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Home bias, exchange rate disconnect, and optimal exchange rate policy☆

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ABSTRACT

This paper examines how much the central bank should adjust the interest rate in response to real exchange rate fluctuations. The paper first demonstrates, in a two-country Dynamic Stochastic General Equilibrium (DSGE) model, that home bias in consumption is important to replicate the exchange rate volatility and exchange rate disconnect documented in the data. When home bias is high, the shock to Uncovered Interest rate Parity (UIP) can substantially drive up exchange rate volatility while leaving the volatility of real macroeconomic variables, such as GDP, almost untouched. The model predicts that the volatility of the real exchange rate relative to that of GDP increases with the extent of home bias. This relation is supported by the data. A second-order accurate solution method is employed to find the optimal operational monetary policy rule. Our model suggests that the monetary authority should not seek to vigorously stabilize exchange rate fluctuations. In particular, when the central bank does not take a strong stance against the inflation rate, exchange rate stabilization may induce substantial welfare loss. The model does not detect welfare gain from international monetary cooperation, which extends Obstfeld and Rogoff's [Obstfeld, M., Rogoff, K.,2002. Global implications of self-oriented national monetary rules, Quarterly Journal of Economics May, 503–535] findings to a DSGE model.

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1. Introduction

Many countries adopted a monetary policy regime defined by John Taylor as a trinity: (1) a flexible exchange rate, (2) an inflation target, and (3) a monetary policy rule. John Taylor (2001) argues that the role of the exchange rate in the monetary policy rule is an important issue for this new policy regime. In this paper we first show that home bias in consumption can help to replicate two findings in the data: 1. Exchange rates are much more volatile than other macroeconomic variables such as GDP (exchange rate volatility); 2. The volatility of output does not respond to the volatility of exchange rates (exchange rate disconnect). Under this explanation of exchange rate volatility and disconnect, our model suggests that the central bank should not vigorously stabilize the real exchange rate in its monetary policy rule.

There are two different strands of literature focusing upon exchange rate stabilization. The first one studies the tradeoff between exchange rate stabilization and the stability of the whole economy. Ball (1999) and Svensson (2000) find that the inclusion of the exchange rate into a monetary policy rule can stabilize output or inflation, or both. In contrast, Obstfeld and Rogoff (1995) warn policymakers that the required interest rate changes for exchange rate stabilization can aggravate instability elsewhere in the economy. In an empirical study on New Zealand, West (2004) finds that exchange rate stabilization would increase the volatility of output, inflation, and the interest rate. Another strand of literature uses welfare-based New Open-Economy Macroeconomic (NOEM) models to study the tradeoff between real exchange rate stabilization and the expenditure-switching effect.[1] Though elegant in allowing for analytical solutions, these NOEM models are usually static with no price persistence, and are therefore unable to address the tradeoff considered in the first strand of literature.

Kollmann (2004) incorporates the tradeoffs in both strands of literature into a two-country Dynamic Stochastic General Equilibrium (DSGE) model. He compares the welfare effects of the exchange rate policy in a sticky-price dynamic model. Our paper is closely related, but we emphasize the connection between home bias in consumption and the exchange rate disconnect puzzle. Several authors have recently used pricing in the importer's currency (Local Currency Pricing, or LCP) to model the low exchange rate pass-through documented in the data.[2] The short-run exchange rate pass-through into import prices is close to zero in those models. In industrial countries, although the pass-through into consumer prices is low, there is still a sizable short-run exchange rate pass-through into import prices.[3] In addition, the LCP in import prices is also criticized by Obstfeld and Rogoff (2000b) on the grounds that it generates counterfactual correlation between the exchange rate and the terms of trade. Therefore, in this paper, we follow Devereux and Engel (2007) by assuming that the imports and exports are priced in the producer's currency (Producer Currency Pricing, or PCP), but final goods are priced in the consumer's currency.

We further assume that both import prices and consumer prices are sticky. When those prices are fixed in the short-run, the import prices in the importer's currency vary with the exchange rate, but the consumer prices do not fluctuate with the exchange rate. In this way, our model allows a low exchange rate pass-through into consumer prices and a relatively high pass-through to import prices. Under this setup, we find that home bias in consumption is critical for our model to replicate the well-documented disconnect between exchange rates and real macroeconomic variables.[4] We follow Devereux and Engel (2002) and Kollmann (2004) by using the Uncovered Interest rate Parity (UIP) shock to generate fluctuations in the nominal exchange rate. However, Devereux and Engel (2002) use the LCP for import prices to insulate the economy from exchange rate fluctuations. After we allow the exchange rate movements to pass through into the import prices, we find that only when the foreign market is a small portion of total output could the UIP shock in the financial market substantially increase the

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1 For example, see Devereux and Engel (2003, 2007), Obstfeld (2001, 2002) and the references cited therein. An exception is Obstfeld (2004). He defends the flexible exchange rate regime in light of its function that allows the central bank to pursue an independent interest rate policy in a world of international capital mobility.

2 For instance, see Devereux and Engel (2002, 2003), Chari, Kehoe, and McGrattan (2002), Duarte and Stockman (2005), and Kollmann (2004).

3 For instance, see Campa and Goldberg (2005), Mumtaz, Oomen and Wang (2006).

4 For empirical studies on the exchange rate disconnect, see Flood and Rose (1995) and Baxter and Stockman (1989).

volatility of the exchange rate while keeping the volatility of real variables, such as GDP, almost unchanged.

The multiple price-stickiness used in this paper also helps us in two additional ways. First, it helps to replicate that the cyclical behavior of CPI inflation generally differs from that of PPI inflation in the data. The latter is typically more volatile and less persistent than the former.[5] More importantly, the multiple price-stickiness incorporates into our model a new tradeoff in the exchange rate policy discussed by Devereux and Engel (2007): when prices of both imports and final consumption goods are sticky, the flexible exchange rate facilitates the expenditure-switching effect for imports and exports, but distorts the prices of final consumption goods across countries. Based on the fact that the expenditure-switching effect is empirically weak, they argue, the exchange rate should be stabilized to eliminate price distortions for final consumption goods. We can investigate the quantitative importance of this tradeoff in a model with home bias in consumption.

We limit our search for the optimal exchange rate policy to a class of simple operational policy rules. Our benchmark model suggests a very weak stance on exchange rate stabilization. Given that the central bank strongly stabilizes the inflation rate, the extra gain from exchange rate stabilization is negligible. Intuitively, the real exchange rate volatility in our model is primarily driven by home bias in consumption and the Uncovered Interest rate Parity (UIP) shock. The similarity between home and foreign final consumption bundles is low when consumption is highly biased toward domestic goods. Therefore, the CPI-based real exchange rate fluctuations do not necessarily imply significant price distortions across countries. In this case, the gain from exchange rate stabilization is small. However, the restriction on exchange rate flexibility obstructs the terms of trade adjustment for intermediate goods. What's more, movements of the interest rate required for exchange rate stabilization induce prolonged deviations of the inflation rate from its steady-state level, which also lowers welfare.

In addition, we find that exchange rate stabilization may induce substantial welfare loss if the central bank takes a weak stance against the inflation rate. When the central bank takes a weak stance on inflation stabilization, aggressively stabilizing the real exchange rate will transmit exchange rate fluctuations into large and prolonged inflation fluctuations through the tradeoff between exchange rate and inflation stabilization. In our model, this policy could be very detrimental. We also find that international monetary cooperation does not generate significant welfare gain compared to the Nash equilibrium. This result extends the analysis of Obstfeld and Rogoff (2002) to a more complicated DSGE model. When both country-specific productivity shocks and price-stickiness exist in an open-economy macro model with imperfect international risk sharing, policymakers may have to strike a balance between mitigating international risk sharing and sticky-price distortions. Obstfeld and Rogoff (2002) discuss this tradeoff thoroughly by deriving an analytical solution to a static New Open-Economy Macroeconomic (NOEM) model. They show that the welfare gain from international monetary cooperation is small. We find similar results in this paper. This finding may reflect the fact that the gain from international risk sharing is usually found to be small in open-economy macroeconomic models.[6] Compared to Obstfeld and Rogoff's (2002) model with static price setting, deviating from flexible price equilibrium is more costly in our model with Calvo-style price setting: it induces price dispersions. The Nash equilibrium and international cooperation coincide if the cost of price dispersions exceeds the benefit from international risk sharing.

As the degree of home bias decreases, we find it is more desirable to stabilize the real exchange rate.[7] Kollmann (2004) and Leith and Wren-Lewis (2006) find similar results. However, we want to be cautious in interpreting this result as offering support for exchange rate stabilization. In the case with

[5] For example, see Clark (1999). This difference may be caused by the CPI smoothing policy of central banks rather than the generic difference in price-stickiness in these two sectors. However, the same pattern has also been found in the case of the mid-1930s (see Means (1935)), when the role of monetary policy was not as significant as it is today. Dong (2006) also finds this difference in estimating a small open-economy DSGE model.

[6] For instance, see Cole and Obstfeld (1991) and Tesar (1995).

[7] Devereux and Engel (2007) have no home bias in their model and find that the central bank should stabilize the exchange rate. When home and foreign consumption bundles are identical, the gain from exchange rate stabilization is higher than that in our benchmark model. Another reason why they get different results is because there is no tradeoff between exchange rate stabilization and inflation stabilization in their model. Therefore, the cost of exchange rate stabilization is lower in their model.

little home bias, the volatility of the real exchange rate relative to that of GDP is much smaller than what is observed in the data. In addition, the disconnect between exchange rate and output volatilities exists only when the home bias is high. Intuitively, when the foreign market is only a very small portion of output (high home bias), the UIP shock in the financial market can drive up exchange rate volatility, but has very limited impact on output. In this sense, our model provides an interesting solution to the exchange rate disconnect puzzle: home bias in consumption.[8] Our results are consistent with Hau's (2002) finding that the volatility of the real exchange rate is positively correlated with the level of home bias. We confirm this finding in our data. In addition, our model also predicts that there is an even stronger relation between the extent of home bias and the volatility of the real exchange rate relative to the volatility of GDP. We find empirical support for this prediction in our OECD-country data as well.

