_{Hit}^{-\frac{1}{\theta_p}} di \right)^{-\theta_p}$. Cost minimization by final output users yields the demand for firm i's output:

$$Y_{it} = \left(\frac{P_{Hit}}{P_{Ht}} \right)^{-\frac{1+\theta_p}{\theta_p}} Y_t \tag{6}$$

with the production function:

$$Y_{it} = K_{it}^{\alpha} L_{it}^{1-\alpha} \tag{7}$$

and pays real wage w_t and capital rent r_{Kt}.

Assuming a Calvo-style price stickiness, firm i can reset price with probability $1 - \xi_p$ at each time period and otherwise must follow the indexation rule:

$$P_{Hit} = P_{Hit-1} \pi_{t-1} \tag{8}$$

3.3 Capital Producers

The representative capital producer generates new capital goods subject to adjustment costs of investment I_t:

$$\phi_{It} = \frac{\psi_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 I_t \tag{9}$$

in the units of the home good, where ψ_I is the investment adjustment cost. The representative capital producer solves:

$$\max_{\{I_{t+j}\}_{j=0}^{\infty}} \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left[q_{t+j} I_{t+j} - \frac{P_{Ht+j}}{P_{t+j}} \phi_{It+j} \right] \right\} \tag{10}$$

where q_t is the real price of capital goods i.e. Tobin's q. $\Lambda_{t,t+1}$ is the domestic household's real stochastic discount factor between t and $t+1$ defined as $\Lambda_{t,t+1} \equiv \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}$.

Similar to consumption, investment goods are composite goods of Home and Foreign goods:

$$I = \left[\omega^{\frac{1}{\theta}} I_H^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} I_F^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{11}$$

Optimizing with respect to the investment aggregate I_t gives rise to an investment-Tobin's q relation:

$$q_t = 1 + \frac{P_{Ht}}{P_t}\left[\psi_I\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}} + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] - \mathbb{E}_t\left\{\Lambda_{t,t+1}\frac{P_{Ht+1}}{P_{t+1}}\psi_I\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right\} \tag{12}$$

3.4 Central Bank

The central bank engages in a Taylor rule and sets the nominal interest rate (R_t^n), with inflation targeting defined as follows:

$$R_{t+1}^n = \beta^{-1}\pi_t^{\gamma_\pi} \tag{13}$$

where γ_π is the response in Taylor rule to inflation.

In each period alongside a Taylor rule, the Home central bank also uses sterilized intervention. To control for exchange rate variation, the central bank engages in sterilized foreign exchange intervention policy. That is, in response to the nominal exchange rate levels (E_t), the central bank sells or buys dollar reserves ($R_t^\$$)[4]. In order to keep the money supply constant and policy interest rate unchanged, the central bank buys/sells sterilized bonds for next period (S_{t+1}^b) to offset any reserve changes, where only domestic banks have access to sterilized bonds.[5]

Consider the reserve accumulation as follows:

$$R_t^\$ = \left(R_{t-1}^\$\right)^\eta \left(\frac{1}{E_t^{\gamma_e}}\right)^{1-\eta}, \eta \in (0,1) \tag{14}$$

where E_t is the nominal exchange rate, η the sensitivity of reserve levels to previous levels, i.e. insensitivity to the nominal exchange rate, and γ_e the response in reserve levels to nominal exchange rate.

[4] At the time of intervention policy, policymakers observes the nominal exchange rate and buy/sell dollars in the FX market, since the real exchange rate is not yet observed. This is similar to the Taylor rule where policymakers can adjust nominal interest rates but not real rates.

[5] There is a lag in the indexation to avoid interdependency between variables. In economic terms, at a given time central bank chooses next periods sterilized bond levels based on today's reserve levels, similar to the indexation of the nominal interest rate.

Structure of equation 14 is consistent with the findings in Figure C.1 as an increase in the exchange rate (E_t) implies EM currency depreciation (i.e. EM inflation) and thus dollar reserves ($R_t^{\$}$) fall proportionally.

Define the sterilization equation, in real terms, as follows:

$$\mathcal{Q}_t(R_t^{\$} - R_t^* R_{t-1}^{\$}) = S_{t+1}^b - R_{t-1} S_t^b \tag{15}$$

This equation implies a change in the stock of public debt held by private sector (i.e. Home banks) in response to a reserve change.[6]

3.5 Banks

Home country financial markets are incomplete, meaning that bankers can only obtain funding via non-contingent deposits. An agency friction in financial markets potentially limits bankers' ability to borrow. Each period, Home banks receive deposits (D_t, in units of Home good) from domestic households and from Foreign investors (D_t^*, in units of Foreign good) to finance purchases of claims on the capital good, denoted S_t and hold central bank issued sterilized bonds (S_t^b), where Home banks alone can hold such bonds to ensure sterilization.

The banking side described below allows for the endogenous UIP deviation implemented by Akinci and Queraltó (2018) with a novel component of the sterilized bonds.

The banks' Budget Sheet (BS) identity is:

$$q_t S_t + S_t^b = D_t + \mathcal{Q}_t D_t^* + N_t \tag{16}$$

where N_t denotes the bank's net worth.

The budget constraint (BC) in real domestic currency is:

$$q_t S_t + S_t^b + R_t D_{t-1} + R_t^* \mathcal{Q}_t D_{t-1}^* \leq R_{Kt} q_{t-1} S_{t-1} + R_t S_{t-1}^b + D_t + \mathcal{Q}_t D_t^* \tag{17}$$

where the left-hand side is banks' use of funds: lending to non-financial firms, lending to public sector, and domestic and foreign deposit repayments. The right-hand side is the banks' source of funds, including return received on past loans and incoming deposits. R_{Kt} denotes the return on capital assets.

There is a random turnover between bankers and workers: bankers alive at period t survive into $t+1$ with probability $\sigma_b > 0$ and workers become bankers with probability $(1 - \sigma_b)$. New bankers receive an endowment ξ_b of the value of the capital stock.

Combining the BS with the BC, the bank's evolution of net worth (conditional upon surviving

[6] The level of government debt held in bank's balance sheet can signal to the stability of the EM banking system especially when exchange rates are volatile.

into $t+1$) is:

$$N_t = (R_{Kt} - R_t)q_{t-1}S_{t-1} + \left(R_t - R_t^* \frac{\mathcal{Q}_t}{\mathcal{Q}_{t-1}}\right)\mathcal{Q}_{t-1}D_{t-1}^* + R_t N_{t-1} \tag{18}$$

Banker's objective is:

$$V_t = \max_{S_t, D_t^*}(1-\sigma_b)\mathbb{E}_t(\Lambda_{t,t+1}N_{t+1}) + \sigma_b\mathbb{E}_t(\Lambda_{t,t+1}V_{t+1}) \tag{19}$$

subject to 18 and

$$(1-\sigma_b)\mathbb{E}_t(\Lambda_{t,t+1}N_{t+1}) + \sigma_b\mathbb{E}_t(\Lambda_{t,t+1}V_{t+1}) \geq \Theta(x_t)(q_t S_t + S_t^b) \tag{20}$$

