The Exchange Rate Response Puzzle

Viktoria Hnatkovska
University of British Columbia
hnatkovs@interchange.ubc.ca

Amartya Lahiri
University of British Columbia
alahiri@interchange.ubc.ca

Carlos A.Vegh
University of Maryland and NBER
vegh@econ.bsos.umd.edu

Draft: June 2011

Abstract

Standard models in open economy macroeconomics predict that an expansionary (contractionary) monetary policy will lead to a currency depreciation (appreciation). Models that generate this prediction include the Dornbusch overshooting model, the flexible price model, the liquidity-effect models, as well as models based on the fiscal theory. The data however reveals an interesting twist to this prediction. We study a sample of 25 industrial and 49 developing countries and find that while the nominal exchange rate does indeed tend to appreciate in response to interest rate increases in developed countries, in developing countries the effect tends to be the opposite. In particular, in 84 percent of the developing countries in our sample, the nominal exchange rate depreciates in response to an increase in the interest rate. These findings represent a puzzle for standard models. To rationalize these empirical facts, we develop a model with two liquid assets (cash and demand-deposits) in which the central bank controls the interest rate on the liquid asset. The government finances its budget deficit with inflationary finance and firms must rely on bank credit to finance their working capital. The model generates opposing effects of interest rate changes on the exchange rate – a money demand effect, a fiscal effect and an output effect. We show that a calibrated version of the model rationalizes the opposing responses in developed and developing countries.

JEL Classification: F3, F4

Keywords: Interest rate policy, flexible exchange rates, currency depreciation

1 Introduction

Standard models in open economy macroeconomics predict that an expansionary (contractionary) monetary policy will lead to a currency depreciation (appreciation). In Dornbusch (1976) celebrated overshooting model, for example, an increase in the money supply results in a lower nominal interest rate and a more-than-proportional increase in the nominal exchange rate.[1] The mechanism is simple enough: due to sticky prices, an increase in the nominal money supply is tantamount to an increase in the real money supply. Since output is taken as exogenous, this incipient excess supply of real money balances requires a fall in the nominal interest rate to equilibrate the money market. Given the interest parity condition, the nominal interest rate can only fall if the public expects an increase in the rate of appreciation of the domestic currency. This is only possible if the nominal exchange rate jumps above its long-run level and then falls over time.[2]

While the Dornbush-Obstfeld-Rogoff paradigm (or Mundell-Fleming in modern clothes) is, by far, the most widely used in monetary models of the open economy, four other types of models yield exactly the same prediction: (i) flexible prices model; (ii) liquidity-type models, (iii) models based on the fiscal theory of the price level, and (iv) models with more than one liquid asset.

(i) *Flexible price models:* While not always recognized, frictions are not needed to rationalize the idea of a negative relationship between nominal interest rates and the level of the exchange rate. Consider the simplest possible monetary model with flexible prices and monetary neutrality. A temporary increase in the level of the nominal money supply will lead, on impact, to a fall in the nominal interest rate and an increase in the nominal exchange rate (i.e., a depreciation of the currency).[3] Intuitively, because the increase in the nominal money supply will be reversed in the future, the nominal exchange rises less than proportionately. A fall in the nominal interest rate is thus needed to equilibrate the money market.

(ii) *Liquidity-type models:* In liquidity-type models, an increase in the money supply also leads to a fall in the nominal interest rate because the increased money supply affects disproportionately some particular agents (say, financial firms).[4] The nominal interest rate must fall for such agents

---

[1] Dornbusch (1976) model is, of course, the traditional Mundell-Fleming model with rational expectations. With added microfoundations and other refinements – as reflected in Obstfeld and Rogoff (1995) highly influential version – this model continues to be the workhorse of international finance well into the 21st century.

[2] It is important to note that we are characterizing the stance of monetary policy by looking at changes in the *level* of the money supply, as opposed to changes in the rate of change of the money supply. In the latter case, inflationary expectations will be affected and an expansionary monetary policy will be associated with a higher nominal interest rate.

[3] This result is easy to show using, for instance, the continuous-time version presented in Vegh (2010). Of course, a permanent change in the nominal money supply would not have no effects on the nominal interest rate.

[4] See, for example, Christiano and Eichenbaum (1992) and Grilli and Roubini (1996).

to absorb the excess liquidity. In an open economy, the fall in the nominal interest rate will be associated with a currency depreciation.

(iii) *Fiscal-theory models:* In open-economy models based on the fiscal theory of the price level (see, for example, Auernheimer (2008)), we can think of the nominal interest rate as the policy instrument. As long as the interest-rate elasticity of money demand is less than one (as is typically the case in practice), an increase in the nominal interest rate raises inflation tax revenues. These higher revenues imply that the government can afford to service a higher real stock of government debt, which requires a fall in the price level (i.e., the nominal exchange rate). Conversely, a reduction in the policy interest rate will lead to a currency depreciation.

(iv) *Imperfect asset substitution models:* In models with imperfect substitution between two liquid assets, we can also think of the nominal interest rate on an interest-bearing liquid asset as a policy instrument.[5] An increase in this policy interest rate leads to an increased demand for the liquid asset, which requires a fall in the nominal exchange rate.

There is thus overwhelming theoretical support for the proposition that expansionary monetary policy (i.e., a lower nominal interest rate) should lead to a currency depreciation and vice versa. But what does the empirical evidence say? Most of the empirical studies have looked at industrial countries and conclude that, indeed, this theoretical proposition holds true. The best-known study for the United States is Eichenbaum and Evans (1995) who conclude, using a vector autoregression (VAR) analysis, that a contractionary monetary policy in the United States leads to an appreciation of the dollar relative to all major currencies. In turn, Kim and Roubini (2000) use a structural VAR approach, which takes care of some identification problems that had plagued this literature up to this point, to look at non-US G-7 countries and reach the same conclusion.

Case closed? Not in our view. In fact,we will argue in this paper that, contrary to the case of industrial countries, in developing countries the currency *depreciates* in response to an increase in interest rates. We establish this stylized fact based on a sample of 25 industrial and 49 developing countries. We first ran individual VARs and conclude that, for industrial countries, the domestic currency appreciates in response to an increase in interest rates in 84 percent of the cases. In sharp contrast, for developing countries we show that the nominal exchange rate increases (i.e., the domestic currency depreciates) in response to higher interest rates in 80 percent of the cases. We also illustrate this finding by running panel VARs for industrial and developing countries separately and showing how, in response to an increase in the interest rate, the currency appreciates in industrial

---

[5] See Calvo and Vegh (1995) and Lahiri and Vegh (2003).

countries but depreciates in developing countries. We will refer to these contrasting findings in industrial versus developing countries as the "exchange rate response puzzle."

How can we solve the exchange rate response puzzle? We present a model with two liquid assets (cash and demand-deposits) in which the central bank controls the interest rate on the liquid asset. The government finances its budget deficit with inflationary finance and firms must rely on bank credit to finance their working capital. In this set-up, an increase in the policy-controlled interest rate has three key effects. First, the higher interest rate increases the interest rate on deposits, which therefore raises the demand for deposits. This *money demand effect* tends to appreciate the currency and thus captures the traditional channel in our set-up. Second, by increasing the government's debt service costs, the higher interest rate raises the required seigniorage revenue to finance government spending and, *ceteris paribus*, increases the inflation rate. The rise in inflation increases the opportunity cost of holding liquid assets and tends to depreciate the currency. We will refer to this channel as the *fiscal effect.* Third, the higher domestic interest rate raises the lending rate to firms and thereby reduces employment and output. The output contraction reduces net revenues for the government and hence, increases the required seigniorage revenue to finance the government budget. This *output effect* also tends to depreciate the currency.

The net effect of a higher policy-controlled interest rate on the nominal exchange rate will thus depend on the relative strength of the money demand, fiscal, and output effects. If the money demand effect dominates the other two, then higher interest rates will lead to an appreciation of the currency. Conversely, if the money demand effect is dominated by the other two, the currency will depreciate. Our way of solving the exchange rate response puzzle is to argue – and then show quantitatively – that the fiscal effect and the output effect will be typically larger in developing than in industrial countries. The fiscal effect is larger because, traditionally, developing countries have ran larger fiscal deficits and relied more on inflationary finance (see, for instance, Fischer, Sahay, and Vegh (2002)). The output effect is larger because firms in developing countries need to rely more on bank credit as they are mostly unable to raise funds by issuing commercial paper.

As a final step, we recalibrate our model to developing and developed countries. We show that the model-generated impulse responses of exchange rates reproduce the patterns estimated in the data. We interpret our results as providing a rationalization for the failure of standard empirical methods to detect any systematic relationship between interest rates and exchange rates in the data.

We should note at the outset that our paper is *not* concerned with the relationship between the nominal market interest rate and the rate of currency depreciation. There is a voluminous literature which attempts to document and/or explain this relationship. This literature is concerned with the failure of the uncovered interest parity (UIP) condition (the "forward premium anomaly"). In our model interest parity holds for internationally traded bonds. Hence, we do not shed any new light on the observed deviations from UIP. Instead, our main focus is on the effects of policy-induced changes in nominal interest rates on the *level* of the exchange rate.

The rest of the paper is organized as follows. The next section presents some empirical evidence from a number of developing and developed countries detailing the mixed results on the relationship between interest rates and the exchange rate. Section 3 presents the model while Section 4 discusses how the model is calibrated and solved. Section 5 presents our quantitative results using the calibrated model. The last section concludes.

2 Empirical facts

We start off by empirically documenting our motivating issue through a look at the data. We use a large sample of countries during 1974-2009 period for which monthly data on exchange rates and interest rates was available. Most of the data is from International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF). We use period average official exchange rates whenever available to measure exchange rates. If official rates are not available, we turn to period average market rates, otherwise we use the period average principal exchange rates. Exchange rates are in domestic currency units per U.S. dollar, so that an increase is a depreciation of local currency relative to the US dollar. Our focus is on policy-controlled interest rates, which we measured in the data as the period average T-bill rate. If T-bill rate was not available, we used the discount rate, or the money market rate for that country. In our analysis we focus on the interest rate differential between home and abroad computed as domestic interest rate minus U.S. Federal Funds.