Our benchmark model suggests that the central bank should not include the real exchange rate in its policy rule. This finding is robust under the preference of habit persistence, though the welfare cost of exchange rate variability is higher under habit persistence.[9] When household preferences are more risk sensitive, welfare loss is higher for given exchange rate variability. However, this does not guarantee that central banks should react to exchange rate variation. The cost of real exchange rate stabilization is also higher under habit persistence. Our model shows that the cost still exceeds the benefit for real exchange rate stabilization in this case.

In this paper, we take home bias in consumption as exogenously given. However, Helpman (1999) argues that there is no clear evidence for such demand patterns. Our treatment of home bias can be taken as a shortcut for a model with no home bias in consumption but with high international trade costs, such as the model in Atkeson and Burstein (2005). Burstein, Neves, and Rebelo (2003) find a trade cost that is large enough to generate the same home bias level as in our model, even after controlling for nominal exchange rate fluctuations. The trade-depressing effect of exchange rate volatility is more plausible for low-frequency movements of the exchange rate for which hedging strategies are unavailable.[10] We doubt this effect would be strong enough to overturn our results at business cycle frequencies.

We want to emphasize that our paper is not about the optimal choice of exchange rate regimes. We limit our discussion to a flexible exchange rate regime and study if the central bank should include the exchange rate in its monetary policy rule. Our model has abstracted away from several benefits of an exchange rate peg. Governments may decide to adopt a peg because it may stimulate international trade, eliminate competitive devaluations, and impede exchange rate speculation.[11] Kollmann (2004) finds that a monetary union (an extreme case of a peg) can raise welfare because it eliminates UIP shocks. In this paper, we assume that the UIP shocks do not respond to monetary policy under a flexible exchange rate regime. We admit that our results may depend on the interaction between exchange rate stabilization and the volatility of UIP shocks. Incorporating this interaction requires a model that can endogenously generate the UIP puzzle and exchange rate volatility. We leave this for future research.

We also abstract from tradability and trade frictions in our model. Leith and Wren-Lewis (2006) argue that exchange rate movements may cause a large misalignment between tradable and non-tradable sectors. They find, in a model with both tradable and nontradable sectors, that this misalignment provides an additional incentive for the central bank to stabilize the exchange rate, though as in our model, they find the gain of exchange rate stabilization is small. Kumhof, Laxton, and Naknoi (2008) show that the exchange rate enters the optimal policy rule in a model in which firms enter and exit foreign markets when the exchange rate fluctuates. Empirical studies on the impacts of business cycle frequency fluctuations of the exchange rate on firms' exporting decisions may be fruitful for future research.

Our benchmark model suggests that the monetary authority should not seek to stabilize the real exchange rate. This result should depend on the way in which the exchange rate is modeled. There is no

[8] Obstfeld and Rogoff (2000a) conjecture that the home bias in consumption caused by trade costs may be important in explaining the exchange rate disconnect puzzle.

[9] Bergin et al. (2007) find similar results.

[10] Empirical findings on this effect are mixed. For instance, see Asseery and Peel (1991) and Koray and Lastrapes (1989).

[11] For instance, see Klein and Shambaugh (2006), Corsetti, et al. (2000), and Pastine (2002).

consensus among economists on exchange rate determination. For instance, Chari, Kehoe, and McGrattan (2002) and Devereux and Engel (2002) attribute exchange rate volatility to nominal stickiness. In contrast, this volatility is mainly driven by home bias in final consumption bundles in Atkeson and Burstein (2005), Ghironi and Melitz (2005), and our model in this paper. Naknoi (2008) argues that exchange rate fluctuations are also affected by the endogenous tradability of goods. Further research is desirable to determine how robust our policy suggestion is in different models of exchange rate determination.

The remainder of the paper is organized as follows: Section 2 lays out the theoretical model; Section 3 provides details about calibration and compares the business cycle statistics of our model with those in the data; Section 4 discusses the solution method and presents our findings for policy evaluation; and Section 5 concludes and discusses potential future research directions.

2. A two-country DSGE model

The world economy consists of two symmetric countries: Home and Foreign. There are two sectors of production in each country: the final goods sector and the intermediate goods sector. Final goods are internationally nontradable, and are produced from the internationally traded Home and Foreign intermediate good composites. The intermediate goods are produced from capital and labor in each country.

In the Home final goods sector, there is a continuum of differentiated final goods $Y_t(i)$ indexed by $i \in [0, 1]$. The representative household of Home country uses them to form a final good composite Y_t according to equation (1) for consumption, investment, saving, and associated costs:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\theta-1}{\theta}} \mathrm{d}i\right]^{\frac{\theta}{\theta-1}}. \tag{1}$$

In equation (1), θ is the elasticity of substitution between differentiated final goods $Y_t(i)$. Each variety of final goods is produced from the Home and Foreign intermediate good composites Y_{Ht} and Y_{Ft} by a single final goods firm. The Home (Foreign) intermediate good composite is composed of differentiated Home (Foreign) intermediate goods $Y_{Ht}(j)$ ($Y_{Ft}(j)$). In the intermediate good sector, each variety of Home (Foreign) intermediate goods is produced by a single firm with capital and labor in the Home (Foreign) country.

2.1. Final goods market

The final good market is monopolistically competitive. In the Home country, each final goods firm produces a variety of final goods from the Home and Foreign intermediate good composites according to equation (2):

$$Y_t^s(i) = \left[\alpha^{\frac{1}{\gamma}} Y_{Ht}^d(i)^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}} Y_{Ft}^d(i)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}. \tag{2}$$

$Y_t^s(i)$ is the supply of final good i, and $Y_{Ht}^d(i)(Y_{Ft}^d(i))$ is the Home (Foreign) intermediate good composite demanded by final good firm i. α is the weight of the home intermediate good composite required for producing final consumption goods. Consumption is home biased when $\alpha > 1/2$. γ is the elasticity of substitution between the home and foreign intermediate good composites. Symmetrically, the production function for Foreign final goods producer i is

$$Y_t^{s*}(i) = \left[\alpha^{\frac{1}{\gamma}} Y_{Ft}^{d*}(i)^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}} Y_{Ht}^{d*}(i)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}. \tag{3}$$

The variables with asterisks in equation (3) are foreign counterparts of the variables in Home country. Due to the symmetry between the two countries, we will focus only on the Home country to describe our model.

In each country, final goods prices are denominated in the consumer's currency. In contrast, intermediate goods are priced in the producer's currency. For given technology, the firms choose prices to maximize the expected profit. We introduce staggered price setting *a lá* Calvo (1983) and Yun (1996). In each period, an individual firm has a probability of $1-\lambda_f$ to re-optimize its price. Otherwise, it will charge a price equal to last period's price multiplied by the long-run inflation rate (π). When a final good firm re-optimizes its price, it will choose a price P_{tt} to maximize the expected life time real profit.[12] So the profit maximization problem can be written as

$$\max_{P_{tt}} \sum_{k=0}^{\infty} E_t\left\{\lambda_f^k \Gamma_{t,t+k} P_{t+k}^{-1}\left[\left(\pi^k P_{tt} - mc_{t+k}\right)\left(\frac{\pi^k P_{tt}}{P_{t+k}}\right)^{-\theta} Y_{t+k}^d\right]\right\},$$

where $\Gamma_{t,t+k}$ is the pricing kernel between period t and $t+k$. We assume all firms are owned by home households, and therefore $\Gamma_{t,t+k}$ is the marginal rate of substitution between time t and time $t+k$ consumption. From the first order condition, we find that the optimal price P_{tt} satisfies

$$P_{tt} = \frac{\theta \sum_{k=0}^{\infty}\left(\lambda_f \pi^{-\theta}\right)^k E_t\left[\Gamma_{t,t+k} mc_{t+k} P_{t+k}^{\theta-1} Y_{t+k}\right]}{(\theta-1)\sum_{k=0}^{\infty}\left(\lambda_f \pi^{1-\theta}\right)^k E_t\left[\Gamma_{t,t+k} P_{t+k}^{\theta-1} Y_{t+k}\right]}. \tag{4}$$

When price is flexible ($\lambda_f=0$), the optimal price reduces to $P_{tt}=\theta mc_t/(\theta-1)$. The monopolist charges a constant markup over its marginal cost.

Under this staggered price setting environment, prices are not synchronized across firms. At any time t, only a fraction of $1-\lambda_f$ firms charge up-to-date optimal price P_{tt}. A fraction of $\lambda_f^k(1-\lambda_f)$ firms charge outdated price $P_{t-k,\,t}$ for $k=1,2,\ldots$ The price of the final goods composite P_t evolves according to equation (5):

$$P_t = \left[\left(1-\lambda_f\right)P_{tt}^{1-\theta} + \lambda_f\left(\pi P_{t-1}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{5}$$

2.2. Intermediate goods market

The Home intermediate good composite used by final good producers is made from a continuum of differentiated intermediate goods indexed by $j \in [0,1]$ according to equation (6):

$$Y_{Ht} = \left[\int_0^1 Y_{Ht}(j)^{\frac{\phi-1}{\phi}} \mathrm{d}j\right]^{\frac{\phi}{\phi-1}}, \tag{6}$$

where ϕ is the elasticity of substitution between differentiated intermediate goods. The Foreign intermediate good composite is made in the same way from Foreign differentiated intermediate goods. We suppose that intermediate goods firms set prices in the producer's currency, and the Law of One Price (LOP) holds in this market. Let $P_{Ht}(j)$ be the price of Home intermediate good j in the Home market, and let $P_{Ht}^*(j)$ be the price in the Foreign market. By LOP, we have $P_{Ht}(j)=S_t P_{Ht}^*(j)$.