This is the banks' Incentive Constraint (IC) to be willing to lend funds to capital producers and to the central bank instead of defaulting on deposits. Assume $\Theta(x_t)$ to be quadratic to induce interior solution for banks' foreign debt portfolio choice, x_t:

$$\Theta(x_t) = \theta_r\left(1 + \frac{\gamma}{2}x_t^2\right) \tag{21}$$

where $x_t \equiv \frac{\mathcal{Q}_t D_t^*}{q_t S_t + S_t^b}$ and θ_r the exogenous default risk probability.[7] Assume that the IC binds. Appendix A contains the derivation of the solution for the bankers' problem. The first order condition is

$$\mu_t^* = y_t\mu_t\left(\frac{\Theta(x_t)}{\Theta'(x_t)} - x_t\right)^{-1} \tag{22}$$

where the coefficient μ_t and μ_t^* are defined as[8]:

$$\mu_t = \mathbb{E}_t\left[\Lambda_{t,t+1}\Omega_{t+1}(R_{Kt+1} - R_{t+1})\right] \tag{23}$$

$$\mu_t^* = \mathbb{E}_t\left[\Lambda_{t,t+1}\Omega_{t+1}(R_{t+1} - R_{t+1}^*\frac{\mathcal{Q}_{t+1}}{\mathcal{Q}_t})\right] \tag{24}$$

with

$$\nu_t = \mathbb{E}_t\left[\Lambda_{t,t+1}\Omega_{t+1}R_{t+1}\right] \tag{25}$$

$$\Omega_t = 1 - \sigma_b + \sigma_b((y_t\mu_t + x_t\mu_t^*)\phi_t + \nu_t) \tag{26}$$

where the leverage ratio is $\phi_t \equiv \frac{q_t S_t + S_t^b}{N_t}$ and the asset choice in capital $y_t \equiv \frac{q_t S_t}{q_t S_t + S_t^b}$. Notice that

[7] γ captures the idea that due to imperfect institutions of the EM it is harder for foreign creditors to recover assets from a default compared to domestic depositors.

[8] Notice μ is the credit spread and μ^* the UIP spread. Also, μ^* is a function of μ.

$\Lambda_{t,t+1}\Omega_{t+1}$ is an augmented discount factor that accounts for the marginal value of funds of the bank.

With this construction it is clear that the level of sterilized bonds S_t^b directly affects the bank's asset choice in capital y_t. High levels of sterilized bonds limits bank's portfolio choice. Further S_t^b also adjusts μ_t^*, the UIP deviation and μ_t, the credit spread through the augmented discount factor.

3.6 Foreign Economy

The foreign economy is defined identical to the Home economy except that the financial markets are complete and the central bank only uses a Taylor rule to control for domestic inflation as follows:

$$R^{n*}{}_{t+1} = \beta^{*-1}\pi_t^{*\gamma_\pi} \tag{27}$$

As described above, Foreign households deposit D_t^* to home banks, Thus define the Foreign households problem as follows: The representative household solves:

$$\max_{\{C^*_{t+j},D^*_{t+j},W^*_{t+j},L^*_{t+j},\}_{j=0}^{\infty}} \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \beta_j^* \frac{C^{*1-\sigma}_t}{1-\sigma} - \chi_0 \frac{L^{*1+\chi}_t}{1+\chi} \right\} \tag{28}$$

subject to

$$P_t^* C_t^* + P_t^* D_t^* + B_t^* \leq W_t^* L_t^* + P_t^* R_t^* D_{t-1}^* + R^{*n}_t B_{t-1}^* \tag{29}$$

where R_t^* is the real return received from deposits in Home country (in real dollars). Aside from the absence of financial frictions, the remainder of the model equations for Foreign country follows similarly to Home economy.

3.7 Market Clearing, Balance of Payments

The market clearing conditions for the final goods Y, and Y^* are as follows:

$$Y = (C_H + I_H) + \frac{1-n}{n}(C_H^* + I_H^*) + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 I_t \tag{30}$$

$$Y^* = (C_F^* + I_F^*) + \frac{n}{1-n}(C_F + I_F) + \frac{\psi_I}{2}\left(\frac{I_t^*}{I_{t-1}^*} - 1\right)^2 I_t^* \tag{31}$$

The aggregate capital stock evolves according to

$$K_{t+1} = (1-\delta)K_t + I_t \tag{32}$$

Further, market clearing for Home physical capital, held by Home banks, implies

$$S_t = (1-\delta)K_t + I_t \tag{33}$$

Since both foreign deposits (D^*) and dollar reserves ($R^{\$}$) flow between the 2 countries, the balance of payment equation, in real terms, is aggregated from the budget constraint of agents in Home country:

$$\mathcal{Q}_t(D_t^* - R_t^* D_{t-1}^* - R_t^{\$} + R_t^* R_{t-1}^{\$}) = C_t + I_t + p_H \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 I_t - p_H Y_t \tag{34}$$

Notice that without sterilization the BOP equation above is the only way dollar reserve changes affect the real exchange rate.

3.8 Discussion of Assumptions

There are a few key assumptions made in the model. Unlike the Foreign country where there are complete financial markets, Home country households cannot own capital directly, nor can they engage in international financial markets directly. Rather, the financial intermediaries, Home banks, borrow from Home households and Foreign investors (in foreign currency) to directly fund capital acquisition and sterilized bonds.

Thus there is market segmentation implying the underlying reason for the failure of UIP and a positive currency risk premium when the EM is more risky than the U.S.. Additionally, financial contracts are less enforceable across borders than within, captured by $\gamma > 0$, contributing to the failure of UIP. Since the standard UIP condition fails, the effectiveness of intervention with a currency risk premium can be analyzed.

In order to achieve sterilized intervention, the central bank buys/sells sterilized bonds to Home banks, where the quantity of such bonds is solely determined by the central bank and the Home banks have to acquire all such bonds. This can be considered a requirement imposed by the government, such as a reserve requirement. Furthermore, sterilized bonds cannot be held by Foreigners by definition of a sterilized intervention.

For simplicity, dollar reserve levels are determined only by the level of sterilized bonds. Additional sources of incoming dollar reserves are not considered in the model.

4 Calibration and Results

4.1 Calibration

Table C.2 describes the values and parameter descriptions. The Foreign economy is calibrated to the United States and Home economy to an EM, either one specific country, such as Mexico, or a bloc of EMs. The calibration is asymmetric: U.S. is much larger than the EM and EM households are relatively impatient ($\beta < \beta^*$), thus introducing the incentives for U.S. investors to invest in the EM. The size of the home country relative to the U.S. (n) is 1/3.

Following Akinci and Queraltó (2018), the intertemporal elasticity of substitution (σ), capital share (α) and capital depreciation rate (δ) are calibrated to the conventional values of 1, 0.33, and 0.025, respectively. Similarly, the steady-state price markup, θ_p is calibrated to 20 percent, a conventional value. The remaining parameters on households and firms are based on estimates from Justiniano et al. (2010): the inverse Frisch elasticity of labor supply(χ), price rigidity (ξ_p), and the investment adjustment cost (ψ_I).

The Taylor rule in the U.S. features inertia with coefficient (γ_r) 0.82, from Justiniano et al. (2010). The standard deviation and persistence of U.S. monetary shocks are calibrated from Akinci and Queraltó (2018) estimates to fit an AR(1) process of ε_t^r, with $\rho_r = 0.25$ and $\sigma_r = 0.20/100$.

International trade parameters ω and ω^* are restricted to $(1 - \omega^*) = \omega n$ frequent in literature (e.g. Blanchard et al. (2016)). Following Akinci and Queraltó (2018), set $1 - \omega = 0.20$ meaning 20% of home economy's output is exported in steady state.