We focus only on those countries and time periods that are characterized by a flexible exchange rate regime. To perform the selection, we rely on the Reinhart and Rogoff (2004) classification of historical exchange rate regimes. We classify a country as having a flexible exchange rate regime if, in a given year, its exchange rate was either (i) within a moving band that is narrower than or equal to +/-2% (i.e., allows for both appreciation and depreciation over time); or (ii) was classified as managed floating; or (iii) was classified as freely floating; or (iv) was classified as freely falling according to Reinhart and Rogoff (2004). These correspond to their fine classification indices of 11, 12, 13, and 14, respectively.[6] We only focus on the post-Bretton Woods period for all countries. High income OECD countries are included in our sample, irrespective of their exchange rate classification by Reinhart and Rogoff (2004). We also require that a country has at least 24 months of data subject to the restrictions above. This gives us a sample of 74 countries, of which 25 are industrial economies and 49 are developing countries.

To illustrate the relationship between interest rate and the exchange rate, we first report some simple time-series correlations. Table 1 summarizes our results. We compute bilateral correlations for both levels and growth rates of exchange rate and interest rate variables, which are shown in the first column. Column "full sample" reports the mean of all the time-series correlations obtained for the countries in our sample. Columns labelled "developed" and "developing" computes the corresponding correlations for the two groups of countries separately. The results show that the correlation between exchange rates and interest rates is low, on average. However, when the sample is broken into developed and developing countries, the correlation is consistently negative in developed countries and consistently positive in developing economies. Recall that negative correlation occurs when an increase in interest rate is accompanied by an appreciation of the exchange rate, as in developed economies. In developing countries, higher interest rates come together with currency depreciation.

Table 1: Correlation between exchange rate and interest rate

	Full sample	Developed	Developing
$corr(\ln E_t, i_t - i_t^{us})$	0.14	-0.09	0.26
$corr(\Delta \ln E, i - i^{us})$	0.01	-0.07	0.05
$corr(\Delta \ln E, \Delta (i - i^{us}))$	0.05	-0.10	0.12

Note: Table reports the mean of the cross-sectional distribution of the correlation coefficient between exchange rate and interest rate (and their various transformations) for our sample of countries.

We next turn to a more formal analysis of the exchange rate-interest rate relationship using unrestricted vector autoregressions (VARs). We estimate VAR on a country-by-country basis for our sample using log exchange rate and interest rate differential between home and abroad. Our VAR specification also includes a constant term in each equation for each country. We use the estimated

---

[6] We also considered the coarse exchange rate classification of Reinhart and Rogoff (2004) to select countries and episodes into the sample. We found the results to be robust with respect to the classification. The coarse classification included countries that were on (i) pre announced crawling band that is wider than or equal to +/-2%; (ii) de facto crawling band that is narrower than or equal to +/-5%; (iii) moving band that is narrower than or equal to +/-2%; (iv) managed floating; (v) freely floating; (vi) freely falling. These correspond to indices 3, 4, and 5 in Reinhart and Rogoff (2004).

VARs to calculate the impulse response of the exchange rate to an orthogonalized one standard deviation innovation in the interest rate differential for each country.[7] Following Eichenbaum and Evans (1995) we compute the impulse responses using the ordering: interest rate differential, exchange rate.[8]

We start by presenting the impulse responses of the nominal exchange rate to interest rate shocks in several selected countries in our sample to illustrate the more general data fact. Figure 1 presents the impulse responses in three developed and three developing countries. The picture reveals some systematic patterns. For the developed countries – Netherlands, Sweden and the UK – there is a significant appreciation of the currency in response to an increase in the interest rate differential. This is the well-known result of Eichenbaum and Evans (1995). For the developing group the effect is the opposite. In Brazil, Mexico and Philippines, a positive innovation in the interest rate differential between home and the United States induces a significant depreciation of the currency.

This differing relationship between interest rates and the exchange rate in developed and developing countries holds more generally in our sample. Table 2 summarizes the results from the individual country VARs. Panel (a) reports the share of developed countries that have experienced appreciations and the share of developing countries that experienced depreciations of their exchange rates following a shock to the interest rate differential between home and abroad. We adopted two approaches to classifying a country as exhibiting appreciation: (i) if the cumulative response of its exchange rate after an interest rate shock is negative on impact (at the end of the 1st month); (ii) if the cumulative response of its exchange rate to an interest rate shock is negative at the end of the 1st quarter (3rd month). Depreciation is defined similarly. The results clearly indicate that an overwhelming majority of industrial economies see their exchange rate appreciating after an interest rate shock both on impact (88% of all industrial countries), as well as three months after (84% of all industrial countries). For developing countries on the other hand, 76% of countries show a depreciation following an interest rate shock in the 1st month, and the proportion increases to 80% if the cutoff is raised to the end of the 3rd month.

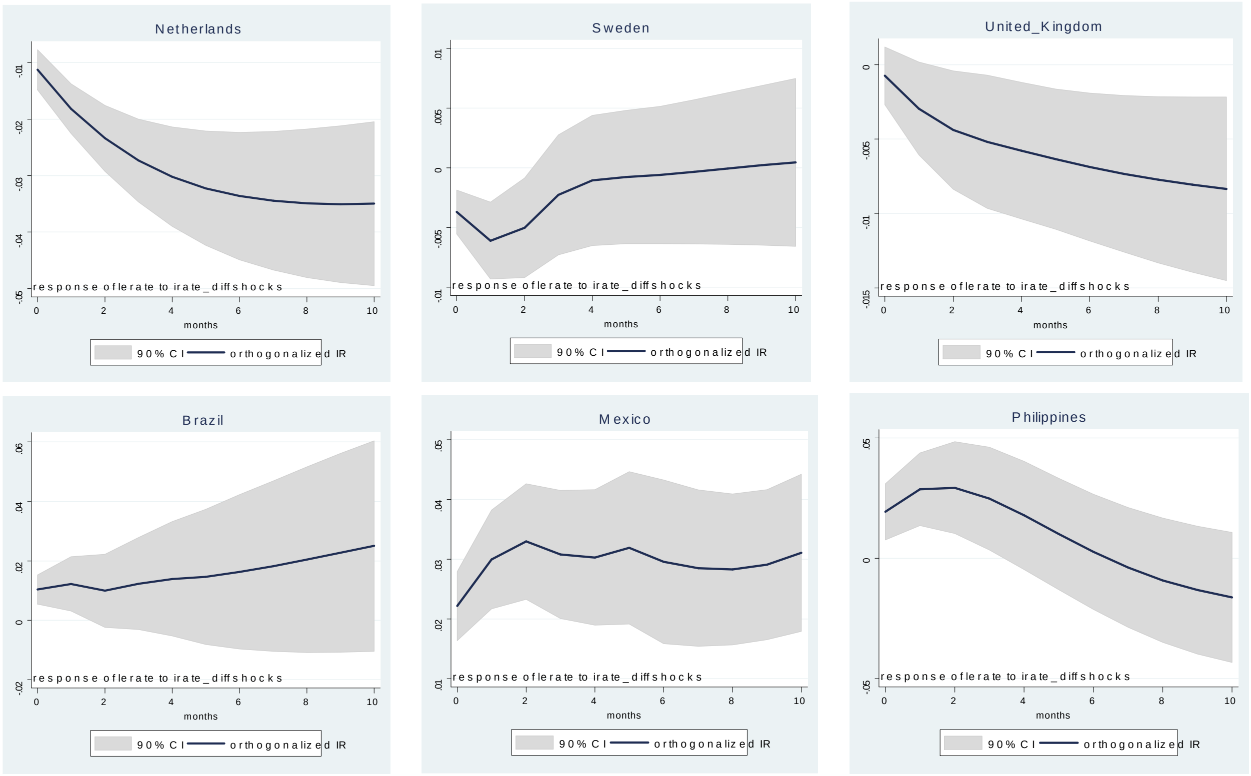
To check the robustness of our findings, we also re-estimate the individual VARs with the first difference of the (log) exchange rate and the interest rate differential. The results of this estimation

---

[7] The Akaike criterion was used to choose the lag length.

[8] Eichenbaum and Evans (1995) also include industrial production and fiscal balance in their analysis. Unfortunately, monthly data for these variables is not available for a large fraction of countries in our sample. So we focus on interest rate differential and exchange rate variables only.

Figure 1: Country VARs: Impulse responses of exchange rate to interest rate shock



and its impulse responses are summarized in panel (b) of Figure 2. Our earlier results remain broadly robust. In particular, we find that among industrial economies, 88% have experienced exchange rate appreciation after interest rate shock on impact, and 56% did so by the end of the first quarter. For the developing countries, the corresponding numbers were 71% and 53%.

Finally, we further confirm our empirical findings by running unrestricted *panel* VARs for industrial and developing countries separately. We start with a simple specification in which both the (log) exchange rate and interest rate variables are included in levels. In the panel VAR analysis country heterogeneity is likely to be important which suggests the presence of unobservable individual country fixed effects. We eliminate country-specific fixed effects and common deterministic trends by de-meaning and linearly de-trending both variables for each country. This within-transformation wipes out fixed effects, but does not eliminate the fact that the lagged dependent variable and the error term are correlated. This could lead the within-estimators to be inconsistent, unless T – the time-series dimension of the data – is large. In our sample, the average number of periods across countries is quite high, equal to 84 months in developing countries and 324 months in developed economies. While this does not eliminate the bias in the estimates, it lends some credibility to

Table 2: Individual country VARs: Summary

	(a). Levels		(b). First-differences	
	1st month	3rd month	1st month	3rd month
Industrial countries: appreciation	88%	84%	88%	56%
Developing countries: depreciation	76%	80%	71%	53%

Note: The table reports the fraction of developed (developing) countries that have experienced an appreciation (depreciation) of their exchange rate following a shock to the interest rate differential. Appreciations and depreciations are defined based on the impact (1st month) and 1st quarter (3 months) impulse responses from a country-by-country VAR analysis.

our level-based results.[9] An alternative transformation that wipes out the fixed effects is the first-difference transformation. We present the results from the panel VARs on the first-differenced data below.

Under either transformation of the data, the correlation between the lagged dependent variable and the remainder error term remains. The standard approach of addressing this correlation is to estimate the model coefficients by an instrumental variable (IV) method. We follow this practice and apply the system generalized method of moments (GMM) of Arellano and Bond (1991) that uses lagged regressors as instruments.