The intermediate good producers rent capital and labor from households. The technology takes a standard Cobb-Douglas form:

$$Y_{Ht}^s(j) = A_t K_t^{\psi}(j) L_t^{1-\psi}(j), \tag{7}$$

where $Y_{Ht}^s(j)$ is the supply of intermediate good j. $K_t(j)$ and $L_t(j)$ are, respectively, capital and labor used by intermediate good company j. A_t (A_t^*) is the technology shock in the Home (Foreign) country,

[12] For the notation P_{tt}, the first time subscript denotes when the price is re-optimized, and the second time subscript gives the current time. For example, P_{tt+k} means the price is re-optimized at time t and is still effective at time $t+k$. From our setup, $P_{tt+k}=\pi^k P_{tt}$.

which is identical for all firms in that country. The logarithms of productivity shocks follow a VAR(1) process:

$$\begin{bmatrix} \log(A_t) \\ \log(A_t^*) \end{bmatrix} = \begin{bmatrix} \xi_{11} & \xi_{12} \\ \xi_{21} & \xi_{22} \end{bmatrix} \begin{bmatrix} \log(A_{t-1}) \\ \log(A_{t-1}^*) \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \varepsilon_t^* \end{bmatrix}, \tag{8}$$

where $\xi_{12} = \xi_{21}$ are technology spillovers. The vector containing ε_t and ε_t^* is i.i.d. with means of zero and a variance-covariance matrix V.

We follow the same way as in the final goods sector to introduce staggered prices. $1 - \lambda_{int}$ is the probability for firm j to re-optimize its problem. When re-optimizing price, the intermediate good producer j chooses a price P_{Htt} to maximize the discounted lifetime real profit

$$\max_{P_{Htt}} \sum_{k=0}^{\infty} E_t \left\{ \lambda_{int}^k \Gamma_{t,t+k} P_{Ht+k}^{-1} \left[\left(\pi^k P_{Htt} - mc_{t+k}^{int} \right) \left(\frac{\pi^k P_{Htt}}{P_{Ht+k}} \right)^{-\phi} Y_{Ht+k}^w \right] \right\},$$

where $Y_{Ht+k}^w = Y_{Ht+k}^d + Y_{Ht+k}^{d*}$ is the world demand for the Home intermediate good composite.

2.3. Household's problem

The representative household maximizes expected lifetime utility, which is given in equation (9):

$$U = E_0 \left[\sum_{t=0}^{\infty} \beta^t u_t(C_t, 1 - L_t) \right], \tag{9}$$

where $E_0[\cdot]$ is the conditional expectation operator, and β is the subjective discount factor. The period utility u_t is a concave function of final goods composite C_t and leisure $1 - L_t$.

The representative household sells labor and rents capital to domestic intermediate goods firms in a competitive market. The law of motion for capital takes the standard form of:

$$K_{t+1} = (1 - \delta)K_t + I_t, \tag{10}$$

where I_t is the investment at time t, and δ is the capital depreciation rate. Capital and investment are in the form of the final good composite. Following the literature, we assume a quadratic capital adjustment cost:

$$AC_t = \frac{1}{2}\Phi\left(\frac{I_t}{K_t} - \delta\right)^2 K_t,$$

where Φ is a scale parameter of capital adjustment cost.

Households can only trade non-state-contingent Home and Foreign nominal bonds. There is a quadratic real cost of holding bonds:

$$F_t = \frac{1}{2}\phi_d\left(\frac{B_{Ht+1}}{P_t}\right)^2 + \frac{1}{2}\phi_f\left(\frac{S_t B_{Ft+1}}{P_t}\right)^2,$$

where B_{Ht+1} (B_{Ft+1}) is the Home (Foreign) bond held by the household in the Home country between period t and period $t+1$. All bonds are denominated in the issuing country's currency. ϕ_d and ϕ_f are parameters of cost for holding domestic bonds and holding foreign bonds, respectively.[13] We introduce this cost to ensure stationarity of the model. By assigning very small values to ϕ_d and ϕ_f, this cost has a negligible effect on model dynamics.[14]

[13] Note that in Foreign country, ϕ_d is the cost of holding Foreign bonds, and ϕ_f is the cost of holding Home bonds.
[14] See Schmitt-Grohé and Uribe (2003) for more details.

Other incomes for households include profits from intermediate and final goods firms. The representative household uses these incomes to buy differentiated final goods and aggregate them into a final good composite (equation (1)). The final good composite can be used for consumption, investment or paying the costs of adjusting the capital stock and holding bonds. Based on the above setup, we obtain the budget constraint:

$$C_t+\frac{B_{Ht+1}}{P_t}+\frac{S_tB_{Ft+1}}{P_t}+I_t+\frac{1}{2}\Phi\left(\frac{I_t}{K_t}-\delta\right)^2K_t+\frac{1}{2}\phi_d\left(\frac{B_{Ht+1}}{P_t}\right)^2+\frac{1}{2}\phi_f\left(\frac{S_tB_{Ft+1}}{P_t}\right)^2 \\ \leq\frac{W_tL_t}{P_t}+\frac{R_tK_t}{P_t}+\frac{B_{Ht}(1+i_{t-1})}{P_t}+\frac{B_{Ft}(1+i^*_{t-1})S_t}{P_t}+\frac{\pi^{int}_t}{P_t}+\frac{\pi^f_t}{P_t}. \tag{11}$$

For any given initial capital stock and asset position, the representative household chooses the paths of consumption C_t, labor supply L_t, capital investment I_t, and bond holdings B_{Ht+1} and B_{Ft+1} to maximize the expected life time utility subject to the above budget constraint.

In this paper, we employ the period utility function as in equation (12):

$$u_t(C_t,1-L_t)\;=\frac{C_t^{1-\sigma}}{1-\sigma}-\rho L_t. \tag{12}$$

The linear form of disutility from labor is used to capture fluctuations in the labor market and can be justified by the indivisible labor assumption, as in Hansen (1985). The first order conditions of the optimal bond holdings approximately imply the uncovered interest rate parity (UIP) condition[15]:

$$E_t\left[\Gamma_{t,t+1}\frac{(1+i_t)}{P_{t+1}/P_t}\right]\approx E_t\left[\Gamma_{t,t+1}\frac{(1+i^*_t)}{(P_{t+1}/S_{t+1})/(P_t/S_t)}\right], \tag{13}$$

where $\Gamma_{t,t+1}=\beta(\partial u/\partial c_{t+1})/(\partial u/\partial c_t)$ is the marginal rate of substitution between time t and time $t+1$ consumption. As it is well-documented that the UIP condition is strongly rejected by data (see Engel, 1996 and Lewis, 1995 for surveys), we follow Kollmann (2004) in introducing a UIP shock into the first order condition:

$$1+\frac{\phi_fS_tB_{Ft+1}}{P_t}\;=\varphi_tE_t\left[\Gamma_{t,t+1}\frac{(1+i^*_t)}{(P_{t+1}/S_{t+1})/(P_t/S_t)}\right], \tag{14}$$

where φ_t is a UIP shock that can be interpreted as the bias of market expectation on time $t+1$ exchange rate.[16] It enters the bond holding condition symmetrically in Foreign country.

2.4. Monetary policy rules and market clearing conditions

In Home country, the monetary authority follows a modified Taylor rule:

$$i_t\;=i+\Xi_\pi\log\left(\frac{\pi_t}{\pi}\right)+\Xi_s\log\left(\frac{Q_t}{Q}\right), \tag{15}$$

where Ξ_π and Ξ_s are policy parameters determined by the monetary authority. The variables without a time script are steady-state values. Q_t is the real exchange rate defined as $S_tP^*_t/P_t$. In this modified Taylor rule, the monetary authority adjusts the interest rate to stabilize the inflation rate and the real exchange rate.[17] Unlike the standard Taylor rule, the interest rate here does not react to the output gap. In a closed economy, Schmitt-Grohé and Uribe (2004b) find that the interest rate should not respond to

[15] To obtain this condition, we delete ϕ_dB_{Ht+1}/P_t and $\phi_fS_tB_{Ft+1}/P_t$ from the first order conditions since these two terms are small by assumption.

[16] Jeanne and Rose (2002) model the market bias with noise traders.

[17] Our results hold if the monetary authority stabilizes the change of the nominal exchange rate.

the output gap. In addition, the computation is very intensive in this paper. Omitting the output gap from the policy rules can substantially reduce our computational burden as well.[18] The Foreign monetary authority follows a similar interest rate rule

$$i_t^* = i^* + \Xi_\pi^* \log\left(\frac{\pi_t^*}{\pi^*}\right) - \Xi_s^* \log\left(\frac{Q_t}{Q}\right). \tag{16}$$

We consider two scenarios in searching for the optimal monetary policy: Nash equilibrium, and international monetary cooperation. In the cooperative equilibrium, the policymakers cooperate to choose policy parameters that maximize the sum of utilities in both countries.

The aggregate demand for the final goods composite can be found from resource constraint:

$$C_t + I_t + \frac{1}{2}\phi_d\left(\frac{B_{Ht+1}}{P_t}\right)^2 + \frac{1}{2}\phi_f\left(\frac{S_t B_{Ft+1}}{P_t}\right)^2 + \frac{1}{2}\Phi\left(\frac{I_t}{K_t} - \delta\right)^2 K_t = Y_t. \tag{17}$$

For the bond market clearing condition, we have:

$$B_{Ht} + B_{Ht}^* = 0, \tag{18}$$

and similar market clearing conditions exist for the Foreign nominal bond and the final goods composite.

3. Calibration and real business cycle statistics

We calibrate our model to match quarterly data. Table 1 shows parameter values used in our calibration. The annual real interest rate is set to 4%, which gives us a quarterly subjective discount factor of 0.99. The home bias (α) is set to match the fact that the ratio of import to GDP is around 15% in the U.S. θ and ϕ are set at levels such that the profit margin is 20% for intermediate and final goods firms. The value for elasticity of substitution between home and foreign goods (γ) is more controversial. Though studies based on micro-level evidence have suggested an elasticity of around 5,[19] Bergin (2004) finds that the elasticity is only slightly above 1 in macro-level data. He argues that the substitution rate between home and foreign goods is lower at the aggregate level. We will follow Bergin's (2004) result to set γ at 1.1.