Finally, financial markets strictly follow Akinci and Queraltó (2018)'s calibration and estimate as follows: the survival rate (σ_b) to 0.95, implying a 6 year expected horizon. Remaining parameters are calibrated as $\theta_r = 0.41$, $\xi_b = 0.07$, and $\gamma = 2.58$.

Intervention specific parameter γ^e, nominal exchange rate coefficient in reserve accumulation is key for the effectiveness of the policy. With a lack of information on intervention data, this parameter is set at 2.09 to match the response to inflation in Taylor rule, γ^π.

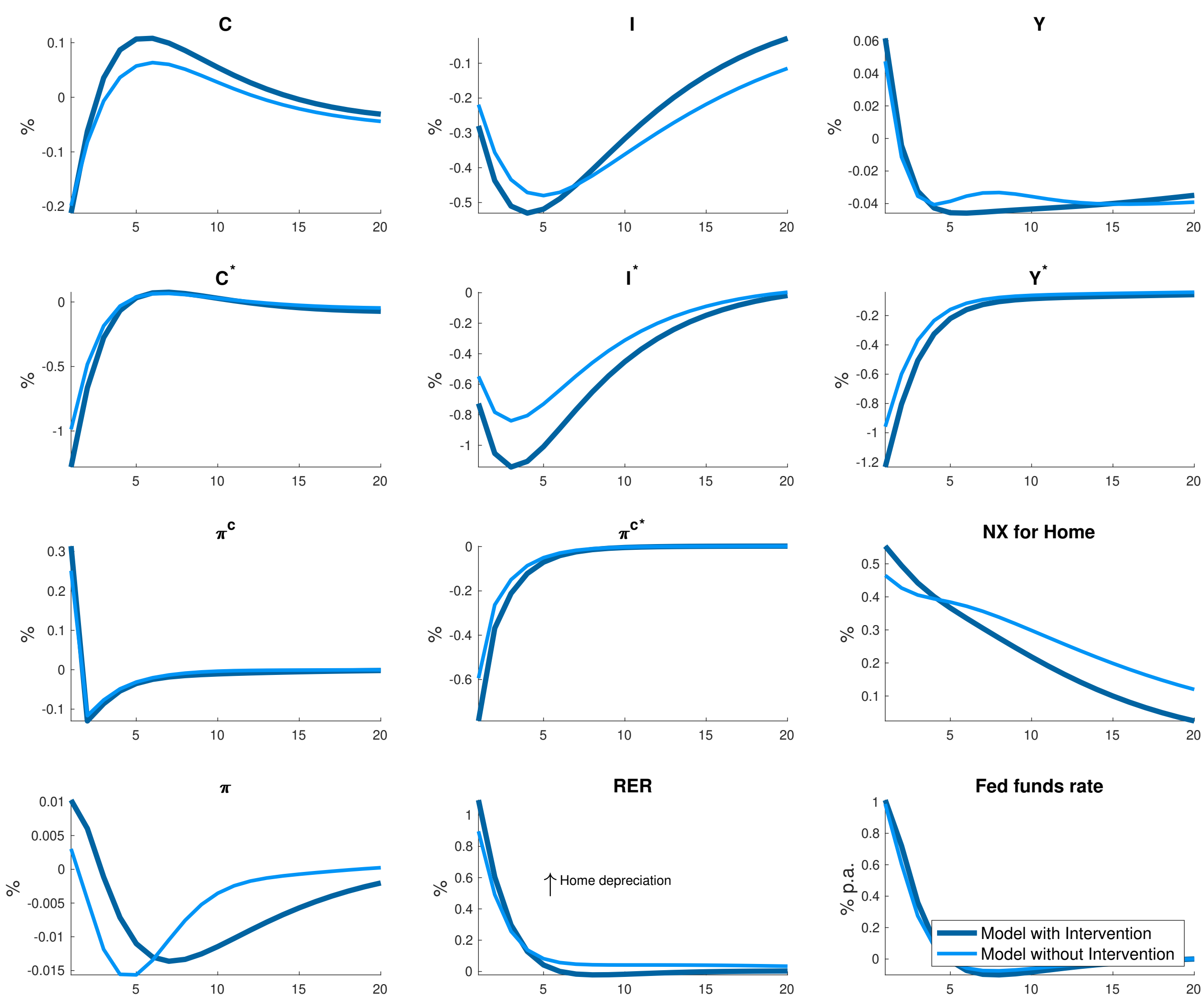
4.2 IRF Plots and Analysis

Simulating the model described in the previous section, this section analyzes impulse response functions for a positive 1 percentage point in the Fed Funds Rate increase. This shock depicts the U.S. monetary tightening policy with each period representing a quarter.

The general mechanism of the model is as follows: due to a positive monetary shock, the U.S. nominal interest rate goes up. This alters the U.S. households consumption-saving decision to save more and consume less by -1% upon impact. Due to international consumption risk sharing, Home consumption also goes down by -0.2%. By raising the nominal interest rate, the U.S. money supply shrinks and due to a lowered demand for consumer goods the U.S. economy incurs a deflation, leading to currency appreciation. Similarly, there is a lower demand for investment and a fall in producer prices. This leads to an increase in terms of trade and thus the real exchange rate by approximately 1%, i.e. a currency depreciation in the Home economy. Combining the effects on consumption and the exchange rate, Home economy incurs inflation smaller in absolute terms than the U.S.. With the currency depreciation of the economy, Home exports are much cheaper than before and U.S. imports are more expensive, thus leading to an increase in the trade balance of the Home economy by 0.5%. The increases in the trade surplus balances out the decreases in consumption and investment totalling to a small increase in Home output. It is important to note the asymmetry of the model: the U.S. is much larger than the Home economy. Due to the asymmetry of the model, the changes in trade are more sizable for the Home economy. The U.S. output sees a 1% downfall mostly due to consumption and investment rather than the trade patterns.

Figure 1 compares the macro variables of the model with and without an intervention policy.

Figure 1. U.S. Monetary Tightening with Imperfect Financial Markets - Macro Variables