Figure 2 presents the impulse response of exchange rate to interest rate innovations together with the 90 percent confidence bands separately for our sample of industrial countries and developing economies. It is easy to see that in response to an increase in the interest rate, the currency appreciates in industrial countries but depreciates in developing countries.

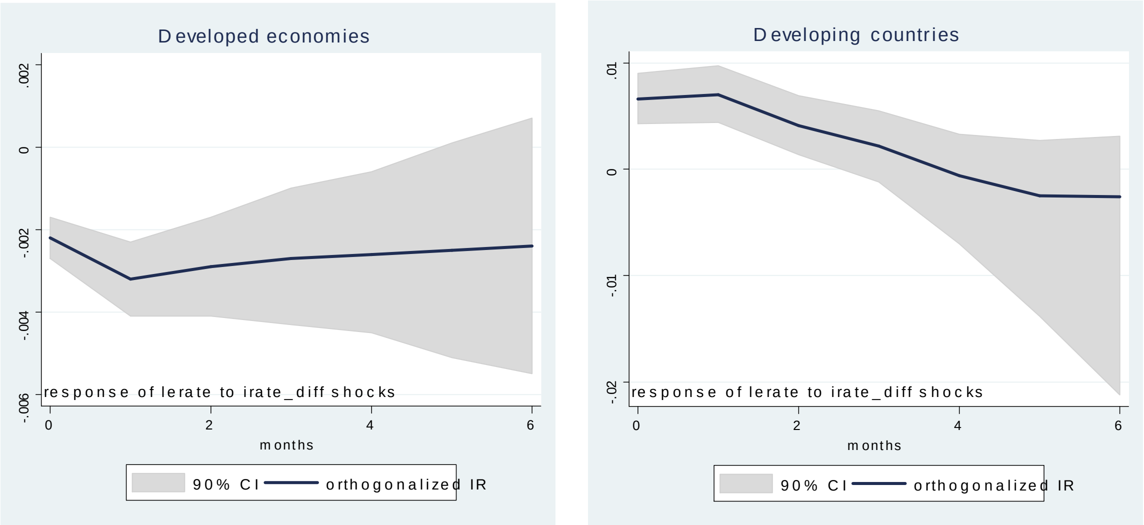
Figure 3 presents the resulting impulse responses from the model estimated in first-differences. As before, the exchange rate appreciates in our sample of developed countries; and depreciates for developing countries, with the key difference being that these responses are more short-lived.

Overall, based on the battery of approaches, the evidence suggests that interest rates and exchange rates are negatively related in industrial countries, consistent with the existing theories. However, the relationship between the two variables is reversed for developing countries, thus challenging the existing theory. We will refer to these contrasting findings in industrial versus

---

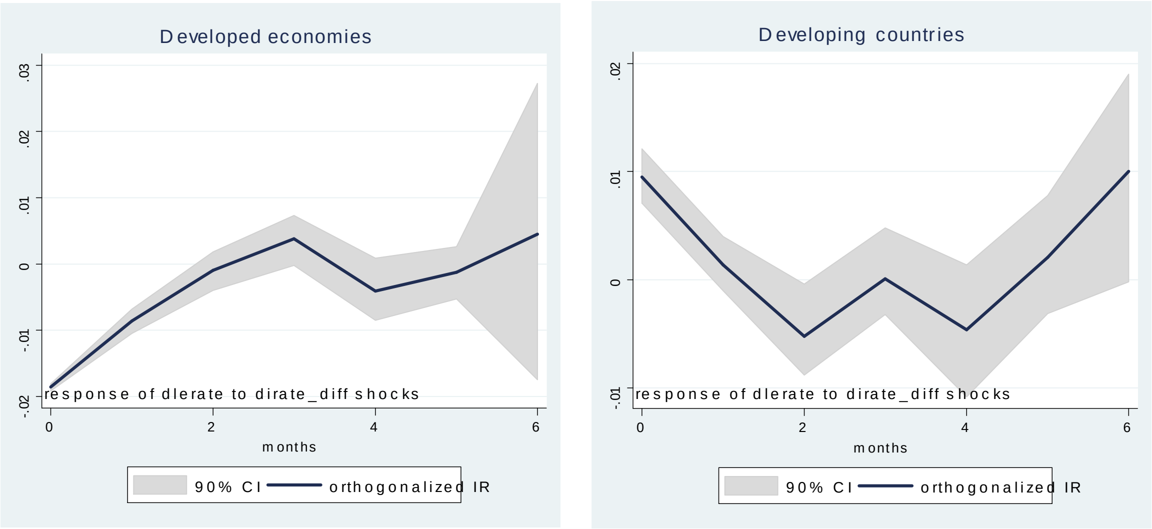
[9] We are interested in obtaining the results from the panel VAR in levels to retain comparability with the individual VAR results we presented earlier. An alternative transformation that preserves the VAR estimation in levels, but does not induce serial correlation, is based on the forward mean differencing (the Helmert procedure) as in Holtz-Eakin, Newey, and Rosen (1988) and Love and Zicchino (2006). We find our results to be robust to this transformation. These results are available from the authors upon request.

Figure 2: Panel VAR: Impulse responses of exchange rate to interest rate shock (levels)



Note: Figures present the impulse responses of the exchange rate to an interest rate differential shock from panel VARs estimated for developed and developing countries. Estimation uses (log) exchange rates and interest rates in leves. Both series are de-meaned and linearly de-trended.

Figure 3: Panel VAR: Impulse responses of exchange rate to interest rate shock (growth rates)



Note: Figures present the impulse responses of the exchange rate to an interest rate differential shock from panel VARs estimated for developed and developing countries. Estimation uses exchange rates and interest rates in growth rates.

developing countries as the “exchange rate response puzzle". In the next section we show that a simple modification of the existing theoretical frameworks can rationalize the puzzle.

3 The model

Consider a representative household model of a small open economy that is perfectly integrated with the rest of the world in both goods and capital markets. The infinitely-lived household receives utility from consuming a (non-storable) good and disutility from supplying labor. The world price of the good in terms of foreign currency is fixed and normalized to unity. Free goods mobility across borders implies that the law of one price applies. The consumer can also trade freely in perfectly competitive world capital markets by buying and selling real bonds which are denominated in terms of the good and pay r units of the good as interest at every point in time.

3.1 Households

Household's lifetime welfare is given by

$$V = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t, x_t\right), \tag{1}$$

where c denotes consumption, x denotes labor supply, and $\beta(> 0)$ is the exogenous and constant rate of time preference. $\mathbb{E}$ denotes expectations. We assume that the period utility function of the representative household is given by

$$U(c,x) = \frac{1}{1-\sigma}\left(c - \zeta x^{\nu}\right)^{1-\sigma}, \qquad \zeta > 0, \quad \nu > 1.$$

Here σ is the intertemporal elasticity of substitution, $\nu - 1$ is the inverse of the elasticity of labor supply with respect to the real wage. These preferences are well-known from the work of Greenwood, Hercowitz, and Huffman (1988), which we will refer to as GHH.[10]

Households use cash, H, and nominal demand deposits, D, for reducing transactions costs. Specifically, the transactions costs technology is given by

$$s_t = v\left(\frac{H_t}{P_t}\right) + \psi\left(\frac{D_t}{P_t}\right), \tag{2}$$

where P is the nominal price of goods in the economy, and s denotes the non-negative transactions costs incurred by the consumer. Let h $(= H/P)$ denote cash and let d $(= D/P)$ denote interest-

---

[10] These preferences have been widely used in the real business cycle literature as they provide a better description of consumption and the trade balance for small open economies than alternative specifications (see, for instance, Correia, Neves, and Rebelo (1995)). As will become clear below, the key analytical simplification introduced by GHH preferences is that there is no wealth effect on labor supply.

bearing demand deposits in real terms. We assume that the transactions technology is strictly convex. In particular, the functions $v(h)$ and $\psi(d)$, defined for $h \in [0,\bar{h}]$, $\bar{h} > 0$, and $d \in [0,\bar{d}]$, $\bar{d} > 0$, respectively, satisfy the following properties:

$$\begin{aligned} v &\geq 0, \;\; v' \leq 0, \;\; v'' > 0, \;\; v'(\bar{h}) = v(\bar{h}) = 0, \\ \psi &\geq 0, \;\; \psi' \leq 0, \;\; \psi'' > 0, \;\; \psi'(\bar{d}) = \psi(\bar{d}) = 0. \end{aligned}$$

Thus, additional cash and demand deposits lower transactions costs but at a decreasing rate. The assumption that $v'(\bar{h}) = \psi'(\bar{d}) = 0$ ensures that the consumer can be satiated with real money balances.

In addition to the two liquid assets, households also hold a real internationally-traded bond, b, and physical capital, k, which they can rent out to firms. The households flow budget constraint in nominal terms is

$$\begin{aligned} & P_t b_{t+1} + D_t + H_t + P_t \left(c_t + I_t + s_t + \kappa_t\right) \\ = \;& P_t \left(Rb_t + w_t x_t + \rho_t k_{t-1} + \tau_t + \Omega_t^f + \Omega_t^b\right) + \left(1 + i_t^d\right) D_{t-1} + H_{t-1}. \end{aligned}$$

Foreign bonds are denominated in terms of the good and pay the gross interest factor $R(= 1 + r)$, which is constant over time. i_t^d denotes the deposit rate contracted in period $t-1$ and paid in period t. w and ρ denote the wage and rental rates. τ denotes lump-sum transfers received from the government. Ω^f and Ω^b represent dividends from firms and banks respectively. κ denotes capital adjustment costs

$$\kappa_t = \kappa\left(I_t, k_{t-1}\right), \quad \kappa_I > 0, \kappa_{II} > 0, \tag{3}$$

i.e., adjustment costs are convex in investment. Lastly,

$$I_t = k_t - (1 - \delta)\, k_{t-1}. \tag{4}$$

In real terms the flow budget constraint facing the representative household is thus given by

$$\begin{aligned} & b_{t+1} + h_t + d_t + c_t + I_t + s_t + \kappa_t \\ = \;& Rb_t + w_t x_t + \rho_t k_{t-1} + \frac{h_{t-1}}{1 + \pi_t} + \left(\frac{1 + i_t^d}{1 + \pi_t}\right) d_{t-1} + \Omega_t^f + \Omega_t^b, \end{aligned} \tag{5}$$

where Ω^f and Ω^b denote dividends received by households from firms and banks, respectively. $1+\pi_t = \frac{P_t}{P_{t-1}}$ denotes the gross rate of inflation between periods $t-1$ and t. It is useful to note that the uncovered interest parity condition dictates that expected returns from investing in domestic nominal bonds and international real bonds must be equalized. Hence, recalling that $P_{t+1}/P_t = 1+\pi_{t+1}$,

$$1+i_{t+1} = R\mathbb{E}_t\left(1+\pi_{t+1}\right).$$

Households maximize their lifetime welfare equation (1) subject to equations (2), (3), (4) and (5).