For the price-stickiness parameters, we set λ_f at 0.75. Under this calibration, final goods firms re-optimize prices every four quarters on average. As we have mentioned, the prices of intermediate goods seem less sticky, so we set λ_{int} equal to 0.5. Under this calibration, intermediate goods firms re-optimize every two quarters on average.[20] The production share of capital is set to 0.3, which is in line with the empirical capital share of the U.S. and the E.U. countries. Following the estimate of Bergin (2004), we set consumption elasticity (σ) to unity. As in Kollmann (2004), the preference parameter ρ is equal to one. The capital adjustment cost is chosen to match the volatility of investment. The cost of holding domestic bonds is equal to zero, and of holding foreign bonds is equal to 0.0038 divided by the steady-state export as in Kollmann (2004). As we have mentioned, we introduce these costs to guarantee the stationarity of our model. They have no effect on our major results. The annual capital depreciation rate is 10%, which gives us the quarterly depreciation rate of $\delta = 0.025$. Steady-state quarterly inflation is set at 1.0103 in both countries, which implies an annual inflation rate of 4.2%. For the technology shocks, we follow the standard setup in the literature and set the AR(1) coefficients at $\xi_{11} = \xi_{22} = 0.9$, and the technology spillovers at $\xi_{12} = \xi_{21} = 0.03$. The standard deviation of the technology disturbance is set to 0.0085 by following Backus, Kehoe, and Kydland (1992). For simplicity, we assume that the disturbances are uncorrelated across countries.

[18] In an exercise not reported in this paper, we add output gap to the Taylor rule and search over a small range for each policy parameter around the optimal point found in this paper ($\Xi_\pi = 3$, $\Xi_s = 0.01$). We find that adding the output gap does not change our result.

[19] For instance, see Harrigan (1993).

[20] This price adjustment frequency is supported by Mumtaz, Oomen, and Wang (2006). In that paper, we find that exchange rate changes are generally passed to import prices within two quarters.

Table 1
Calibration.

Parameter	Value	Description
β	0.99	Subjective discount factor
α	0.85	Home bias
θ	6	Elasticity of substitution between final goods
ϕ	6	Elasticity of substitution between intermediate goods
γ	1.1	Elasticity of substitution between home and foreign goods
λ_f	0.75	Probability of not re-optimizing for final goods firm
λ_{int}	0.5	Probability of not re-optimizing for intermediate goods firm
ψ	0.3	Share of capital in production
σ	1	Preference parameter
ρ	1	Preference parameter
Φ	8	Cost parameter of capital adjustment
ϕ_d	0	Cost parameter of holding domestic bonds
ϕ_f	$0.0038/Y_H^*$	Cost parameter of holding foreign bonds
δ	0.025	Capital depreciation rate
π	1.0103	Steady-state inflation rate in Home country
π^*	1.0103	Steady-state inflation rate in Foreign country
A	1	Steady-state technology shock in Home country
A^*	1	Steady-state technology shock in Foreign country
$\xi_{11} = \xi_{22}$	0.9	Technology shock AR(1) coefficient
$\xi_{12} = \xi_{21}$	0.03	Technology spillovers
λ_a	0.88	UIP shock parameter
ζ	0.8	Habit persistence parameter

We follow Kollmann's (2004) two-factor structure to calibrate the uncovered interest rate parity (UIP) shock:

$$\log(\varphi_t) = a_t + \mu_t$$

$$a_t = \lambda_a a_{t-1} + \eta_{at}. \tag{19}$$

The parameter λ_a equals 0.88. The standard deviations of white noises are $\sigma_\eta = 0.0109$ and $\sigma_\mu = 0.022$.

Table 2 reports the business cycle statistics of our model. The table shows the results for our benchmark model (Benchmark), the benchmark model without the UIP shock (No UIP) and the model with habit persistence preference (Habit). Under the above calibration, our model can successfully replicate some major business cycle properties found in the data. The standard deviation of GDP is of the same order as that in the data. Consumption is less volatile than GDP, and investment is about three times as volatile as GDP. An important difference between our benchmark model and the model without the UIP shock is the volatility of the real exchange rate. With the UIP shock, we can replicate the fact that the real exchange rate is about four times as volatile as GDP. The duplication of this property is very important for the analysis of the exchange rate policy.

4. Solution method and policy evaluation

It is well known that the standard first order approximation method can generate spurious welfare rankings when long-run distortions exist in the model.[21] Therefore, we employ a second-order accurate solution method developed by Schmitt-Grohé and Uribe (2004a).[22] Following Schmitt-Grohé and Uribe (2004b), we assume that in the initial state, all state variables are in their non-stochastic steady states, and monetary policies are evaluated by the conditional expectations of the discounted lifetime utility.

[21] For instance, see Kim and Kim (2003).
[22] Other works of a second-order accurate solution method include Kim, Kim, Schaumburg, and Sims (2003)

Table 2
Business cycle statistics.

	SD of GDP (%)	Standard deviations relative to that of GDP			
		Consumption	Investment	Employment	RE
US Data	1.82	0.83	2.78	0.67	4.36
Benchmark	1.54	0.88	2.83	0.95	3.86
No UIP	1.59	0.62	2.72	0.26	0.61
Habit	1.59	0.46	2.72	1.18	3.45
	Autocorrelation				
	GDP	Consumption	Investment	Employment	RE
US Data	0.88	0.89	0.91	0.90	0.83
Benchmark	0.63	0.66	0.65	0.58	0.63
No UIP	0.68	0.68	0.67	0.66	0.68
Habit	0.70	0.91	0.65	0.63	0.66

Note:

- Statistics of the US data are from Chari et al. (2002).
- Model statistics are the average of 100 simulations. All artificial data from simulations are logged and H-P filtered with a smoothing parameter of 1600.
- The standard deviation of productivity shocks in Benchmark is 0.0085 by following Backus, Kehoe, and Kydland (1992). It is set to 0.011 in models of "No UIP" and "Habit" such that GDP in all three models has approximately the same volatility. Capital adjustment cost is calibrated to match the volatility of investment. All other parameters are the same for all three models.

The welfare loss (τ) of a particular monetary policy relative to the optimal one is measured as the percentage of consumption obtained under the optimal monetary policy that the household is willing to give up to achieve the same welfare level obtained in an alternative monetary policy. Let V_t^{opt} be the welfare obtained under optimal monetary policy, and let $\{C_s^{opt}, L_s^{opt}\}_{s=t}^{\infty}$ be the associated consumption and labor paths:

$$V_t^{opt} \equiv E_t \sum_{s=t}^{\infty} \beta^{s-t} u\left(C_s^{opt}, L_s^{opt}\right). \tag{20}$$

Let V_t^a be the welfare level obtained from an alternative monetary policy, and by the definition of τ:

$$V_t^a = E_t \sum_{s=t}^{\infty} \beta^{s-t} u\left((1-\tau\%)C_s^{opt}, L_s^{opt}\right). \tag{21}$$

Substituting the period utility function into the above equation, we can find the formula for calculating τ:

$$\tau = 100 \times \left(1 - e^{(1-\beta)(V_t^a - V_t^{opt})}\right). \tag{22}$$

In searching for the optimal monetary policy, we limit our attention to simple operational rules, as defined in Section 2.4. We require that the operational rules induce a locally unique equilibrium, and that the nominal interest rate be non-negative. For technical reasons, we are unable to impose the non-negativity constraint into our model directly.[23] We follow Schmitt-Grohé and Uribe (2004b) to require that the target value of the nominal interest rate be at least twice as large as the standard deviation of the nominal interest rate. This constraint guarantees a positive interest rate 98% of time if the equilibrium nominal interest rate is normally distributed.

[23] See Rotemberg and Woodford (1999, p.75) and Schmitt-Grohé and Uribe (2004b) for more discussion.

A policy rule is optimal if it satisfies the above requirements and also yields the highest level of welfare. We use the method of grid search to determine the optimal rule. The welfare surface obtained from a grid search shows us how much the welfare level changes in cases of policy mistakes. We would prefer to have a policy regime in which welfare is less sensitive to policy errors. We also limit our grid search to a reasonable range for each policy parameter. The optimal value for the inflation stabilization parameter Ξ_π has usually been found to be around 1.5 in other studies. We search over a slightly broader interval of [0, 3] for this parameter in steps of 0.1. The reaction of the interest rate to the exchange rate is relatively smaller, so we set the interval as [0, 0.1] in steps of 0.01.[24]

4.1. CPI inflation targeting

We first consider the simplest rule where the interest rate reacts only to CPI inflation. There are two distinct price indices in our model: CPI and PPI. In a quick comparison between CPI and other inflation targeting regimes, we do not find obvious advantages of other regimes.[25] Furthermore, only CPI inflation is formally targeted by central banks in practice, though both indices are available. Fig. 1 shows conditional welfare as a function of the policy parameter Ξ_π. The welfare is obtained through a grid search over [0, 3] for Ξ_π in increments of 0.1. The plot begins at $\Xi_\pi = 1.1$ because equilibrium is indeterminate when Ξ_π is less than or equal to unity.[26]

Fig. 1 suggests a strong stance on inflation for central banks: in an optimal monetary policy, Ξ_π should be set to its highest possible level of 3. However, the curvature of welfare is very flat after $\Xi_\pi = 1.5$. Therefore, the marginal gain from stabilizing the inflation rate is very small after this point. Empirical studies show that $\Xi_\pi = 1.5$ has been a realistic policy benchmark for industrial countries over the past two decades.