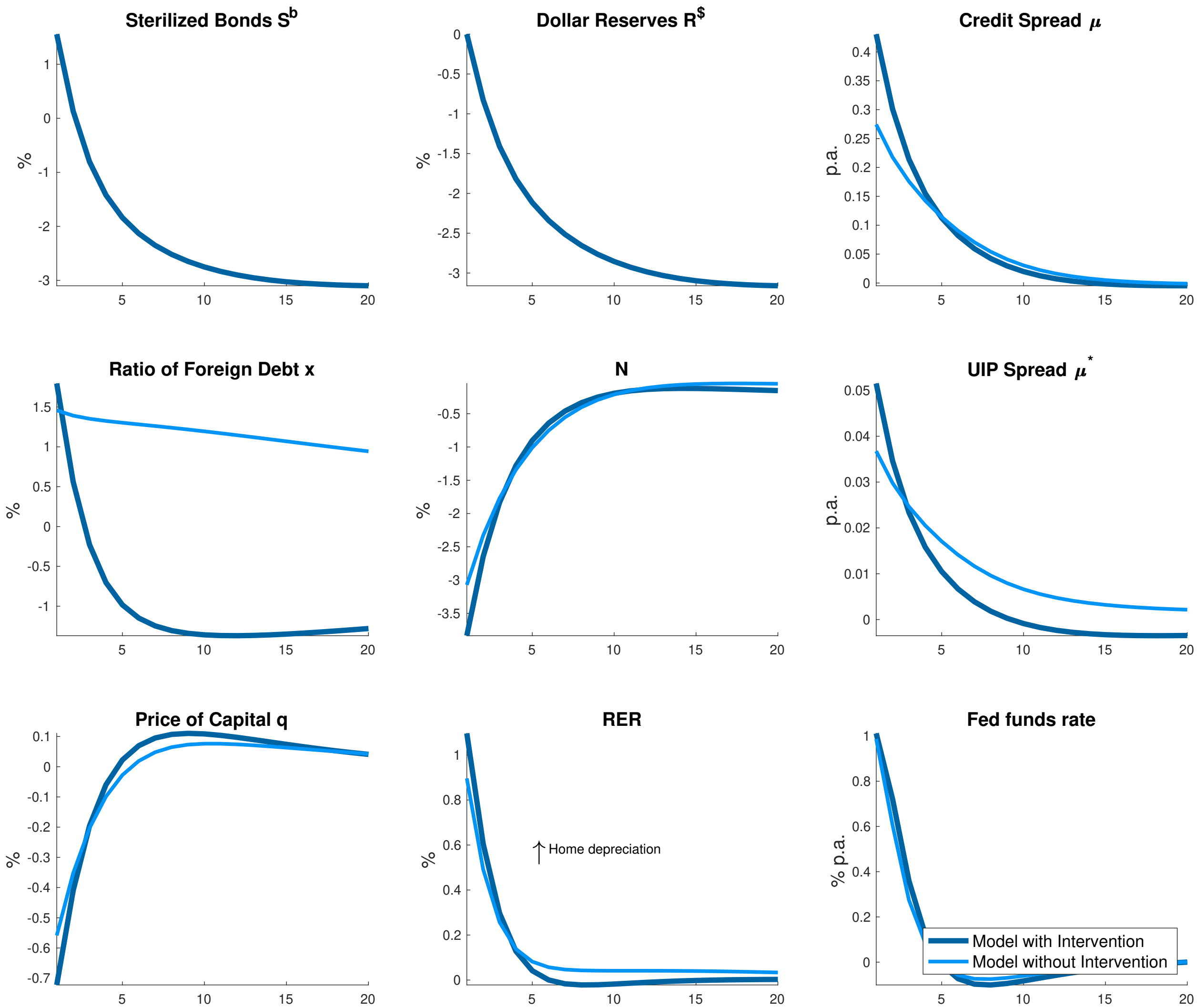
Note: The dark blue line shows the effects, in the units of deviations from steady state, of a 1 percentage point increase in the U.S. policy rate in the model with sterilized foreign exchange intervention policy. The light blue line shows the effects of the same model without intervention.

Comparing the model with and without intervention, notice that the real exchange rate initially remains unchanged by intervention while reaching a slightly lower level in the long run. This is due to the price stickiness of the model as well as the delay in sterilization. CPI-inflation remains unchanged by intervention, perhaps echoing results from Backus and Kehoe (1988). While intervention does not change CPI-inflation (π^c) it does change producer price inflation (π). In the first 6 quarters intervention results in a less volatile inflation, afterwards the model without intervention converges faster to the steady state. This can be viewed as a transfer of volatility across time. The model suggests that upon impact firms benefit more than consumers when there is intervention. This is supported by the faster convergence of investment with intervention. Thus, an intervention policy could be effective for controlling domestic producer prices, at the level of price stickiness. Since the Taylor rule uses π this result implies that sterilized intervention is an effective short run supplementary tool to the Taylor rule, especially at the presence of exchange rate hikes. As predicted, there is a much lower net export since there is a lower exchange rate achieved and slightly higher consumption, thus shrinking the demand for Home exports and the trade balance. Combining these results, output is slightly higher after 20 periods with intervention.

Even though most implications are due to spillover effects from the U.S., there appears to be a surprising spill-back effect on U.S. CPI-inflation with intervention. Under intervention policy the U.S. incurs a larger CPI-deflation. The mechanism can be explained as follows: when the Home central bank sells dollar reserves to its counterpart, this reduces further the dollar supply from the market thus amplifying the mechanism described earlier. Though it is unlikely that one EM engaging in intervention can have sizable impact on the U.S., enough EMs simultaneously using intervention can have some spill-back effect for U.S. prices.

Figure 2 makes the same comparison for the banking side of the model which is of particular interest given the sterilization mechanism.

Figure 2. U.S. Monetary Tightening with Imperfect Financial Markets - Banking Side



Note: The dark blue line shows the effects, in the units of deviations from steady state, of a 1 percentage point increase in the U.S. policy rate in the model with sterilized foreign exchange intervention policy. The light blue line shows the effects of the same model without intervention.

With a fall in investment the price of capital, i.e. Tobin's q falls. Both spreads μ and μ^* comove with the exchange rate, as suggested by Akinci and Queraltó (2018), see equations 22 and 23. Due to an increased domestic credit spread the effective cost of investment rises. The ratio of foreign debt (x) rises upon impact due to an increased exchange rate and similarly banks net worth (N) decreases due to dollar-denominated deposits.

With the intervention policy, the Home central bank responds to the currency depreciation by engaging in sterilized intervention thus selling dollar reserves and buying back an equivalent amount of sterilized bonds from the Home banks. From the balance of payments equation 34 a fall in dollar reserves also leads to a fall in dollar deposits coming in converging to a new dollar dependency steady state. The credit and UIP spreads are lowered faster by the sterilization since the central bank sells reserves and buys back bonds thus freeing up Home banks' resources and changing private to public debt ratio by giving more loans to capital producers. Freeing up banks' resources also leads to a slightly faster recovery of Tobin's q. Further the UIP Spread (μ^*) achieves a much lower level after 20 periods suggesting a long term effect of narrowing the spread with intervention. It is interesting however that upon impact the spreads are more volatile with intervention. This is because banks were forced to invest a portion of their deposits in bonds thus limiting the banks balance sheet and thus their ability to freely lend to non-financial firms on top of the existing bank frictions.

After 20 periods (i.e., 5 years), dollar reserves and sterilized bonds do not go back to the steady state levels. This echoes the concerns that foreign investors have had about repeated intervention and the continued shrinking of dollar reserves. If such shocks are persistent enough there could be a constant fall in reserves, which raises concerns about the financial credibility of the government and the domestic currency. On the other hand, a slightly lower real exchange rate and UIP spread is achieved suggesting that intervention does have long term effects on the financial sector as well as international variables. The spillovers from a lower long run exchange rate and UIP spread reflect also a lower steady state for foreign debt ratio (x).