3.2 Firms

The representative firm in this economy produces the perishable good using a constant returns to scale technology over capital and labor

$$y_t = F\left(k_{t-1}, A_t l_t\right) = A_t k_{t-1}^{\alpha} l_t^{1-\alpha}, \tag{6}$$

with $\alpha > 0$, and A_t denoting the current state of productivity which is stochastic. l is labor demand. At the beginning of the period, firms observe shocks for the period and then make production plans. They rent capital and labor. However, a fraction ϕ of the total wage bill needs to be paid upfront to workers. Since output is only realized at the end of the period, firms finance this payment through loans from banks. The loan amount along with the interest is paid back to banks next period.[11] Formally, this constraint is given by

$$N_t = \phi P_t w_t l_t, \quad \phi > 0, \tag{7}$$

where N denotes the nominal value of bank loans. The assumption that firms must use bank credit to pay the wage bill is needed to generate a demand for bank loans.

The firm's flow constraint in nominal terms is given by

$$P_t b_{t+1}^f - N_t = P_t\left(Rb_t^f + y_t - w_t l_t - \rho_t k_{t-1} - \Omega_t^f\right) - \left(1+i_t^l\right) N_{t-1},$$

---

[11] Alternatively, we could assume that bank credit is an input in the production function, in which case the derived demand for credit would be interest rate elastic. This would considerably complicate the model without adding any additional insights.

where i^l is the lending rate charged by bank for their loans and Ω^f denotes dividends paid out by the firms to their shareholders. b^f denotes foreign bonds held by firms which pay the going world interest factor R. In real terms the flow constraint reduces to

$$b^f_{t+1} - n_t = Rb^f_t - \left(\frac{1+i^l_t}{1+\pi_t}\right) n_{t-1} + y_t - w_t l_t - \rho_t k_{t-1} - \Omega^f_t.$$

Define

$$a^f_{t+1} \equiv b^f_{t+1} - \frac{\left(1+i^l_{t+1}\right)}{R\left(1+\pi_{t+1}\right)} n_t.$$

Substituting this expression together with the credit-in-advance constraint into the firm's flow constraint in real terms gives

$$a^f_{t+1} + \Omega^f_t = Ra^f_t + y_t - \rho_t k_{t-1} - w_t l_t \left[1 + \phi \left\{\frac{1+i^l_{t+1} - R\left(1+\pi_{t+1}\right)}{R\left(1+\pi_{t+1}\right)}\right\}\right]. \tag{8}$$

Note that $\phi\left\{\frac{1+i^l_{t+1}-R(1+\pi_{t+1})}{R(1+\pi_{t+1})}\right\} w_t l_t = \left\{\frac{1+i^l_{t+1}-R(1+\pi_{t+1})}{R(1+\pi_{t+1})}\right\} n_t$ is the additional resource cost that is incurred by firms due to the credit-in-advance constraint.[12]

The firm chooses a path of l and k to maximize the present discounted value of dividends subject to equations (6), (7) and (8). Given that households own the firms, this formulation is equivalent to the firm using the household's stochastic discount factor to optimize. The first order conditions for this problem are given by two usual conditions and an Euler equation which is identical to the household's Euler equation. The two usual conditions are standard – the firm equates the marginal product of the factor to its marginal cost. In the case of labor the cost includes the cost of credit. This is proportional to the difference between the nominal lending rate and the nominal interest rate.

3.3 Banks

The banking sector is assumed to be perfectly competitive. The representative bank holds foreign real debt, d^b, accepts deposits from consumers and lends to both firms, N, and the government in the form of domestic government bonds, Z.[13] It also holds required cash reserves, θD, where $\theta > 0$

---

[12] We should note that the credit-in-advance constraint given by equation (7) holds as an equality only along paths where the lending spread $1 + i^l - R\left(1+\pi\right)$ is strictly positive. We will assume that if the lending spread is zero, this constraint also holds with equality.

[13] Commercial bank lending to governments is particularly common in developing countries. Government debt is held not only as compulsory (and remunerated) reserve requirements but also voluntarily due to the lack of profitable investment opportunities in crisis-prone countries. This phenomenon was so pervasive in some Latin American

is the reserve-requirement ratio imposed on the representative bank by the central bank. Banks face a cost q (in real terms) of managing their portfolio of foreign assets. Moreover, we assume that banks also face a constant proportional cost ϕ^n per unit of loans to firms. This is intended to capture the fact that domestic loans to private firms are potentially special as banks need to spend additional resources in monitoring loans to private firms.[14] The nominal flow constraint for the bank is

$$\begin{aligned} N_t + Z_t - (1-\theta) D_t + P_t q_t - P_t d^b_{t+1} &= \left(1 + i^l_t - \phi^n\right) N_{t-1} + \left(1 + i^g_t\right) Z_{t-1} \\ &\quad - \left(1 + i^d_t\right) D_{t-1} + \theta D_{t-1} - P_t R d^b_t - P_t \Omega^b_t, \end{aligned} \tag{9}$$

where i^g is the interest rate on government bonds. We assume that banking costs are a convex function of the foreign debt held by the bank:

$$q_t = q\left(d^b_{t+1}\right), \qquad q' > 0,\ q'' > 0,$$

where q' denotes the derivative of the function q with respect to its argument, while q'' denotes the second derivative. The costly banking assumption is needed to break the interest parity condition between domestic and foreign bonds. Throughout the paper we assume that the banking cost technology is given by the quadratic function:

$$q_t = \frac{\gamma}{2}\left(d^b_{t+1} - \bar{d}^b\right)^2, \tag{10}$$

where $\gamma > 0$ and $\bar{d}^b$ are constant parameters.[15]

Deflating the nominal flow constraint by the price level gives the bank's flow constraint in real terms:

$$\Omega^b_t = \left[\frac{R(1+\pi_t) - 1}{1+\pi_t}\right]\left[(1-\theta)\, d_{t-1} - n_{t-1} - z_{t-1}\right] + \frac{i^l_t - \phi^n}{1+\pi_t} n_{t-1} + \frac{i^g_t}{1+\pi_t} z_{t-1} - \frac{i^d_t}{1+\pi_t} d_{t-1} - q_t, \tag{11}$$

---

countries during the 1980's that Rodriguez (1991) aptly refers to such governments as "borrowers of first resort". For evidence, see Rodriguez (1991) and Druck and Garibaldi (2000).

[14] We should note that this cost ϕ^n is needed solely for numerical reasons since, as will become clear below, it gives us a bigger range of policy-controlled interest rates to experiment with. Qualitatively, all our results would go through with $\phi^n = 0$.

[15] Similar treatment of banking costs of managing assets and liabilities can be found in Diaz-Gimenez, Prescott, Fitzgerald, and Alvarez (1992) and Edwards and Vegh (1997). This approach to breaking the interest parity condition is similar in spirit to Calvo and Vegh (1995).

where we have used the bank's balance sheet identity: $P_t d^b_{t+1} = N_t + Z_t - (1-\theta) D_t$. Note that this is equivalent to setting the bank's net worth to zero at all times. Also, the quadratic specification for banking costs along with the zero net worth assumption implies that these banking costs can also be reinterpreted as a cost of managing the portfolio of net domestic assets since $d^b_{t+1} = \frac{N_t+Z_t-(1-\theta)D_t}{P_t}$.

The representative bank chooses sequences of N, Z, and D to maximize the present discounted value of profits subject to equations (9) taking as given the paths for interest rates i^l, i^d, i^g, i, and the value of θ and ϕ^n. We assume that the bank uses the household's stochastic discount factor to value its profits. Note that i^g_{t+1}, i^l_{t+1} and i^d_{t+1} are all part of the information set of the household at time t.

The bank optimality conditions imply that we must have

$$\begin{aligned} i^l_{t+1} &= i^g_{t+1} + \phi^n, & (12) \\ i^d_{t+1} &= (1-\theta)\, i^g_{t+1}. & (13) \end{aligned}$$

These conditions are intuitive. Loans to firms and loans to the government are perfect substitutes from the perspective of commercial banks up to the constant extra marginal cost ϕ^n of monitoring loans to private firms. Hence, equation (12) says that the interest rate charged by banks on private loans should equal the rate on loans to the government plus ϕ^n. For every unit of deposits held the representative bank has to pay i^d as interest. The bank can earn i^g by lending out the deposit. However, it has to retain a fraction θ of deposits as required reserves. Hence, equation (13) shows that at an optimum the deposit rate must equal the interest on government bonds net of the resource cost of holding required reserves. We should note that the parameter ϕ^n plays no role in the theoretical results that we derive below. Hence, in our main propositions we set $\phi^n = 0$. This parameter is useful in the quantitative sections later where it allows us to calibrate some key interest rate spreads.

It is instructive to note that as the marginal banking costs becomes larger the bank will choose to keep its holdings of foreign assets closer to $\bar{d}^b$. This can be checked from the bank first order conditions; all of them imply that $\lim_{\gamma\to\infty} d^b_{t+1} = \bar{d}^b$. Hence, in the limit as banking costs becomes prohibitively large, the bank will choose to maintain a constant portfolio of external assets or liabilities.