As we have mentioned, we follow Schmitt-Grohé and Uribe (2004b) in requiring that the steady-state interest rate be at least twice as large as the standard deviation of the nominal interest rate. Table 3 shows the standard deviation of the nominal interest rate and the ratio of the steady-state interest rate to this variable under different policy parameters. All parameter values satisfy our non-negativity condition with a ratio bigger than two. Note that the standard deviation of the interest rate actually decreases with the central bank's stance on inflation rate. When the monetary authority is more aggressive against the inflation rate, the interest rate has less opportunity to hit the zero bound. For a given inflation volatility, it should be easier to hit the zero bound if the central bank adjusts the interest rate more aggressively to fight against inflation. However, in a rational expectation model, the volatility of the inflation rate decreases with the central bank's stance against inflation fluctuations. Our result suggests that the decrease of inflation rate volatility is the dominant effect in our model. We will follow the same method in checking the non-negativity condition in the following policy analysis.

4.2. Exchange rate stabilization

In this section we study whether the interest rate should directly react to real exchange rate fluctuations in the Nash equilibrium. The interest rate rules are defined in equations (15) and (16). We find Nash equilibrium by searching over [0, 0.1] in steps of 0.01 for Ξ_s and Ξ_s^*, and over [0, 3] in steps of 0.1 for Ξ_π and Ξ_π^*. In Nash equilibrium, the optimal monetary policy is symmetric with $\Xi_s = \Xi_s^* = 0.01$ and $\Xi_\pi = \Xi_\pi^* = 3$. This result suggests a very loose stance against exchange rate stabilization: an increase of 40 basis points for the annual interest rate in the face of 10 percent real depreciation. The welfare gain from exchange rate stabilization is also negligible. In Table 4, we compare the Nash equilibrium with other symmetric policies. In comparison with the case of no exchange rate stabilization ($\Xi_\pi = \Xi_\pi^* = 3$

[24] We also search a broader range ([0, 1]) at a larger step size (0.05).

[25] Results are available upon request. Huang and Liu (2005) find that it is optimal to target both CPI and PPI inflations if final and intermediate goods sectors are subject to different shocks.

[26] This is consistent with the Taylor principle, in which the central bank should raise the interest rate instrument more than one-for-one with increases in inflation. Such an interest rate feedback rule can be compatible with a determinate equilibrium price level. See Taylor (1999) for more discussion about the desirability of this principle.

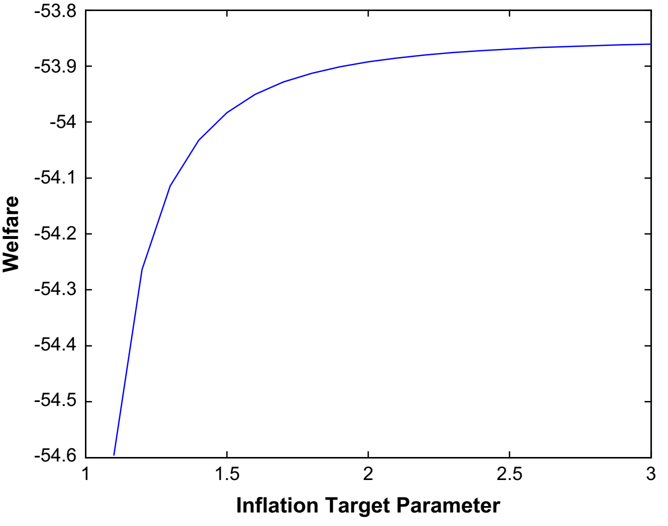

Fig. 1. Welfare as a function of Ξ_π.
Note: The monetary policy is $i_t = i + \Xi_\pi \log(\pi_t/\pi)$, where Ξ_π is the inflation target parameter.

and $\Xi_s = \Xi_s^* = 0$), the welfare gain is only 0.0007% of consumption. This is negligible relative to the welfare gain from inflation stabilization, which is 0.7383% of consumption. Furthermore, when the central bank takes a looser stance on inflation, our results suggest that mistakenly targeting the exchange rate may, in fact, be very destructive. For example, when $\Xi_\pi = 1.1$, welfare loss is more than one percent of consumption if the central banks set Ξ_s at 0.08 or higher.[27]

To understand our results, we first consider the behavior of the real exchange rate when all prices are flexible. When both λ_f and λ_{int} are equal to zero, all firms change prices every period, and our model reduces to the one with flexible prices. From the calculation of standard deviations and the impulse response functions, we find the real exchange rate is not constant, even when prices are fully flexible. The standard deviation of the real exchange rate in the flexible price model is about 85% as volatile as that in the sticky-price model.[28] This result questions exchange rate stabilization as a legitimate goal of monetary policy: exchange rate stabilization does not help replicate flexible price allocations if the flexible price exchange rate itself is not constant.

From our model it is easy for us to derive the CPI when all prices are flexible:

$$P_t = \frac{\theta}{\theta - 1}\left[\alpha P_{Ht}^{1-\gamma} + (1-\alpha)(P_{Ft})^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{23}$$

$$P_t^* = \frac{\theta}{\theta - 1}\left[\alpha\left(P_{Ft}^*\right)^{1-\gamma} + (1-\alpha)\left(P_{Ht}^*\right)^{1-\gamma}\right]^{\frac{1}{1-\gamma}}. \tag{24}$$

Though we have assumed the Law of One Price for the intermediate goods market with $P_{Ht} = P_{Ht}^* S_t$ and $P_{Ft} = P_{Ft}^* S_t$, Purchasing Power Parity (PPP) is not generally satisfied except when $\alpha = 1/2$.[29] Intuitively, when there is home bias in the final goods sector, final consumption goods are not identical across countries. Even if all prices are flexible, we cannot expect the final good composite to have the same

[27] These results also hold when prices are set in the currency of the local market (local currency pricing, or LCP). We thank an anonymous referee for suggesting we consider this setup. Results are available upon request.

[28] The standard deviation of the (log) real exchange rate is 5.10% and 5.94% for the flexible- and sticky-price models, respectively.

[29] Another case in which the condition of PPP holds is when $P_{Ht} = P_{Ft}$. That is, the terms of trade is equal to unity all the time. This condition is obviously not true when there is a country-specific productivity shock and prices are flexible.

Table 3
Non-negativity check of nominal interest rate.

Ξ_π	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
SD (%)	0.958	0.848	0.765	0.705	0.660	0.626	0.600	0.578	0.561	0.546
Ratio[a]	2.119	2.394	2.653	2.879	3.074	3.241	3.386	3.511	3.620	3.715
Ξ_π	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
SD (%)	0.534	0.524	0.516	0.508	0.502	0.496	0.491	0.487	0.484	0.480
Ratio[a]	3.799	3.872	3.937	3.994	4.045	4.090	4.130	4.166	4.198	4.227

[a] Ratio of steady-state interest rate to standard deviation of the interest rate.

value when denominated in the same currency. In this case, CPI-based real exchange rate fluctuations do not necessarily suggest significant price distortions for final consumption goods across borders. Therefore, there is not much welfare gain from exchange rate stabilization.

In contrast, the restrictions on exchange rate movements obstruct the expenditure-switching effect for intermediate goods: in the face of country-specific technology shocks, the nominal exchange rate cannot move freely to adjust the terms of trade. It can be seen more clearly in Fig. 2 that the impulse response function of the terms of trade is closer to that of the flexible price terms of trade when there is no exchange rate stabilization. The exchange rate stabilization also increases inflation volatility in our benchmark model, which reduces the welfare level under staggered price setting. Fig. 3(a) shows impulse response functions to a one-percent technology shock in the home country. We denote by circles (asterisks) the policy with (without) exchange rate stabilization. Although the real exchange rate is more stable when the interest rate directly reacts to exchange rate fluctuations, the inflation rates are more volatile. Fig. 3(b) shows impulse response functions to the UIP shock. The Home currency depreciates in the face of the shock, which induces the increase of CPI inflation. Therefore, the central bank should increase the interest rate in response. If the central bank also stabilizes the real exchange rate, the depreciation of the home currency also calls for an increase of the interest rate, which will reinforce inflation stabilization. As a result, CPI inflation is more stable on the impact of the shock. However, CPI inflation converges back to its steady-state more slowly in this case. Meanwhile, the increase in the interest rate suppresses market demand so much that the prices of intermediate goods even decrease and become more volatile. The increase of inflation rate volatility induces higher price dispersions among firms and hence lowers the welfare level.

The welfare loss from exchange rate stabilization is sensitive to the central bank's stance on the inflation rate. Intuitively, when the central bank takes a strong stance against the inflation rate, the inflation instability caused by exchange rate stabilization will be offset by the inflation stabilization term Ξ_π in the policy rule. However, with the decrease of Ξ_π, exchange rate stabilization becomes more harmful. Our results suggest no exchange rate stabilization in this case.

We also consider the case in which policymakers cooperate to maximize the sum of utilities in both countries. We assume the central planner gives equal weights to the Home and Foreign countries. The optimal monetary policy coincides with that in the Nash equilibrium.[30] This result suggests that the welfare gain from international monetary cooperation is small, if there is any. This result is consistent with Obstfeld and Rogoff's (2002) finding that the lack of international coordination in setting monetary policy rules may not be an important issue. In this paper, we extend their results to a DSGE model.

As we have mentioned, the gain from exchange rate stabilization is small when the similarity of final consumption bundles is low. Intuitively, exchange rate stabilization should become more desirable when home bias declines. Table 5 shows the results when the home bias parameter α is set to the lower level of 0.6. Our results suggest a much stronger stance against exchange rate fluctuations: the annual interest rate should increase 5.6 percentage points in face of 10% real depreciation. When home bias decreases, there are two effects on real exchange rate stabilization: 1) The final consumption bundles become more similar, so we can gain more from real exchange rate stabilization. 2) Our model

[30] We also tried grid searches at smaller step size (0.005 for Ξ_s and Ξ_s^*, and 0.02 for Ξ_π and X_π^*). The Nash equilibrium still coincides with international cooperation.

Table 4
Exchange rate stabilization in benchmark model.