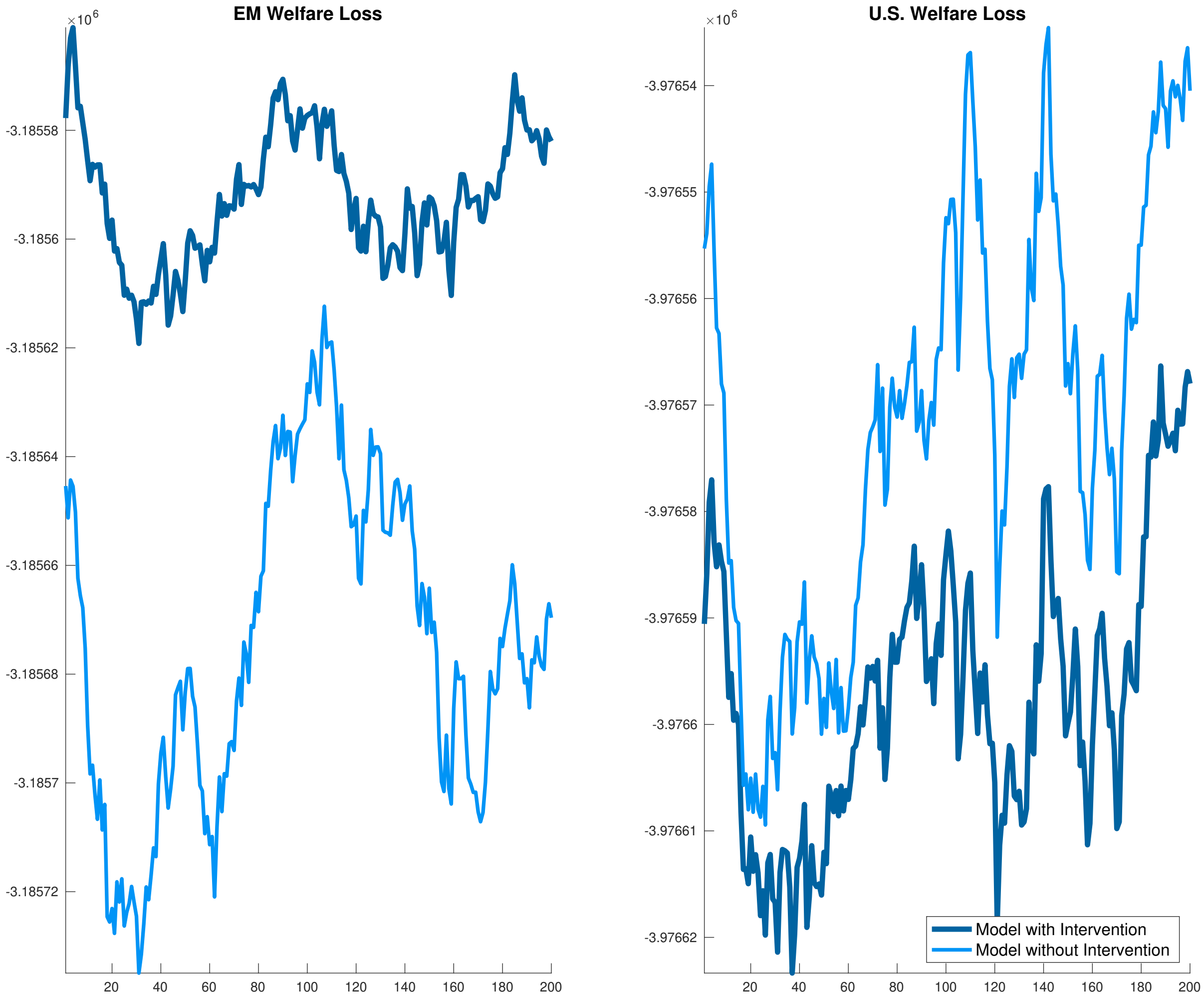
5 Should Central Banks Use Sterilized FX Intervention?

In this section I compare the model with and without sterilized intervention to compare welfare losses expressed by the consumption-equivalent welfare. In particular, the households welfare $\mathcal{W}_t$ is given by:

$$\mathcal{W}_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi_0 \frac{L_t^{1+\chi}}{1+\chi} + \beta \mathcal{W}_{t+1} \tag{35}$$

Computing the welfare losses implied by the model using equation 35, Figure 3 compares EM and U.S. welfare losses with and without intervention.

Figure 3. EM v. U.S. Welfare Losses from Intervention



Note: Left figure shows EM welfare losses under the model with and without intervention. Whereas the right figure shows similarly for the U.S.

These results show that sterilized intervention reduces EM welfare losses while increasing U.S. welfare losses. This change implies a welfare shift from the U.S. to the EM caused by intervention. This finding rationalizes EM policymakers decision making and can have policy implications for the U.S.

From a volatility perspective for the EM, sterilized intervention reduces both PPI and CPI inflation volatility as well as output gap and real exchange rate volatility. Given the importance of exchange rate stability to the dollar-dominated EM financial market this result is consistent with the welfare findings of Figure 3.

Moreover, since sterilization reduces welfare losses in this framework, it breaks the divine coincidence in a non-traditional channel. As noted by Akinci and Queraltó (2018), the financial friction setup implemented in the model does not break the divine coincidence since they find NER stabilization is not welfare maximizing, consistent with Galí and Monacelli (2005). Yet sterilized intervention policy given an exclusively domestic inflation regime reduces model-implied welfare losses, thus breaking the divine coincidence. This finding is consistent with that of Alla et al. (2017) though the deviation from the divine coincidence is now endogenous to the model and is linked directly to the dollar-dependent banking sector and the endogenous UIP deviation.

6 Further Expansions

Currently, the model includes a simple foreign exchange intervention rule that pins down the optimal reserve accumulation for the central bank. The Home economy is only dollar dependent in its foreign financing for capital.

Dominant Currency Pricing

Further extensions of the model are aimed to capture the exposure of the Home economy prices to the exchange rate and the value of the dollar. To reflect this, a Dominant Currency Pricing (DCP) scheme can be added to the Home economy equations following Gopinath et al. (2018), also implemented in Akinci and Queraltó (2018). Previous works have used DCP to show the spillovers from the exchange rate can have on the performance of the Home economy. This has been a very common trade pattern since the dollar has been the dominant trading currency and thus the benefits from a currency depreciation to increased demand of export goods is diminished relative to the baseline model with PCP. With additional vulnerability to the dollar, intervention policy could be more effective in controlling domestic prices.

Country Risk Premium Shock

Due to the developments involving Covid-19, a country risk premium shock rather than U.S. monetary policy shock approach for IRFs would give a more insightful analysis.

Conclusion

In this paper I developed a two-country New Keynesian model with imperfect financial markets to study the effectiveness of a sterilized foreign exchange intervention policy by an EM central bank. The model incorporates strong financial amplification due to endogenous UIP deviations and dollar-denominated debt. This model captures spillovers and some spill-back from a U.S. monetary policy. Sterilized intervention reduces model implied welfare losses for EMs while further increasing that of the U.S., thus breaking the divine coincidence and rationalizing EM policymakers decisions to implement intervention.

Under heightened dollar dependency of the banking sector, a sterilized intervention is effective in the long run to control exchange rate hikes and effective in the short run for controlling producer prices. The intervention leads the model to converge to a new steady state with a significantly lower dollar debt ratio, a lower real exchange rate, UIP spread and dollar reserve levels. It is an unexpected result that intervention can lead to a spill-back effect on U.S. CPI-inflation further deflating the dollar. Though this effect is rather small, if enough EMs simultaneously implement such policies during U.S. monetary tightening periods, the model implies that the U.S. could have further deflation.

It can be speculated that the size of EM sterilized foreign exchange intervention should be included in the decision-making of the Fed on monetary policy. For EM central banks, such interventions can be theoretically effective for the economic and financial stability and reducing welfare losses. Yet repeated intervention could lead to a depletion of foreign reserves of the EM central bank.

Looking ahead, it would be beneficial to adopt a dominant currency paradigm where EM exports are dollar-denominated. Under such circumstances the EM would be more exposed to exchange rate fluctuations and could amplify the effectiveness of an intervention policy for controlling domestic consumption prices as well.