3.4 Government

The government issues high powered money, M, and domestic bonds, Z, makes lump-sum transfers, τ, to the public, and sets the reserve requirement ratio, θ, on deposits. Domestic bonds are interest bearing and pay i^g per unit. Since we are focusing on flexible exchange rates, we assume with no loss of generality that the central bank's holdings of international reserves are zero. We assume that the government's transfers to the private sector are fixed exogenously at $\bar{\tau}$ for all t. Hence, the consolidated government's nominal flow constraint is

$$P_t\bar{\tau} + (1 + i_t^g)\, Z_{t-1} = M_t - M_{t-1} + Z_t.$$

As indicated by the left-hand-side of this expression, total expenditures consist of lump-sum transfers, debt redemption and debt service. These expenditures may be financed by issuing either high powered money or bonds. In real terms the government's flow constraint reduces to

$$\bar{\tau} + \frac{1 + i_t^g}{1 + \pi_t} z_{t-1} = m_t + z_t - \frac{1}{1 + \pi_t} m_{t-1}. \tag{14}$$

Lastly, the rate of growth of the nominal money supply is given by:

$$\frac{M_{t+1}}{M_t} = 1 + \mu_{t+1}, \qquad M_0 \text{ given.} \tag{15}$$

It is worth noting that from the central bank's balance sheet the money base in the economy is given by

$$M_t = H_t + \theta D_t.$$

Hence, M can also be interpreted as the level of nominal domestic credit in the economy.

The consolidated government (both the fiscal and monetary authorities) has three policy instruments: (a) monetary policy which entails setting the rate of growth of nominal money supply; (b) interest rate policy which involves setting i^g (or alternatively, setting the composition of m and z and letting i^g be market determined); and (c) the level of lump sum transfers to the private sector τ. Given that lump-sum transfers are exogenously-given, only one of the other two instruments can be chosen freely while the second gets determined through the government's flow constraint (equation (14)). Since the focus of this paper is on the effects of interest rate policy, we shall assume throughout that i^g is an actively chosen policy instrument. This implies that the rate of money growth μ adjusts endogenously so that equation (14) is satisfied.

3.5 Resource constraint

By combining the flow constraints for the consumer, the firm, the bank, and the government (equations (5), (8), (11) and (14)) and using equations (6) and (7), we get the economy's flow resource constraint:

$$a_{t+1} = Ra_t + y_t - c_t - I_t - \kappa_t - s_t - q_t, \tag{16}$$

where $a = b + b^f - d^b$. Note that the right hand side of equation (16) is simply the current account.

3.6 Equilibrium relations

We start by defining an equilibrium for this model economy. The three exogenous variables in the economy are the productivity process A and the two policy variables $\bar{\tau}$ and i^g. We denote the entire state history of the economy till date t by $s^t = (s_0, s_1, s_2, ..., s_t)$. An equilibrium for this economy is defined as:

Given a sequence of realizations $A\left(s^t\right), i^g\left(s^t\right),\ r$ *and* $\bar{\tau}$*, an equilibrium is a sequence of state contingent allocations* $\left\{c\left(s^t\right), x\left(s^t\right), l\left(s^t\right), h\left(s^t\right), d\left(s^t\right), k\left(s^t\right), b\left(s^t\right), b^f\left(s^t\right), d^b\left(s^t\right), n\left(s^t\right), z\left(s^t\right)\right\}$ *and prices* $\left\{P\left(s^t\right), \pi\left(s^t\right), i\left(s^t\right), i^d\left(s^t\right), i^l\left(s^t\right), w\left(s^t\right), \rho\left(s^t\right)\right\}$ *such that (a) at the prices the allocations solve the problems faced by households, firms and banks; (b) factor markets clear; and (c) the government budget constraint (equation (14)) is satisfied.*

Combining the government flow constraint with the central and commercial bank balance sheets yields the combined government flow constraint:

$$\bar{\tau} = h_t - \left(\frac{1}{1+\pi_t}\right) h_{t-1} + \theta\left(d_t - \frac{d_{t-1}}{1+\pi_t}\right) + z_t - \left(\frac{1+i_t^g}{1+\pi_t}\right) z_{t-1}. \tag{17}$$

For future reference, the nominal interest rate in this economy is given by the standard no arbitrage condition between a one-period nominal bond bought at time t which pays i_{t+1} as interest in domestic currency at $t+1$ and an international real bond which pays r as interest in terms of the good:

$$1 + i_{t+1} = R\mathbb{E}_t\left(1 + \pi_{t+1}\right). \tag{18}$$

It is useful at this stage to clarify the process of nominal exchange rate determination in this model. Let $m = M/E$ be real money while nominal money is denoted by $M = H + \theta D$. Since

h and d are functions of i and $i - i^d$ respectively, the money market equilibrium condition can be written implicitly as $h + \theta d = L(i, i^g)$ where L denotes the implicit aggregate demand for cash and deposits. Note that in writing the implicit L function we have used the fact i^d is linked one-for-one with i^g. At any date t, M_t is known while its growth rate μ_{t+1} is endogenous. Money market equilibrium then dictates that at date t the nominal exchange rate is given by

$$E_t = \frac{M_t}{L(i_t, i_t^g)}. \tag{19}$$

For any given policy rate i_t^g, the inflation rate π_t (and hence the nominal interest rate i_t) is determined from the government budget constraint (17). From equation (19), knowledge of i_t^g and i_t are sufficient to determine the nominal exchange rate E_t at that date for a given M_t. Note that the rate of nominal money growth μ between dates t and $t + 1$ also gets determined at date from equation (14). Hence, M_{t+1} gets determined at date t.

3.7 The tradeoffs

The model laid out above has the three key margins that we set out to include. To see this note that a rise in the policy controlled interest rate i^g has two direct effects. First, it raises both the lending rate rate i^l and the deposit rate i^d. *Ceteris paribus*, this raises the lending spread $i^l - i$ and reduces the deposit spread $i - i^d$. The effect on the lending spread reduces the demand for loans and thereby also reduces output. This is the "output" effect wherein higher interest rates have a recessionary effect by raising the cost of financing working capital requirements. The lower deposit spread, on the other hand, raises the demand for deposits. This increases the demand for money – the "money demand" effect.

The fiscal effect is more complicated. Notice that an increase in i^g directly increases the cost of servicing government bonds Z which increases the fiscal burden. However, there are two other indirect ways in which changes in the policy controlled rate impacts the fiscal balance of the government. First, since a higher i^g lowers the amount of private loans N, for a given level of demand deposits commercial banks make more loans to the public sector, i.e., Z rises. This reduces the reliance on inflationary finance today but raises the future fiscal burden through a higher base level of debt. This effect arises as a consequence of the "output" effect. On the other side, a higher i^d raises demand deposits with commercial banks. For a given level of private loans, this reduces the reliance on inflationary finance today to finance government spending. This effect arises due to the “money demand” effect.

The effect of an interest rate increase on the equilibrium nominal exchange rate then depends on the net effect of these often offsetting effects. Notice that the exchange rate depends not just on monetary conditions but also on the real side of the economy as well as the state of public finances. They are all fundamental determinants of the exchange rate. Interest rate changes impact these fundamentals in often opposing ways. This is likely to make its end effect on the exchange rate non-linear and possibly non-monotonic. We explore these possibilities quantitatively below.

4 Calibration

Our next point of interest is whether this model can generate the difference in exchange rate behavior between developed and developing countries that we saw in the data In order to examine this, we conduct policy experiments on a calibrated version of the model developed above. We proceed by choosing two different sets of parameterizations for the calibrated model – one for developed and another for developing countries. We then examine whether the response of the exchange rate to domestic interest rate shocks can reproduce the documented differences between developed and developing countries.

In this section we calibrate the parameters of the model as well as the processes for productivity, interest rate, and fiscal policy shocks. We calibrate the model to match the properties of the two groups of countries. The benchmark parameterization for the developed countries group utilizes data for 6 industrial economies – Australia, Canada, Netherlands, New Zealand, Sweden and UK – during the period 1974-2010. For developing countries we use the data for Argentina, Brazil, Korea, Mexico, Philippines, and Thailand for the same 1974-2010 period. When focusing on nominal variables, i.e. nominal interest rates, we restrict the sample to 1998-2010 period to eliminate the periods of high interest rate volatility and high inflation in developing countries before and during the East Asian crisis. Detailed data description and data sources are discussed in the Appendix.

The model calibration is such that one period in the model corresponds to one quarter.

4.1 Functional forms and parameters

We assume that the capital adjustment cost technology is given by

$$\kappa(I_t, k_{t-1}) = \frac{\xi}{2} k_{t-1} \left(\frac{I_t - \delta k_{t-1}}{k_{t-1}} \right)^2, \qquad \xi > 0,$$

with ξ being the level parameter.

As in Rebelo and Vegh (1995), we assume that the transactions costs functions $\upsilon(.)$ and $\psi(.)$ have quadratic forms given by

$$s_{\varkappa}\left(\varkappa^2 - \lambda_{\varkappa}\varkappa + \left(\frac{\lambda_{\varkappa}}{2}\right)^2\right),$$

where $\varkappa$ represents cash or demand deposits, $\varkappa = \{h, d\}$, while $s_{\varkappa}$ and $\lambda_{\varkappa}$ are the level parameters. This formulation implies that the demand for money components are finite and that transaction costs are zero when the nominal interest rate is zero.

The transaction technology for the banks is given by a quadratic function

$$q_t = \frac{\gamma}{2}\left(d^b_{t+1} - \bar{d}^b\right)^2,$$

where $d^b_{t+1} = \frac{N_t + Z_t - (1-\theta)D_t}{P_t}$. Here γ is a constant and $\bar{d}^b$ is a steady state level of banks' debt to GDP ratio.

We begin by discussing parameters that are set to be common to both developed and developing countries. Most of these parameter values are borrowed from Neumeyer and Perri (2005). In particular, we set the coefficient of relative risk aversion, σ, to 5, while the curvature of the labor, υ, is set to 1.6. This value is within the range of values used in the literature.[16] This implies the elasticity of labor demand with respect to real wage, $\frac{1}{\upsilon-1}$, equal to 1.67, consistent with the estimates for the U.S. Labor weight parameter ζ in the utility function is chosen to match the average working time of 1/5 of total time and is set to 2.48. Subjective discount factor, β, is set to 0.97, as in Uribe and Yue (2006). Capital income share, α, is chosen to be equal to 0.38, while a depreciation rate for capital, δ, of 4.4% per quarter. Capital adjustment costs parameter ξ is calibrated to replicate the volatility of investment relative to the volatility of output in Argentina.