Ξ_s	$\Xi_\pi = 3.0$		$\Xi_\pi = 1.1$	
	Welfare Level	Welfare Loss (%)[a]	Welfare Level	Welfare Loss (%)[a]
0.00	−53.8608	0.0007	**−54.5964**	**0.0000**
0.01	**−53.8601**	**0.0000**	−54.6144	0.0180
0.02	−53.8609	0.0008	−54.7097	0.1132
0.03	−53.8632	0.0031	−54.8449	0.2481
0.04	−53.8667	0.0067	−54.9985	0.4013
0.05	−53.8715	0.0114	−55.1587	0.5607
0.06	−53.8773	0.0172	−55.3186	0.7196
0.07	−53.8841	0.0240	−55.4745	0.8742
0.08	−53.8918	0.0317	−55.6244	1.0227
0.09	−53.9004	0.0403	−55.7674	1.1642
0.10	−53.9097	0.0496	−55.9031	1.2982

Note: Monetary policy takes the form of $i_t = i + \Xi_\pi \log(\pi_t/\pi) + \Xi_s \log(Q_t/Q)$. The optimal monetary policy is displayed in bold.
[a] Welfare loss is measured by the percentage consumption loss.

predicts a more stable real exchange rate for given exogenous shocks in the case of less home bias. Therefore, central banks do not have to adjust the interest rate as much as before to stabilize the real exchange rate, which reduces the cost of real exchange rate stabilization.

However, we should be cautious in interpreting this result as support for exchange rate stabilization. We have noticed that in the above case with low home bias, volatility of the real exchange rate relative to volatility of GDP is too small to match the data. Unlike in Devereux and Engel (2002), we cannot increase the relative volatility simply by increasing the UIP shock. When we increase the UIP shock, both the real exchange rate and GDP become more volatile. As a result, the relative volatility of the real exchange rate to that of GDP becomes pretty stable at around 1.4 (see Panel A of Table 6), even with big increases in the UIP shock. Intuitively, we have assumed LOP for the intermediate goods market. So any exchange rate shock will pass through to the prices of exports immediately. If the foreign market makes up a big portion of the total output, as in the case with little home bias, increasing the UIP shock drives up the volatility of GDP when we use it to pump up the volatility of the real exchange rate. This result is contradictory to the well-documented exchange rate disconnect puzzle.

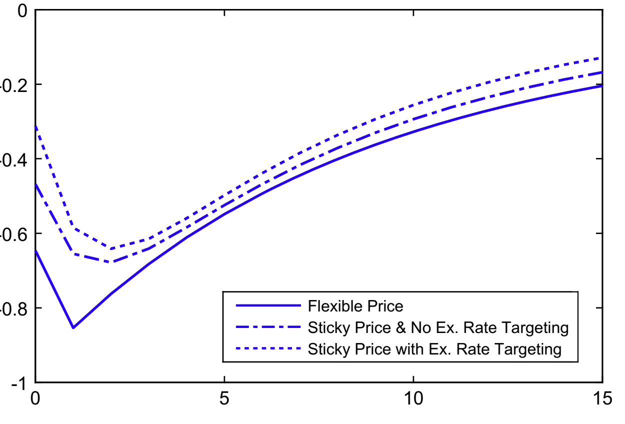

Fig. 2. Impulse Response Functions of the Terms of Trade to Technology Shock.
Note: –In the sticky-price model with no exchange rate targeting, the monetary policy $i_t = i + 1.5 \log(\pi_t/\pi)$.
–In the sticky-price with exchange rate targeting, the monetary policy is $i_t = i + 1.5 \log(\pi_t/\pi) + 0.1 \log(Q_t/Q)$

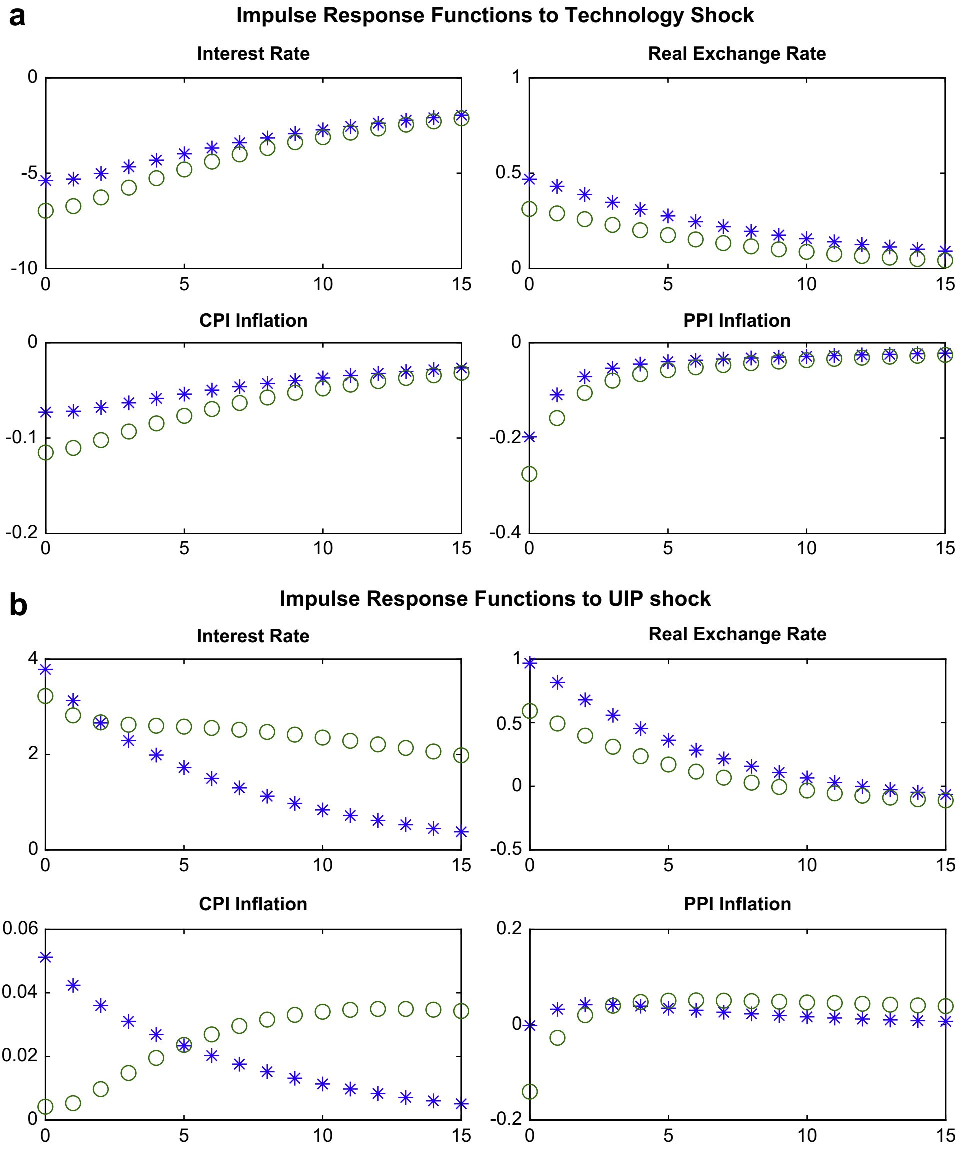

Fig. 3. IRFs with and without Exchange Rate Stabilization.
Note: –The plots with asterisks are results from the benchmark model without exchange rate stabilization ($\Xi_\pi = 1.5$ and $\Xi_s = 0$).
–The plots with circles are results from the benchmark model with exchange rate stabilization ($\Xi_\pi = 1.5$ and $\Xi_s = 0.1$)

We also notice that the welfare gain of directly reacting to the exchange rate is very small in both cases. As we have mentioned, it is not surprising to find negligible gains in our benchmark model, since real exchange rate fluctuations do not imply significant price distortions across borders. In the case with less home bias, the welfare gain is higher but is still at only about 0.01% of consumption. There are two possible reasons for this case. Exchange rate stabilization helps eliminate price distortions across countries, and therefore facilitates international risk sharing. However, the gain from international risk sharing is generally small, especially in a production economy with capital

Table 5
Exchange rate stabilization in the model with less home bias ($\alpha = 0.6$).

$\Xi_\pi = 3.0$			$\Xi_\pi = 1.1$		
Ξ_s	Welfare Level	Welfare Loss (%)[a]	Ξ_s	Welfare Level	Welfare Loss (%)[a]
0.00	−53.9726	0.0115	**0.00**	**−54.5214**	**0.0000**
0.02	−53.9689	0.0078	0.01	−54.5502	0.0288
0.04	−53.9660	0.0050	0.02	−54.5856	0.0641
0.06	−53.9639	0.0029	0.03	−54.6294	0.1079
0.08	−53.9625	0.0014	0.04	−54.6840	0.1624
0.10	−53.9616	0.0005	0.05	−54.7526	0.2309
0.12	−53.9611	0.0001	0.06	−54.8400	0.3180
0.14	**−53.9611**	**0.0000**	0.07	−54.9526	0.4303
0.16	−53.9614	0.0003	0.08	−55.1003	0.5772
0.18	−53.9620	0.0009	0.09	−55.2979	0.7734
0.20	−53.9629	0.0018	0.10	−55.3690	0.8440

Note: Monetary policy takes the form of $i_t = i + \Xi_\pi \log(\pi_t/\pi) + \Xi_s \log(Q_t/Q)$. The optimal monetary policy is displayed in bold.
[a] Welfare loss is measured by the percentage consumption loss.

accumulation like ours. For example, Kim and Kim (2003) find the gain is between 0.005% and 0.02%.[31] This result may also be caused by the unrealistically small real exchange rate volatility in the case with less home bias.

4.3. *Home bias and exchange rate disconnect*

In this section, we provide empirical support for our model predictions.