References

Akinci, Ozge and Albert Queraltó, "Exchange rate dynamics and monetary spillovers with imperfect financial markets," Staff Reports 849, Federal Reserve Bank of New York June 2018. 1, 2, 3, 3.2, 3.5, 4.1, 4.2, 5, 6

Alla, Zineddine, Raphael A Espinoza, and Atish R. Ghosh, "FX Intervention in the New Keynesian Model," IMF Working Papers 2017/207, International Monetary Fund September 2017. 2, 5

Backus, David K. and Patrick J. Kehoe, "On the denomination of government debt: a critique of the portfolio balance approach," Staff Report 116, Federal Reserve Bank of Minneapolis 1988. 2, 4.2

Blanchard, Olivier, Christopher Erceg, and Jesper Linde, "Jump-Starting the Euro Area Recovery: Would a Rise in Core Fiscal Spending Help the Periphery?," in "NBER Macroeconomics Annual 2016, Volume 31," National Bureau of Economic Research, Inc, 2016, pp. 103–182. 4.1

Chang, Roberto, "Foreign Exchange Intervention Redux," NBER Working Papers 24463, National Bureau of Economic Research, Inc March 2018. 2

di Giovanni, Julian, Sebnem Kalemli-Ozcan, Mehmet Fatih Ulu, and Yusuf Soner Baskaya, "International Spillovers and Local Credit Cycles," Working Paper 23149, National Bureau of Economic Research February 2017. 1

Erceg, Christopher J, Luca Guerrieri, and Christopher Gust, "SIGMA: A New Open Economy Model for Policy Analysis," *International Journal of Central Banking*, 2006. 1, 2, 3

Galí, Jordi and Tommaso Monacelli, "Monetary Policy and Exchange Rate Volatility in a Small Open Economy," *Review of Economic Studies*, 2005, *72* (3), 707–734. 1, 2, 5

Gertler, Mark and Nobuhiro Kiyotaki, "Financial Intermediation and Credit Policy in Business Cycle Analysis," in Benjamin M. Friedman and Michael Woodford, eds., *Handbook of Monetary Economics*, Vol. 3, Elsevier, 2010, chapter 11, pp. 547–599. 2

Gopinath, Gita, Emine Boz, Camila Casas, Federico Diez, Pierre-Olivier Gourinchas, and Mikkel Plagborg-Møller, "Dominant Currency Paradigm," *NBER Working Paper*, 2018, (22943). 1, 2, 6

Justiniano, Alejandro, Giorgio E Primiceri, and Andrea Tambalotti, "Investment shocks and business cycles," *Journal of Monetary Economics*, 2010, *57* (2), 132–145. 4.1

Appendix

A Solving Banker's Problem

To solve the bankers' problem assume the value function is linear in New Worth (N_t) such that $V_t = \alpha_t N_t$. Define variables μ_t, ν_t and μ_t^*:

$$\mu_t = \mathbb{E}_t \left[\Lambda_{t,t+1}(1-\sigma_b+\sigma_b\alpha_{t+1})(R_{Kt+1}-R_{t+1})\right] \tag{A.1}$$

$$\nu_t = \mathbb{E}_t \left(\Lambda_{t,t+1}(1-\sigma_b+\sigma_b\alpha_{t+1})\right) R_{t+1} \tag{A.2}$$

$$\mu_t^* = \mathbb{E}_t \left[\Lambda_{t,t+1}(1-\sigma_b+\sigma_b\alpha_{t+1})(R_{t+1}-R_{t+1}^*\frac{\mathcal{Q}_{t+1}}{\mathcal{Q}_t})\right] \tag{A.3}$$

Redefining the bankers' objective as before:

$$\alpha_t = \max_{\phi_t,x_t}(y_t\mu_t + x_t\mu_t^*)\phi_t + \nu_t \tag{A.4}$$

subject to

$$\alpha_t = \max_{\phi_t,x_t}(y_t\mu_t + x_t\mu_t^*)\phi_t + \nu_t \tag{A.5}$$

, where y_t is defined as $y_t \equiv \frac{q_tS_t}{q_tS_t+S_t^b}$ and the bank's leverage ratio $\phi_t \equiv \frac{q_tS_t+S_t^b}{N_t}$. Solving for the 2 Lagrangian F.O.C.s:

$$y_t\mu_t + x_t\mu_t^* = \frac{\lambda_t}{1+\lambda_t}\Theta(x_t) \tag{A.6}$$

$$\mu_t^* = \frac{\lambda_t}{1+\lambda_t}\Theta'(x_t) \tag{A.7}$$

Combining the above 2 equations we get:

$$\mu_t^* = y_t\mu_t\left(\frac{\Theta(x_t)}{\Theta'(x_t)} - x_t\right)^{-1} \tag{A.8}$$

Assuming the IC binds:

$$\phi_t = \frac{\nu_t}{\Theta(x_t) - (y_t\mu_t + x_t\mu_t^*)} \tag{A.9}$$

Therefore we can solve for the undefined coefficient using

$$\alpha_t = (y_t\mu_t + x_t\mu_t^*)\phi_t + \nu_t \tag{A.10}$$

Define Ω_t as:

$$\begin{aligned}\Omega_t &= 1-\sigma_b+\sigma_b\alpha_t \\ &= 1-\sigma_b+\sigma_b((y_t\mu_t+x_t\mu_t^*)\phi_t+\nu_t)\end{aligned} \tag{A.11}$$

Banks' net worth evolution becomes:

$$N_t = \sigma_b\left[R_{Kt}-R_t)q_{t-1}S_{t-1}+\left(R_t-R_t^*\frac{\mathcal{Q}_t}{\mathcal{Q}_{t-1}}\right)\mathcal{Q}_{t-1}D_{t-1}^*+R_tN_{t-1}\right]+(1-\sigma_b)\xi_b(q_{t-1}S_{t-1}+S_t^b) \tag{A.12}$$

B List of Model Equations

Home Country:

$$C_t^{-\sigma} = \beta\mathbb{E}_t\left[\frac{C_{t+1}^{-\sigma}R_{t+1}^n}{\pi_{t+1}^c}\right] \tag{B.1}$$

$$\Lambda_{t,t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \tag{B.2}$$

$$C_H = \omega\left(p_H\right)^{-\theta}C \tag{B.3}$$

$$C_F = (1-\omega)\left(\mathcal{T}p_H\right)^{-\theta}C \tag{B.4}$$

$$C^\sigma L^\chi = w \tag{B.5}$$

$$p_H = \left[\omega+(1-\omega)\left(\mathcal{T}\right)^{1-\theta}\right]^{\frac{-1}{1-\theta}} \tag{B.6}$$

$$Y = \overline{K}^\alpha L^{1-\alpha} \tag{B.7}$$

$$mc = \left(\frac{w}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_K}{\alpha}\right)^\alpha \tag{B.8}$$

$$w = \frac{(1-\alpha)}{\alpha}\frac{\overline{K}}{L}r_K \tag{B.9}$$

$$x_{1t} = C_t^{-\sigma}mc_tY_t+\beta\xi_p\pi_t^{-\frac{1+\theta_p}{\theta_p}}\mathbb{E}_t\left\{x_{1t+1}\pi_{t+1}^{\frac{1+\theta_p}{\theta_p}}\right\} \tag{B.10}$$