The remaining parameters are calibrated to developed and developing countries separately. Parameter θ determines the reserve requirement ratio in the model and is calibrated to match the observed reserve requirements in each group of countries. We measure reserve requirements in the data following Brock (1989), who computes reserve requirements as the ratio of monetary base less currency outside banks to M2 less currency outside banks. This gives us θ equal to 0.03 in developed countries and 0.10 in developing economies over our sample period. Reserve requirement ratio θ, together with $s_{\varkappa}$ and $\lambda_{\varkappa}, \varkappa = \{h, d\}$ parameters in the transactions costs technology for banks,

---

[16] For example, Mendoza (1991) uses υ equal to 1.455 for Canada, while Correia, Neves, and Rebelo (1995) set υ to 1.7 for Portugal.

jointly determine the level of money demand in the model. We calibrate them to match several targets. First, we match the average ratios of M1 to GDP in the data equal to 20% in developed countries and 10% in developing economies. Second, we match the relative size of deposits to currency in circulation in the data equal to 1 in developing countries and 4 in industrial economies. Finally, since the estimates for the interest elasticities of deposits and cash are not readily available, we discipline our calibration by picking parameters such that these elasticities are equalized within each group of countries in the steady state.

The lump-sum transfers paid by the government to the private sector, τ, are are measured as the net lending/borrowing by the general government as a share of GDP. Over our sample period, this ratio is equal to -1.3% in developed economies, and -2.1% in developing countries. We calibrate parameters γ and $\bar{d}^b$ to match the average net foreign asset position to GDP ratios equal to -0.26% in developed economies and -0.33% in developing countries over our sample period.

The share of wage bill paid in advance, ϕ, is a difficult parameter to calibrate. Most of the existing studies that incorporate such working capital constraint focus on industrial economies, and typically assume that firms must borrow the entire wage bill in advance (see Christiano, Eichenbaum, and Evans (2005), Altig, Christiano, Eichenbaum, and Linde (2011)). Schmitt-Grohé and Uribe (2006) deviate from this practice and calibrate the share of wage bill paid in advance to match the average money-to-output ratio in the post-war US data. Their calibration implies that only 51% of wage payments must be held in money. Rabanal (2007), whose main goal is to assess the importance of the cost channel in monetary policy, estimates the wage-in-advance parameter in the U.S. equal to 0.15. For developing countries, Neumeyer and Perri (2005) assume ϕ equal to 1, while Uribe and Yue (2006), find that a value of ϕ greater than 1 is needed to match the empirical impulse responses of several macroeconomic aggregates with their counterparts in their model. Given the great uncertainty in the literature associated with this parameter, we proceed as follows. We use the value for ϕ equal to 0.15, as estimated by Rabanal (2007), and we fix this value to be the same for both developed and developing countries. We then investigate the sensitivity of our quantitative results with respect to this parameter. As we will argue later, this parameter determines the strength of the "output" effect in the model, which works to depreciate the exchange rate following rises in i^g. By requiring ϕ to be the same in developed and developing countries under our benchmark parameterization, we eliminate the differential contribution of this effect to the exchange rate dynamics in the two sets of countries. If the working capital requirements are more pronounced in developing countries, so that the output effect is stronger for them, by setting

ϕ to be the same in developed and developing countries, we give up an important degree of freedom in generating depreciation in developing countries in our quantitative exercises.

The proportional cost parameter ϕ^n in the banking sector' problem is chosen to match the average spread of nominal lending rate over money market rate equal 9% in developing countries and 5% in developed economies over our sample period. Table 3 summarizes parameter values under our benchmark parametrization.[17]

Table 3: Benchmark parameter values

PREFERENCES		DEVELOPED	DEVELOPING
discount factor	β	0.971	0.971
risk-aversion	σ	5	5
labor curvature	υ	1.6	1.6
labor weight	ζ	2.48	2.48
TECHNOLOGY			
capital income share	α	0.38	0.38
depreciation rate	δ	0.044	0.044
share of wage-in-advance	ϕ	0.15	0.15
capital adjustment costs	ξ	4.5	4.5
MONEY			
reserve requirement	θ	0.03	0.10
transaction cost technology	$\lambda_\varkappa, \varkappa = \{h, d\}$	λ_h =0.24, λ_d =0.98	λ_h =0.125, λ_d =0.138
banks cost technology	γ	100	100
per unit loans costs	ϕ^n	0.05	0.09
lump-sum transfers	τ	1.3% of GDP	2.1% of GDP

4.2 Calibration of the shock processes

There are two sources of uncertainty in our benchmark model: exogenous productivity realizations, A, and the policy-controlled interest rate realizations, i^g. We now describe how we calibrate the total factor productivity (TFP) and the process for interest rates. We will use a "hat" over a variable to denote the deviation of that variable from its balanced growth path.

We assume that productivity, $\hat{A}_t$, in both developed and developing countries is an independent AR(1) process with autoregressive coefficient, ρ_{A}, equal to 0.95. The innovations, ε^{A}, to this process are assumed to be independent and identically normally distributed with the standard deviation, $\sigma(\varepsilon^{\text{A}})$, equal to 0.0195. This process is commonly used to describe total factor productivity in the U.S. In the absence of quarterly data on employment for our sample of countries, we rely on it to

---

[17] For all the experiments reported below we checked to ensure that the implied inflation tax revenues are on the upward sloping portion of the Laffer-curve.

calibrate the dynamics of $\hat{A}_t$, as in Neumeyer and Perri (2005).

We estimate the process for the policy-controlled interest rate i^g separately for developed and developing countries. To proxy the policy-controlled interest rates in the data we use the period average T-bill rate. For Netherlands we used a 3-month interbank rate in the Euro area. For Argentina, Australia, Brazil, Korea, Philippines and Thailand the T-bill rate was either not available or had large gaps in coverage, so we used the money market rate for these countries. We focus on the period between 1997:Q3 and 2010:Q4 to eliminate the periods of excess volatility in interest rates before and during the East Asian crisis. During the period under study, the average (annualized) level of i^g was 9% in developing countries and 4% in developed economies. We obtain $\hat{\imath}^g$ as a differential between a country interest rate and the U.S. Federal Funds rate, and then estimate the first-order autoregressive process for $\hat{\imath}^g$ as

$$\hat{\imath}_t^g = \rho_g \hat{\imath}_{t-1}^g + \varepsilon_t^g,$$

where ε_t^g are i.i.d. normal innovations.[18] We conduct the estimation of the equation above separately for a panel of developed and developing countries. This approach is intended to capture the dynamics of $\hat{\imath}_t^g$ in an average emerging market economy and an average industrial country. We find $\rho^g = 0.95$ (with standard error of 0.0307) in emerging market economies and $\rho^g = 0.98$ (with standard error of 0.0160) in industrial countries. While the two processes exhibit similar persistence, we find interest rates in developing countries to be significantly more volatile - the average standard deviation of $\hat{\imath}_t^g$ is 1.53% in developed countries and 4.50% in developing economies.[19] We also get $\sigma(\varepsilon_t^g) = 0.0049$ in developed countries and $\sigma(\varepsilon_t^g) = 0.0216$ in developing countries, on average.[20]

Once the shock processes and other parameter values are set, we solve the model using the perturbation method (Judd (1998), Schmitt-Grohe and Uribe (2004)). In particular, we take the second-order approximations of the model equilibrium conditions around the non-stochastic steady state, and then solve the resulting system of equations following the procedure described in Schmitt-Grohe and Uribe (2004).[21]

---

[18] Measuring $\hat{\imath}^g$ as a deviation of the money market rate from world interest rate proxied by U.S. Federal Funds rate is consistent with the VAR specification reported in Section 2. Moreover, it also provides a detrend of the interest rate data.

[19] In the estimation of the process for $\hat{\imath}^g$ for developing countries we excluded Argentina as its interest rate turned out to be 3 times more volatile than in any of the developing countries in our sample.

[20] We also estimated country-specific processes for $\hat{\imath}^g$, and found them to be along the lines of the aggregate estimates.

[21] In our economy, international bonds follow a unit root process. To account for this potential non-stationarity, we impose a small quadratic bond holding cost, $\Phi(a_t) = \frac{\vartheta}{2} y_t \left(\frac{a_t}{y_t} - \bar{a}\right)^2$, where $\bar{a}$ denotes the steady state ratio of bond

5 Results

We analyze the equilibrium properties of the model by studying how in our basic framework exchange rate responds to interest rate shocks. We compute the level of nominal exchange rate in the model as follows. First, from the money market equilibrium condition in conjunction with PPP, $M_0/E_0 = m^d(i_0^g, i_0)$, we get the initial level of exchange rate, E_0, for a given level of M_0. Next, with E_0 in hand, we construct the sequence of E_t using the process for exchange rate depreciation, π_t, predicted by the model. Clearly, the exchange rate is non-stationary in our model. We transform E_t into stationary terms by dividing it by the model-implied M_t. This is a standard transformation used in the literature to normalize nominal non-stationary variables in monetary models.

Figure 4 presents impulse responses of the exchange rate and the market interest rate to a temporary positive one standard deviation shock to the policy-controlled interest rate i^g in the model. Panel (a) is based on the model parameterized for a developed country, while panel (b) is for the model calibrated to a developing country.

For developed countries, the model predicts an impact appreciation of the exchange rate,. In particular, a one standard deviation increase in i^g is associated with a 0.0034% appreciation of the exchange rate in developed countries. On the other hand, a corresponding positive shock to i^g in an emerging market economy leads to a 0.06% depreciation of its exchange rate on impact. The market interest rate, i, however, increases after the shock to i^g in both countries. This can be seen from Panel (b) of 4.

The impulse responses in Panels (a) and (b) of 4 highlight the inherent non-monotonicities in the relationship between interest rates and the exchange rate present in our model. In particular, they show that the relationship between the market interest rate and exchange rate also depends on the country in question; there may be positive comovements between the two in developing countries but negative comovement in developed countries rather than a systematic relationship for all.