4.3.1. *Model prediction*

We have shown in Table 2 that our benchmark model can successfully replicate exchange rate volatility. Our model also exhibits exchange rate disconnect when home bias is high. In Panel B of Table 6, we show how the standard deviations of the real exchange rate and GDP change with the UIP shock. With the increase of the UIP shock, the standard deviation of the real exchange rate becomes about 10 times larger than before, while the standard deviation of GDP increases only by about 30 percent. This property is consistent with the empirical finding of Baxter and Stockman (1989): the behavior of macroeconomic aggregates did not significantly change when exchange rates became much more volatile.

Panel C of Table 6 shows that the volatility of the real exchange rate relative to the volatility of GDP increases with the extent of home bias in our model. For a given monetary policy (left panel of Panel C), a higher home bias has two effects on the relative volatility: the real exchange rate is more volatile, since the final consumption goods are more different across countries; at the same time, GDP is less volatile, in that the exchange rate shock has impacts on a smaller portion of the total output. As a result, the relative volatility increases with home bias at a faster rate than does the standard deviation of the real exchange rate as shown in Panel C. If monetary policy is re-optimized under each home bias level (right panel of Panel C), the positive relation between the extent of home bias and the volatility of the real exchange rate (relative to the volatility of GDP) is strengthened, because more open (less home biased) countries put more weight on exchange rate stabilization in our model.[32]

Hau (2002) finds in the data that real exchange rate volatility is negatively correlated with the openness of a country (or positively correlated with home bias). In our model, we predict that a stronger relation exists between the openness and **the ratio** of real exchange rate volatility to GDP volatility. It is of interest to find out if our prediction is consistent with the data.

[31] Tesar (1995) reports similar results.
[32] We thank an anonymous referee for suggesting we explore this issue.

Table 6
Exchange rate disconnect.

Panel A: No exchange rate disconnect if home bias is low ($\alpha = 0.6$).										
UIP Shock (σ_μ, %)	0.00	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	
UIP Shock (σ_η, %)	0.00	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	
SD of GDP (%)	1.12	1.20	1.29	1.44	1.62	1.85	2.13	2.38	2.61	
SD of RER (%)	0.21	0.54	1.02	1.52	1.97	2.46	2.97	3.46	3.95	
SD of RER/SD of GDP	0.19	0.45	0.80	1.06	1.22	1.33	1.39	1.46	1.51	
Panel B: Exchange Rate Disconnect in Benchmark ($\alpha = 0.85$)										
UIP Shock (σ_μ, %)	0.00	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	
UIP Shock (σ_η, %)	0.00	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	
SD of GDP (%)	1.19	1.18	1.23	1.27	1.29	1.37	1.45	1.52	1.60	
SD of RER (%)	0.76	1.09	1.78	2.60	3.42	4.11	4.90	5.76	6.52	
SD of RER/SD of GDP	0.64	0.92	1.44	2.05	2.66	3.00	3.38	3.78	4.08	
Panel C: Relative Volatility Changes with Home Bias										
	Constant Monetary Policy					Optimal Monetary Policy				
Home Bias (α)	0.50	0.60	0.70	0.80	0.90	0.50	0.60	0.70	0.80	0.90
SD of RER (%)	1.94	2.41	3.29	4.59	6.23	0.47	1.94	3.11	4.43	6.12
SD of RER/SD of GDP	0.73	1.09	1.81	2.95	4.43	0.20	0.95	1.74	2.90	4.50

Note:
- Model statistics are the average of 100 simulations. All artificial data from simulations are logged and H-P filtered with a smoothing parameter of 1600.
- Home bias parameter (α) is set to 0.6 in Panel A and 0.85 in Panel B (Benchmark).
- In Panels A and B, all other parameters are fixed to their benchmark values while the volatility of UIP shocks increases. Monetary policy (Taylor rule) is fixed at $i_t = i + 1.5 \log(\pi_t/\pi)$.
- Panel C: All other parameters are fixed to their benchmark values while home bias varies. Under Constant Monetary Policy, the monetary policy is fixed at $i_t = i + 1.5 \log(\pi_t/\pi)$. Monetary policy ($i_t = i + \Xi_\pi \log(\pi_t/\pi) + \Xi_s \log(Q_t/Q)$) is re-optimized for each home bias level under Optimal Monetary Policy.

4.3.2. *Empirical support*

We use the following data of OECD countries from International Financial Statistics (IFS): (1) real effective exchange rates, (2) imports and exports of goods and services and (3) GDP per capita.[33] Following Hau (2002), we use data for the period between 1980 and 1998, but we choose to use quarterly data, hoping to find a strong relation between relative real exchange rate volatility and openness, even with relatively high frequency data.

We follow the same method as Hau (2002) in calculating the openness and the volatility of the real exchange rate. The openness at period t is measured by the ratio of average imports and exports to GDP. The openness of country i is the average openness during our sampling period.[34] The volatility of the real exchange rate is measured by the variation of the percentage change of the exchange rate as in equation (25):

$$vol_s^i = \left[\frac{1}{T} \sum_{t=1}^{T} \left(\frac{s_{t+1} - s_t}{s_t} \right)^2 \right]^{\frac{1}{2}}, \tag{25}$$

where s is the real effective exchange rate of country i. To obtain the volatility of GDP per capita, we first detrend the logarithm of GDP per capita with the HP filter and then calculate the standard deviation of the detrended data for each country. Our sample includes 22 countries that are members of the OECD during the sample period.[35] Fig. 4 shows the scatter diagrams of Real Effective Exchange Rate (REER)

[33] GDP per capita is calculated as GDP divided by the total population in each country.

[34] There is no obvious trend for openness in most countries, and our results do not change after we take out the countries in which openness seems to have a significant trend during our sampling period. These countries include Canada, Ireland, Japan and Spain.

[35] We exclude Greece and Luxembourg due to unavailability of data.

volatility and REER volatility relative to GDP volatility against openness. Both variables display some negative correlation with openness. However, the relation between the relative volatility of REER and openness seems stronger.[36]

Table 7 reports our OLS regression results. In Panel A, we regress the volatility of the real exchange rate and relative volatility against openness. The coefficients are significant at least at a 10% level in both regressions. As we have mentioned, the negative correlation between real exchange rate volatility and openness may simply reflect the endogeneity of the exchange rate regime: more open economies are more likely to stabilize their exchange rates. In an exercise that is not reported in this paper, we include Reinhart and Rogoff's (2002) classification of exchange rate regimes in our regressions. We do find that the exchange rate policy has significant effects on exchange rate volatility. However, openness remains significant in our regressions.[37] In Panel B, we take logarithms of both the dependent and independent variables. In this case, β is the elasticity of y_i against openness. Let β_1 be the elasticity of REER volatility over openness, and let β_2 be the elasticity of the relative volatility. We find the volatility of the real exchange rate relative to that of GDP responds more to openness than the volatility of the real exchange rate does ($\beta_2 < \beta_1$),[38] which is consistent with our prediction.

Our results are also robust for a larger sample size. We include similar countries as Hau (2002) in our sample with 46 countries.[39] Since for most countries, GDP data are available only at an annual frequency, we expand our sample period to include data between 1975 and 1998 in order to have more observations for each country. The results of the sample with 46 countries are also reported in Table 7. The findings are very similar to those from the OECD data.[40]

4.4. Robustness analysis

In this section, we test whether our results are robust under different model specifications.

4.4.1. Habit persistence

Bergin et al. (2007) find that habit persistence has important impacts on welfare loss caused by exchange rate variations. They report a welfare loss of 4.554% consumption in the case of habit persistence in contrast to 0.144% otherwise. Will this higher welfare loss provide grounds for exchange rate stabilization?

We modify our utility function in equation (12) to accommodate habit persistence:

$$u_t(C_t, 1-L_t) = \frac{(C_t - \zeta C_{t-1})^{1-\sigma}}{1-\sigma} - \rho L_t. \tag{26}$$

In this new period utility function, households try to smooth a weighted average of current consumption and the change of consumption. ζ is the weight put on the change of consumption. Under this preference, households are more sensitive to exogenous risks. This form of the utility function has been widely used in literature explaining the equity premium puzzle.

We calibrate ζ as 0.8, which is found to be a reasonable value by Deaton (1987) and Constantinides (1990) to explain aggregate consumption smoothness and the equity premium puzzle. The real

[36] Belgium and Ireland seem to be two outliers in Fig. 4. Our results reported below are robust even after we remove these two countries from the sample.

[37] Results are available upon request.

[38] The null hypothesis that $\beta_2 - \beta_1 \geq 0$ is rejected at 10% level.

[39] These countries include Algeria, Australia, Austria, Bahrain, Belgium, Burundi, Canada, Chile, Colombia, Cyprus, Denmark, Dominican Republic, Fiji, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Lesotho, Malawi, Malaysia, Malta, Morocco, Netherlands, New Zealand, Norway, Pakistan, Papua New Guinea, Paraguay, Philippines, Poland, Portugal, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Trinidad and Tobago, Tunisia, United Kingdom, United States, Uruguay, and Venezuela. Compared to Hau (2002), Ecuador, Greece, and Luxemburg are excluded from our sample due to unavailability of data. We also include Iceland, which is not in Hau's sample.

[40] We marginally missed the 10% significant level for the null hypothesis that $\beta_2 - \beta_1 \geq 0$ in this sample, but the point estimates are still consistent with our model prediction. We assume a constant exchange rate shock across countries in our model prediction. This assumption is more likely to be violated when we include developing countries into our sample.