$$x_{2t} = C_t^{-\sigma}pH_tY_t+\beta\xi_p\pi_t^{1-\frac{1+\theta_p}{\theta_p}}\mathbb{E}_t\left\{x_{2t+1}\pi_{t+1}^{\frac{1+\theta_p}{\theta_p}-1}\right\} \tag{B.11}$$

$$\pi_t^o = (1+\theta_p)\frac{x_{1t}}{x_{2t}}\pi_t \tag{B.12}$$

$$\pi_t = \left((1-\xi_p)(\pi_t^o)^{-\frac{1}{\theta_p}}+\xi_p(\pi_{t-1})^{-\frac{1}{\theta_p}}\right)^{-\theta_p} \tag{B.13}$$

$$I_H = \omega\left(p_H\right)^{-\theta}I \tag{B.14}$$

$$I_F = (1-\omega)\left(\mathcal{T}p_H\right)^{-\theta}I \tag{B.15}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{B.16}$$

$$q_t = 1 + pH_t\left[\psi_I\left(\frac{I_t}{I_{t-1}}-1\right)\frac{I_t}{I_{t-1}} + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right] \tag{B.17}$$
$$-\mathbb{E}_t\Lambda_{t,t+1}pH_{t+1}\psi_I\left(\frac{I_{t+1}}{I_t}-1\right)\left(\frac{I_{t+1}}{I_t}\right)^2$$

$$R_t^{\$} = \left(R_{t-1}^{\$}\right)^{\eta}\left(\frac{1}{E_t^{\gamma_e}}\right)^{1-\eta} \tag{B.18}$$

$$\mathcal{Q}_t(R_t^{\$} - R_t^* R_{t-1}^{\$}) = S_{t+1}^b - R_{t-1}S_t^b \tag{B.19}$$

$$R_{Kt} = \frac{r_{Kt} + (1-\delta)q_t}{q_{t-1}} \tag{B.20}$$

$$N_t = \sigma_b\left[R_{Kt} - R_t)q_{t-1}S_{t-1} + \left(R_t - R_t^*\frac{\mathcal{Q}_t}{\mathcal{Q}_{t-1}}\right)\mathcal{Q}_{t-1}D_{t-1}^* + R_tN_{t-1}\right] \tag{B.21}$$
$$+(1-\sigma_b)\xi_b(q_{t-1}S_{t-1} + S_t^b)$$

$$q_tS_t + S_t^b = \phi_tN_t \tag{B.22}$$

$$\mathcal{Q}_tD_t^* = x_t\phi_tN_t \tag{B.23}$$

$$q_tS_t = y_t\phi_tN_t \tag{B.24}$$

$$x_t = \left(\frac{\mu_t^*}{y_t\mu_t}\right)^{-1}\left(-1 + \sqrt{1 + \frac{2}{\gamma}\left(\frac{\mu_t^*}{y_t\mu_t}\right)^2}\right) \tag{B.25}$$

$$\mu_t = \mathbb{E}_t\left[\Lambda_{t,t+1}\Omega_{t+1}(R_{Kt+1} - R_{t+1})\right] \tag{B.26}$$

$$\mu_t^* = \mathbb{E}_t\left[\Lambda_{t,t+1}\Omega_{t+1}(R_{t+1} - R_{t+1}^*\frac{\mathcal{Q}_{t+1}}{\mathcal{Q}_t})\right] \tag{B.27}$$

$$\nu_t = \mathbb{E}_t\left[\Lambda_{t,t+1}\Omega_{t+1}R_{t+1}\right] \tag{B.28}$$

$$\Omega_t = 1 - \sigma_b + \sigma_b((y_t\mu_t + x_t\mu_t^*)\phi_t + \nu_t) \tag{B.29}$$

$$\phi_t = \frac{\nu_t}{\theta_r\left(1 + \frac{\gamma}{2}x_t^2\right) - (y_t\mu_t + x_t\mu_t^*)} \tag{B.30}$$

$$S_t = (1-\delta)K_t + I_t \tag{B.31}$$

$$Y = C_H + I_H + \frac{1-n}{n}(C_H^* + I_H^*) + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2 I_t \tag{B.32}$$

$$R_{t+1}^n = \beta^{-1}\pi_t^{\gamma_\pi} \tag{B.33}$$

$$\pi_t = \pi_t^c\frac{p_{H,t}}{p_{H,t-1}} \tag{B.34}$$

$$R_t = \frac{R_t^n}{\pi_{t+1}^c} \tag{B.35}$$

Equations (19) and (20) reflect the reserve accumulation and sterilized intervention respectively. Dollar reserves also appear in the balance of payments equation (59).

Foreign Country:

$$
\begin{aligned}
C_t^{*-\sigma} &= \beta \mathbb{E}_t \left[\frac{C_{t+1}^{*}{}^{-\sigma} R^{*n}{}_{t+1}}{\pi^{*c}{}_{t+1}} \right] && \text{(B.36)}\\
\Lambda_{t,t+1}^{*} &= \beta \left(\frac{C_{t+1}^{*}}{C_t^{*}} \right)^{-\sigma} && \text{(B.37)}\\
C_H^{*} &= \omega^{*} \left(\frac{p_F}{\mathcal{T}} \right)^{-\theta} C^{*} && \text{(B.38)}\\
C_F^{*} &= (1-\omega^{*}) (p_F)^{-\theta} C^{*} && \text{(B.39)}\\
C^{*\sigma} L^{*\chi} &= w^{*} && \text{(B.40)}\\
p_F &= \left[\omega^{*} \left(\frac{1}{\mathcal{T}} \right)^{1-\theta} + (1-\omega^{*}) \right]^{\frac{-1}{1-\theta}} && \text{(B.41)}\\
Y^{*} &= \overline{K^{*}}^{\alpha} L^{*1-\alpha} && \text{(B.42)}\\
mc^{*} &= \left(\frac{w^{*}}{1-\alpha} \right)^{1-\alpha} \left(\frac{r_K^{*}}{\alpha} \right)^{\alpha} && \text{(B.43)}\\
w^{*} &= \frac{(1-\alpha)}{\alpha} \frac{\overline{K}^{*}}{L^{*}} r_K^{*} && \text{(B.44)}\\
x_{1t}^{*} &= C_t^{*-\sigma} mc_t^{*} Y_t^{*} + \beta \xi_p \pi_t^{*}{}^{-\frac{1+\theta_p}{\theta_p}} \mathbb{E}_t \left\{ x_{1t+1}^{*} \pi_{t+1}^{*}{}^{\frac{1+\theta_p}{\theta_p}} \right\} && \text{(B.45)}\\
x_{2t}^{*} &= C_t^{*-\sigma} pF_t Y_t^{*} + \beta \xi_p \pi_t^{*}{}^{1-\frac{1+\theta_p}{\theta_p}} \mathbb{E}_t \left\{ x_{2t+1}^{*} \pi_{t+1}^{*}{}^{\frac{1+\theta_p}{\theta_p}-1} \right\} && \text{(B.46)}\\
\pi_t^{o*} &= (1+\theta_p) \frac{x_{1t}^{*}}{x_{2t}^{*}} \pi_t^{*} && \text{(B.47)}\\
\pi_t^{*} &= \left((1-\xi_p)(\pi_t^{o*})^{-\frac{1}{\theta_p}} + \xi_p (\pi_{t-1}^{*})^{-\frac{1}{\theta_p}} \right)^{-\theta_p} && \text{(B.48)}\\
I_H^{*} &= \omega^{*} \left(\frac{p_F}{\mathcal{T}} \right)^{-\theta} I^{*} && \text{(B.49)}\\
I_F^{*} &= (1-\omega^{*}) (p_F)^{-\theta} I^{*} && \text{(B.50)}\\
K_{t+1}^{*} &= (1-\delta) K_t^{*} + I_t^{*} && \text{(B.51)}\\
q_t^{*} &= 1 + pF_t \left[\psi_I \left(\frac{I_t^{*}}{I_{t-1}^{*}} - 1 \right) \frac{I_t^{*}}{I_{t-1}^{*}} + \frac{\psi_I}{2} \left(\frac{I_t^{*}}{I_{t-1}^{*}} - 1 \right)^2 \right] && \text{(B.52)}\\
&\quad - \mathbb{E}_t \Lambda_{t,t+1}^{*} pF_{t+1} \psi_I \left(\frac{I_{t+1}^{*}}{I_t^{*}} - 1 \right) \left(\frac{I_{t+1}^{*}}{I_t^{*}} \right)^2 \\
q_t^{*} &= \mathbb{E}_t \Lambda_{t,t+1}^{*} \left(r_{Kt+1}^{*} + (1-\delta) q_{t+1}^{*} \right) && \text{(B.53)}\\
Y^{*} &= (C_F^{*} + I_F^{*}) + \frac{n}{1-n} (C_F + I_F) + \frac{\psi_I}{2} \left(\frac{I_t^{*}}{I_{t-1}^{*}} - 1 \right)^2 I_t^{*} && \text{(B.54)}\\
R^{n*}{}_{t+1} &= (R_t^{n*})^{\gamma_r} \left(\beta^{-1} \pi_t^{*\gamma_\pi} \right)^{1-\gamma_r} \varepsilon_t^r && \text{(B.55)}\\
\pi^{*c}{}_t &= \pi_t^{*} \frac{p_{F,t-1}}{p_{F,t}} && \text{(B.56)}
\end{aligned}
$$