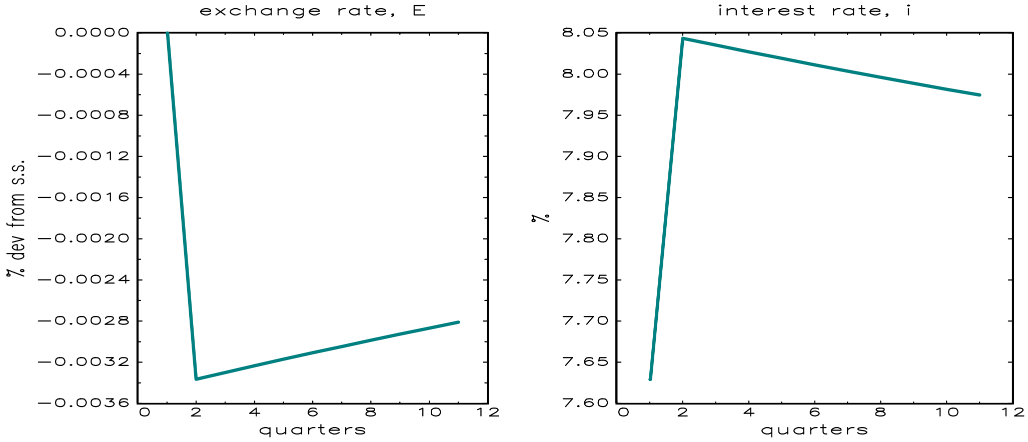
5.1 Under the hood

So what is behind these contrasting dynamics in interest rates and the exchange rate in developed and developing countries? As we discussed earlier, the interaction between the two variables in the model is built around three key effects: the "money demand" effect, the "fiscal" effect and the

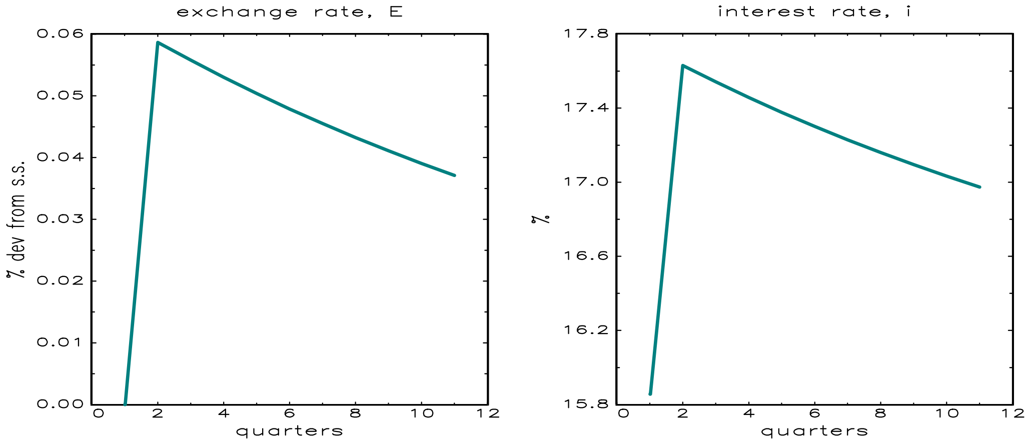
---

holdings to GDP, and ϑ is a level parameter. This does not alter the model dynamics substantially, and therefore when discussing the results, we focus on the case with no bond holding costs.

Figure 4: Impulse responses following 1 std dev shock to i^g



Panel (a). Developed countries



Panel (b). Developing countries

Note: The left panels present the responses of nominal exchange rate to a 1 std dev positive shock to policy-controlled interest rate, i^g. The right panels show the response of the market interest rate, i, to the same shock. Panel (a) presents impulse responses from the model calibrated to developed countries, while panel (b) does the same for developing countries.

"output" effect. While the money demand effect tends to strengthen the currency after an increase in i^g, the fiscal and output effects tend to weaken the currency. The net effect on the exchange rate is determined by the relative strength of each of these effects.

To build intuition for the results, consider a perfect foresight version of the model. In addition, assume that $\gamma \approx \infty$ so that banking costs are infinitely large. In this case the banking sector will hold a constant amount of foreign assets, i.e., $d^b = \bar{d}^b$. The exchange rate at any date t is given by the money market equilibrium condition (real money supply equals real money demand) which can be written as $E_t = \frac{M_t}{h_t+\theta d_t}$ where M_t is given. Log differentiating this relationship gives

$$\hat{E}_t = \hat{M}_t - \frac{h}{m}\hat{h}_t - \frac{\theta d}{m}\hat{d}_t \tag{20}$$

where hats over a variable indicate its percentage change and $m = M/E$. Suppose $\hat{M} = 0$, i.e., nominal supply is unchanged at date t. If both h and d rise in response to a shock then the exchange rate, E, appreciates while if both decline then E depreciates. Our interest is in the effect of changes in i^g on E. The preceding relation then makes it clear that this depends on the effect that changes in i^g have on h and d.

The optimality conditions for cash and deposits holdings along with the definition for the nominal interest rate under perfect foresight, $1 + i_{t+1} = R(1 + \pi_{t+1})$, yield the equilibrium cash and deposit demands in the model as $h_t = \tilde{h}\left(\frac{i_{t+1}}{1+i_{t+1}}\right)$ and $d_t = \tilde{d}\left(\frac{i_{t+1}-(1-\theta)i^g_{t+1}}{1+i_{t+1}}\right)$ where both functions are decreasing in their arguments. Clearly, a rise in i^g positively affects E by increasing the demand for deposits d. However, i^g also affects E indirectly through its effect on i since the market interest rate i affects the demand for both cash and deposits. The effect of i^g on i in turn is determined from the government flow budget constraint

$$\bar{\tau} + \frac{1+i^g_t}{1+\pi_t}z_{t-1} = h_t - \frac{h_{t-1}}{1+\pi_t} + \theta d_t - \frac{\theta d_{t-1}}{1+\pi_t} + z_t \tag{21}$$

where $z = (1-\theta)d - n + \bar{d}^b$ (assuming $\gamma \approx \infty$). The left hand side of equation (21) gives total expenditures while the right hand side gives net revenues. For a given $\bar{\tau}$ and i^g, equations (21) and (20) along with the equilibrium conditions for cash and demand deposits pin down both π_t and i_{t+1}. Note that i_t and i^g_t are given at any date t while π_t and P_t are determined within the period. Since $\pi_t = \frac{P_t}{P_{t-1}}$ and P_{t-1} is given, pinning down π_t is equivalent to determining P_t.[22] For future reference, also note that in a perfect foresight steady state, equation (21) reduces to

$$\bar{\tau} = \left(\frac{i-r}{1+i}\right)(h_{ss} + \theta d_{ss}) + \left(\frac{1+i-R(1+i^g)}{1+i}\right)z_{ss} \tag{22}$$

where we have used the steady state relation $1 + i = R(1+\pi)$.

The first of our three effects is the *fiscal effect.* The size of the fiscal burden in the model

---

[22] It is important to note that pinning down i_{t+1} is not equivalent to pinning down P_{t+1}. To see this, note that $1 + i_{t+1} = RE_t(1+\pi_{t+1}) = RE_t\left(1 + \frac{P_{t+1}}{P_t}\right)$. However, this is not equivalent to determining P_{t+1} since this is just the expectation. P_{t+1} is free to deviate from the expectation of it in period t in response to shocks that hit the economy after the formation of expectations about period $t+1$.

is captured by $\bar{\tau}$ and i^g. An increase in $\bar{\tau}$, ceteris paribus, raises the financing burden on the government. Equation (21) makes clear that the financing can be done by some combination of a rise in π_t (or equivalently, P_t) and i_{t+1}.[23] In terms of the steady state effect, from equation (22) a higher $\bar{\tau}$ necessitates a higher steady state i. Since $1 + i = R(1 + \pi)$ and $1 + \pi_t = \frac{E_t}{E_{t-1}}$, a higher i implies an immediate depreciation of the currency. Clearly, the model predicts that the higher is $\bar{\tau}$ the more depreciated the country's currency.

Figure 5 shows the fiscal effect in play for both developed countries (left panel) and emerging economies (right panel). In the each panel, the figures have two lines – a solid line and a dashed line. Both lines are derived for the baseline calibration for the country in question. The solid line plots the initial level of the exchange rate as a function of τ for a given and constant initial level of money supply M_0. The initial level of the exchange rate is measured on the left axis. The dashed lines in the two panels of the Figure 5 depict the *impact* effect of an increase in i^g on the exchange rate (expressed as percent deviation from the steady state). This is measured on the right axis.

The solid lines in the Figure show that the initial E rises with $\bar{\tau}$ for both developed and emerging economies, exactly as the model suggests. The dashed lines reveal an important difference between the two groups. For developing countries, a higher i^g induces a currency appreciation for the entire range of $\bar{\tau}$'s plotted. For emerging economies however, a higher i^g induces a depreciation of the currency on impact, i.e., a rise in E. Note though that the size of the impact depreciation declines as τ becomes larger, reflecting partly the fact that the exchange rate changes are in percent deviations from the steady state and the higher τ raises the steady state level of E itself for both groups.

We draw two main conclusions from these results. First, for any given level of nominal money supply, a higher τ, which is partially responsible for the strength of the fiscal effect, always leads to a more depreciated currency in the steady state. Second, the difference between developed and emerging economies that we found in Figure 4 is robust to changes in the level of $\bar{\tau}$ since changes in τ do not appear to qualitatively change the impact effect of i^g on the exchange rate.