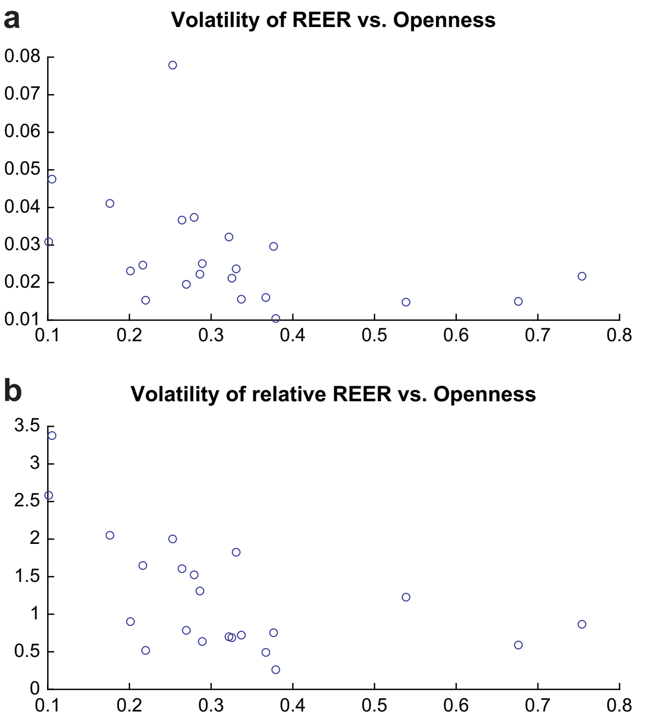

Fig. 4. Scatter Diagram of REER and Relative REER Volatility against Openness.

business cycle statistics are reported in Table 2. Table 8 shows the welfare level and loss under habit persistence preference. We find this change does not affect our results: the interest rate should not directly react to the exchange rate. Households are more risk averse with habit persistence, so welfare loss is higher for given exchange rate variation. However, the cost of exchange rate stabilization is also higher because the welfare loss from inflation instability is also higher under habit persistence. Our results show the latter still wins in the competition.

Table 7
OLS regression results.

Panel A: $y_i = \alpha + \beta openness_i + \epsilon_i$				
$y_i = REER\ vol$			$y_i = REER\ vol/GDP\ vol$	
	OECD	46 Countries	OECD	46 Countries
β	−0.037 (0.019)*	−0.054 (0.030)*	−2.550 (0.928)**	−0.754 (0.327)**
R-squared	0.163	0.068	0.274	0.108
# of obs.	22	46	22	46
Panel B: $Log(y_i) = \alpha + \beta Log(openness_i) + \epsilon_i$				
	$y_i = REER\ vol$		$y_i = REER\ vol/GDP\ vol$	
	OECD	46 Countries	OECD	46 Countries
β	−0.481 (0.182)**	−0.311 (0.159)*	−0.754 (0.233)***	−0.525 (0.185)***
R-squared	0.258	0.080	0.344	0.154
# of obs.	22	46	22	46

Note: Standard deviations are reported in parentheses.
* – 10% significant, ** – 5% significant, *** – 1% significant.

Table 8
Exchange rate stabilization with habit persistence.

Ξ_s	$\Xi_\pi = 3.0$		$\Xi_\pi = 1.1$	
	Welfare level	Welfare loss (%)[a]	Welfare level	Welfare loss (%)[a]
0.00	**−287.5157**	**0.0000**	**−288.2299**	**0.0000**
0.01	−287.5190	0.0033	−288.2644	0.0345
0.02	−287.5239	0.0082	−288.3717	0.1417
0.03	−287.5304	0.0147	−288.5160	0.2857
0.04	−287.5382	0.0225	−288.6769	0.4460
0.05	−287.5473	0.0316	−288.8429	0.6112
0.06	−287.5575	0.0418	−289.0078	0.7749
0.07	−287.5688	0.0531	−289.1679	0.9336
0.08	−287.5810	0.0653	−289.3215	1.0857
0.09	−287.5941	0.0784	−289.4678	1.2302
0.10	−287.6080	0.0922	−289.6064	1.3671

– Monetary policy takes the form of $i_t = i + \Xi_\pi log(\pi_t/\pi) + \Xi_s log(Q_t/Q)$. The optimal monetary policy is displayed in bold.

[a] Welfare loss is measured by the percentage consumption loss.

4.4.2. Exchange rate disconnect and monetary policy

In this section, we check the extent to which our explanation of the exchange rate disconnect puzzle depends on the format of interest rate rules. We are particularly interested in whether the inclusion of exchange rate stabilization in the policy rule will change our results.

Table 9 reports how the volatility of the real exchange rate and GDP changes with the UIP shock if central banks set the exchange rate policy parameter Ξ_s at 0.1, 0.2, and 0.5. When Ξ_s equals 0.1 or less, the exchange rate disconnect still exists in our model. With the increase of the UIP shock, the standard deviation of GDP increases less than 15%, while the real exchange rate is over 7 times more volatile than before.

However, when the central bank puts more weight on exchange rate stabilization, the UIP shock exerts greater impact on the standard deviation of GDP. Intuitively, with a stronger stance against exchange rate fluctuations, the central bank moves the interest rate more to fight against exchange rate shocks. Therefore, the financial market shock becomes more influential for real variables. With the increase of Ξ_s, we find in Panel A that the GDP becomes more volatile, while the real exchange rate becomes less volatile.[41] As a result, at the volatility of GDP observed in the data, the volatility of the real exchange rate relative to that of GDP is much smaller than what we have seen in the data. For example, when Ξ_s is equal to 0.5, the ratio of exchange rate volatility to GDP volatility is only 0.73 if the standard deviation of GDP is equal to 1.73%.

In Panel B of Table 9, we find that the relation between home bias and the volatility of the exchange rate relative to the volatility of GDP is weaker when central banks stabilize the exchange rate. In particular, the relative volatility decreases with home bias when α is greater than 0.8, and Ξ_s is equal to or greater than 0.2. However, if central banks choose Ξ_s optimally for each home bias level, there exists a strong negative relation between the relative volatility and home bias.

To sum up, our explanation of exchange rate volatility and the exchange rate disconnect puzzle is sensitive to the assumption made about monetary policy. However, in empirical studies, the estimate

[41] We find the standard deviation of GDP decreases with Ξ_s in the first column of data. There is no financial market shock in this column. The real exchange rate volatility is caused by technology shocks. In this case, exchange rate and GDP stabilizations are consistent.

Table 9
GDP and exchange rate volatility under exchange rate targeting.

Panel A: Standard Deviation Changes with UIP Shock										
UIP Shock (σ_μ, %)		0.00	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40
UIP Shock (σ_η, %)		0.00	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20
SD of GDP (%)	$\Xi_s = 0.1$	1.09	1.13	1.10	1.08	1.13	1.15	1.14	1.17	1.15
	$\Xi_s = 0.2$	1.08	1.09	1.08	1.10	1.19	1.19	1.29	1.33	1.38
	$\Xi_s = 0.5$	1.02	1.06	1.09	1.19	1.31	1.44	1.55	1.73	1.87
SD of RER (%)	$\Xi_s = 0.1$	0.51	0.69	1.06	1.49	1.93	2.39	2.79	3.32	3.74
	$\Xi_s = 0.2$	0.38	0.50	0.77	1.07	1.38	1.68	2.03	2.40	2.70
	$\Xi_s = 0.5$	0.21	0.27	0.41	0.57	0.73	0.89	1.07	1.25	1.39
SD of RER/SD of GDP	$\Xi_s = 0.1$	0.46	0.61	0.96	1.37	1.71	2.08	2.43	2.83	3.25
	$\Xi_s = 0.2$	0.36	0.46	0.71	0.97	1.16	1.41	1.57	1.80	1.95
	$\Xi_s = 0.5$	0.21	0.26	0.37	0.48	0.56	0.62	0.69	0.73	0.75
Panel B: Relative Volatility Changes with Home Bias										
Home Bias (α)		0.5	0.6	0.7	0.8	0.9				
SD of RER/SD of GDP	$\Xi_s = 0.1$	0.82	1.16	1.79	2.75	2.92				
	$\Xi_s = 0.2$	0.71	1.00	1.54	1.97	1.61				
	$\Xi_s = 0.5$	0.50	0.73	1.07	1.00	0.65				
	Optimal	0.20	0.95	1.74	2.90	4.50				

Note:

- Model statistics are the average of 100 simulations. All artificial data from simulations are logged and H-P filtered with a smoothing parameter of 1600.
- Monetary policy rule is $i_t = i + 1.5log(\pi_t/\pi) + \Xi_s log(Q_t/Q)$ except for the row of Optimal (last row). The row of Optimal shows results under optimal monetary policy.

of Ξ_s is usually well below 0.1. For example, see Clarida, Gali, and Gertler (1998) and Bergin (2004).[42] Judging from empirical relevance, our explanation is still valid under exchange rate stabilization.

5. Conclusion

In this paper, we examine how much the interest rate should react to real exchange rate fluctuations in a two-country DSGE model. In our model the exchange rate volatility is mainly driven by home bias in consumption and the UIP shock to the exchange rate. Our results suggest a very loose stance against exchange rate stabilization. In particular, when the central bank does not take a strong stance against the inflation rate, the inclusion of the exchange rate into the monetary policy rule may induce significant welfare loss. We also find that there is no welfare gain from international monetary cooperation, which extends Obstfeld and Rogoff's (2002) findings to a DSGE model. We show that to match some other important empirical regularities, home bias in consumption is crucial for a model to replicate exchange rate volatility and exchange rate disconnect. We find support in the data for our explanation of the exchange rate disconnect puzzle.

Our policy evaluations are admittedly contingent on the assumption that real exchange rate volatility is mainly driven by home bias and the exchange rate shock. Though home bias in consumption can be justified by a more carefully structured model with high international trade costs, we could explore in more details the microstructure of the UIP shock, and how this shock interacts with the exchange rate policy. Since our results also show the extent of home bias has important implications for exchange rate policy, it is also desirable for future research to test whether the optimal exchange rate policy varies with assumptions that drive exchange rate volatility in the model.

[42] In Clarida et al. (1998), the estimate of the exchange rate stabilization parameter for the annualized interest rate is 0.05. Therefore, the relevant one for our quarterly interest rate is $0.05 \div 4 = 0.0125$. Similarly, the relevant estimate from Bergin (2004) is $0.1128 \div 4 = 0.03$.

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