$$R_t^* = \frac{R_t^{n*}}{\pi_{t+1}^{c}{}^*} \tag{B.57}$$

Common to Two Countries:

$$\mathcal{Q} = \left[\frac{\omega^* + (1-\omega^*)\mathcal{T}^{1-\theta}}{\omega + (1-\omega)\mathcal{T}^{1-\theta}}\right]^{\frac{1}{1-\theta}} \tag{B.58}$$

$$\mathcal{Q}_t(D_t^* - R_t^* D_{t-1}^* - R_t^{\$} + R_t^* R_{t-1}^{\$}) = C_t + I_t + p_H \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 I_t - p_H Y_t \tag{B.59}$$

List of Variables(59): C, C^*, C_H, C_H^*, C_F, C_F^*, I, I^*, I_H, I_H^*, I_F, I_F^*, $\Lambda_{t,t+1}$, $\Lambda_{t,t+1}^*$, Y, Y^*, K, K^*, L, L^*, mc, mc^*, w, w^*, r_K, r_K^*, q, q^*, R_K, R^n, R^{n*}, R, $R^{\$}$, R^*, x_1, x_2, π^o, π, x_1^*, x_2^*, π^{o*}, π^*, π^c, π^{c*}, p_H, p_F, N, D^*, S, S^b, ϕ, Ω, ν, μ, μ^*, x, y, $\mathcal{Q}$, $\mathcal{T}$

where $p_H \equiv \frac{P_H}{P}$, $p_F \equiv \frac{P_F^*}{P^*}$, $mc \equiv \frac{MC}{P}$, $mc^* \equiv \frac{MC^*}{P^*}$,$w \equiv \frac{W}{P}$, $w^* \equiv \frac{W^*}{P^*}$, $r_K \equiv \frac{R_K}{P}$, $r_K^* \equiv \frac{R_K^*}{P^*}$.

C Tables

Correlation Table

Table C.1. Correlation between Central Bank Foreign Reserves and CPI Inflation

EM Country	Correlation
Albania	-0.506
Angola	0.601
Armenia	-0.096
Bangladesh	-0.749
Belarus	0.013
Bolivia	0.236
Bosnia and Herzegovina	-0.170
Brazil	-0.317
Bulgaria	-0.380
Cambodia	-0.314
Cameroon	0.426
Chile	-0.041
China	0.161
Costa Rica	-0.843
Croatia	-0.337
Czech Republic	0.023
Dominican Republic	0.393
Ecuador	0.100
Egypt	0.183
El Salvador	-0.520
Estonia	0.314
Gabon	0.079
Georgia	-0.308
Ghana	-0.531
Guatemala	-0.084
Honduras	-0.391
Hong Kong	0.407
Hungary	-0.497
India	0.015
Indonesia	-0.708
Israel	-0.360
Jordan	-0.247
Kenya	-0.241
South Korea	-0.692
Kosovo	0.427
Kuwait	-0.262
Kyrgyz Republic	0.076
Latvia	-0.016

EM Country	Correlation
Lebanon	-0.636
Lesotho	0.067
Lithuania	0.391
Malaysia	0.169
Mexico	-0.379
Moldova	-0.561
Mongolia	-0.231
Montenegro	-0.284
Morocco	-0.241
Namibia	-0.031
North Macedonia	-0.000
Nicaragua	-0.710
Oman	-0.151
Pakistan	-0.281
Palestine	0.290
Philippines	-0.399
Poland	-0.147
Romania	-0.799
Russia	-0.629
Rwanda	-0.034
Saudi Arabia	0.314
Senegal	-0.123
Serbia	0.076
Singapore	0.024
Slovakia	0.529
Slovenia	0.459
Seychelles	-0.639
South Africa	0.022
Sri Lanka	-0.210
Taiwan	0.048
Thailand	-0.336
Trinidad & Tobago	0.112
Turkey	-0.635
Ukraine	-0.066
United Arab Emirates	-0.182
Uzbekistan	-0.098
Zambia	-0.259

Notes: CPI inflation is calculated as year-to-year growth of CPI. Foreign reserve and CPI data is from Haver Analytics spanning from 2000 to 2021 in monthly frequency. For each country, only datapoints where both variables have data are used for calculating correlations.

Calibration Table

Table C.2. Parameter Descriptions and Values

Parameter	Description	Value
α	output elasticity of capital	0.33
β	Home consumer's discount rate	0.99688
β^*	Foreign consumer's discount rate	0.997503
χ	inverse labor supply elasticity	3.79
δ	capital depreciation rate	0.025
η	$ reserve inflexibility to nominal exchange rate	0.82
γ	Home bias in bank funding	2.58
γ_e	response in reserve accumulation to nominal exchange rate	2.09
γ^π	response in taylor rule to inflation	2.09
γ_r	Foreign Taylor rule inertia coefficient	0.82
n	Home country size ratio	1/3
ω	weight given to Home good in Home consumption	0.80
ω^*	weight given to Home good in Foreign consumption	0.20/3
ψ_I	investment adjustment cost	2.85
ρ_r	persistence of Foreign monetary shock	0.25
σ	inverse elasticity of substitution	1.00
σ_b	banks' survival rate	0.95
σ_r	standard deviation of Foreign monetary shock	0.20/100
θ	trade price elasticity	0.90
θ_p	net price markup	0.20
θ_r	banks' default probability	0.41
ξ_b	transfer rate to entering banks	0.07
ξ_p	price stickiness	0.84