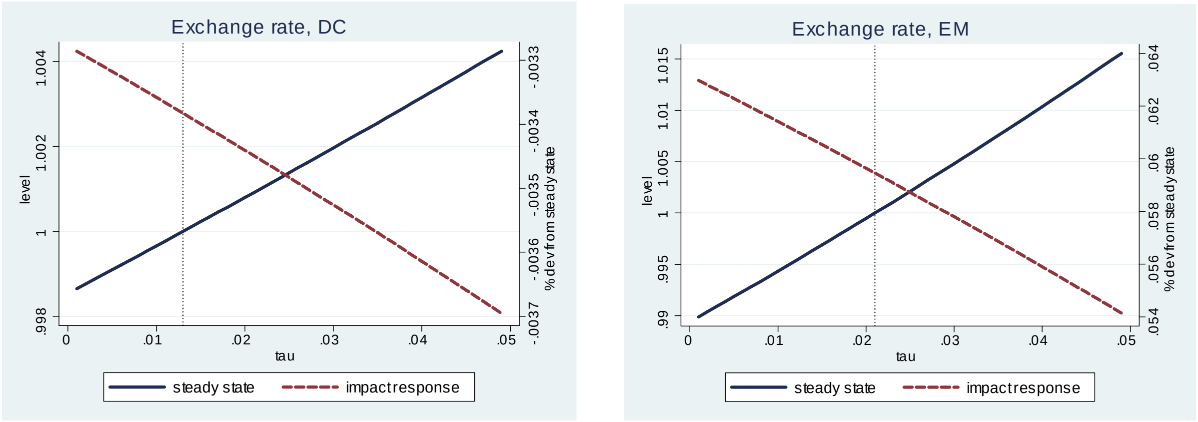
The second effect in the model is the money demand effect. A key parameter that controls the strength of this effect is θ which is the share of deposits that comprises the money base (bank reserves). In the model, the higher is θ the greater is the base money in the economy. The greater money base implies that the same $\bar{\tau}$ can now be financed with a lower initial level of E (or

---

[23] Note equation 21 can be rewritten as a first order difference equation in i_{t+1} and i_t. The standard condition for a unique flexible price monetary equilibrium is that the difference equation in i be unstable. We impose it through out. It can be verified that this stability condition also implies government revenues are increasing in the nominal interest rate i.

Figure 5: Comparative statics for parameter τ

(a). Developed countries (b). Emerging markets



Note: The figure presents the responses of nominal exchange rate to changes in $\mathcal{T}$. The developed country calibration is shown in the left panel while the right panel shows the developing country calibration. Vertical line indicates the level of $\mathcal{T}$ under our benchmark calibration in each country group.

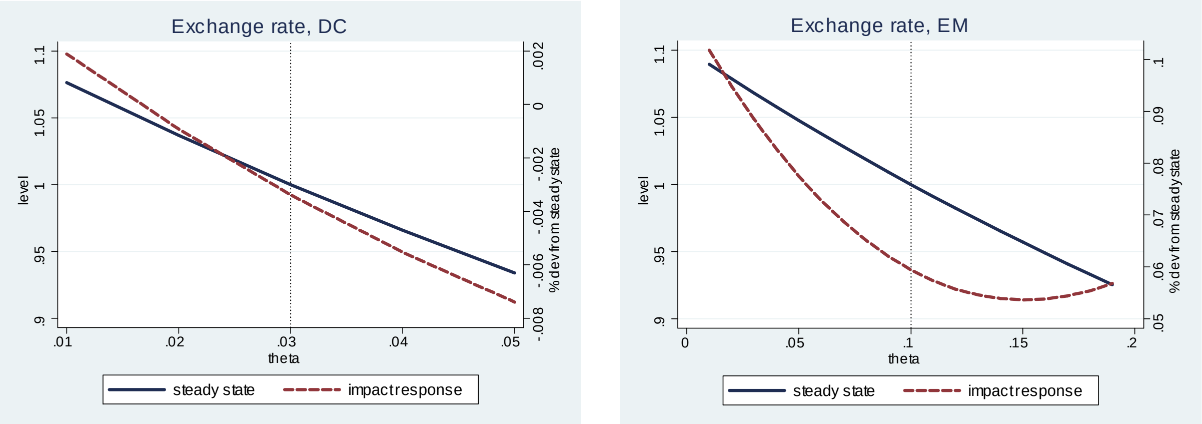
equivalently a lower π) as well as a lower steady state rate of currency depreciation. It is easy to check that the right hand side of equation 22 is increasing in both π and i. However, for a given i^g a higher θ also reduces the deposit rate since $i^d = (1-\theta)\, i^g$. This tends to reduce the demand for deposits. The resultant fall in overall real money demand tends to depreciate the currency. Which of these two effects dominates depends on the specific parameters governing the relationship.

Figure 6 shows the effect of the parameter θ on the exchange rate. The figure is symmetric to the one for the fiscal spending parameter τ above. The solid lines depict the effect of θ on the initial level of the exchange rate for a constant initial nominal money supply. The dashed lines show the impact effect of a temporary increase in i^g on the exchange rate (the initial response on impact) for different values of θ. The initial levels are measured on the left axis while the impact responses in percent deviations from steady state are measured on the right axis.

The downward sloping solid lines in Figure 6 show that the initial value of the exchange rate (both in levels and rates) is a decreasing function of θ, i.e., as the reserve requirement ratio rises the initial level of E declines due to a strengthening of the money demand effect. Importantly, this effect is the same in both groups of countries. In terms of the impact effect of i^g on the exchange rate however, there are differences between the two sets of countries. In emerging economies, a higher domestic interest rate i^g induces an initial depreciation of the currency (positive numbers in the right axis of the right panel). As the dashed lines indicate, this is true for the broad range of relevant θ's ranging from 0.01 to 0.2. For developed countries on the other hand, the impact effect is a depreciation if the reserve requirement ratio is low enough (below 0.015), but an appreciation for higher values of θ. More generally, for developed countries a higher domestic interest rate would depreciate the currency for very low levels of θ but begin to appreciate it for higher θ's.

The switch in the impulse response of E in developed countries from depreciation to appreciation as one changes θ suggests that the differences in the impulse responses of the two groups to interest rate shocks that we found in 4 depend crucially on the reserve requirement parameter θ.

Figure 6: Comparative statics for parameter θ



(a). Developed countries

(b). Emerging markets

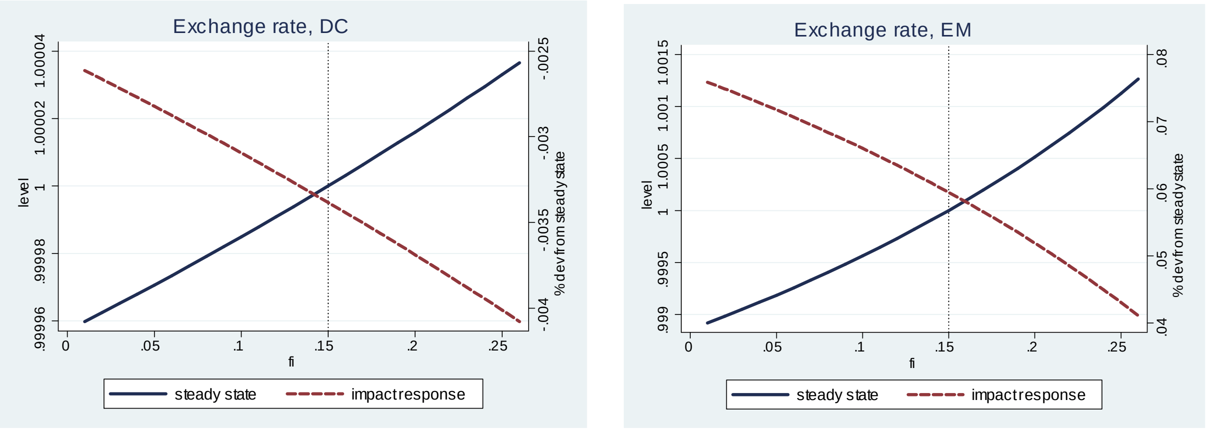
Note: The top panel presents the responses of nominal exchange rate to changes in θ. The developed country calibration is shown in the left panel while the right panel shows the developing country calibration. Vertical line indicates the level of θ under our benchmark calibration in each country group.

Our third effect is the output effect. The size of this effect is captured by the wage-in-advance parameter ϕ. The higher is ϕ the greater is the wage-in-advance requirement and hence the demand for loans. All else equal, a higher loan portfolio of banks reduces the amount of government bonds that banks buy, i.e., z falls. From equation 22 it is easy to see that a lower z reduces government revenues. Financing of a given fiscal spending $\bar{\tau}$ then requires a combination of a higher π (a more depreciated initial exchange rate) along with a higher steady state depreciation rate.

As we noted earlier, there are complications in calibrating this parameter with precision. However, this makes it all the more important to examine the sensitivity of the results to variations in ϕ. Figure 7 shows the effects of varying ϕ in our model. The figure is symmetric to the ones for τ and θ. The upward sloping solid lines in the two panels of Figure 7 demonstrate that the higher is ϕ the more depreciated is the exchange rate in the initial steady state for a constant level of initial nominal money supply M_0. In terms of the impact effect of a temporary increase in i^g on the exchange rate, in developed countries the response is an appreciation while in emerging economies it is a depreciation for a broad range of values for ϕ.

Given that Figure 7 consistently reveals a depreciation for developing countries and an appreciation for developed economies for a broad range of values for ϕ leads us to conclude that the differences in the impulse responses for the two groups to interest rate shocks highlighted in Figure 4 are robust to variations in the wage-in-advance parameter ϕ.

Figure 7: Comparative statics for parameter ϕ



(a). Developed countries

(b). Emerging markets

Note: The top panel presents the responses of nominal exchange rate to changes in ϕ. The developed country calibration is shown in the left panel while the right panel shows the developing country calibration. Vertical line indicates the level of ϕ under our benchmark calibration in each country group.

How does this help us understand the different impulse responses for developed and developing countries? As we showed above, the strength of the effects considered in the model are different in developed and developing countries. In developing countries, both τ and i^g are about twice as high relative to developed economies. This leads to a much higher interest burden on the government in developing countries. As a result, the fiscal effect is larger which contributes to the tendency for exchange rates to depreciate in response to interest rate increases in developing countries.

Concurrently, the reserve requirement ratio is about three times higher in developing countries relative to developed countries in our sample. This would suggest a stronger money demand effect in developing countries. However, there are two other important ratios that also influence the size of the money demand effect. These are the ratio of base money to output and the ratio of deposits to cash. The higher these ratios, the stronger the money demand effect of higher interest rates. The base money to output ratio in developing countries is half of that in developed countries while the ratio of deposits to cash is four times smaller in developing countries relative to developed economies. These two effects tend to swamp the effect of a higher θ and make the money demand effect substantially weaker in developing countries relative to developed economies. As panel (a) of Figure 6 shows, if bank reserves were slightly lower in developed economies than the benchmark level of 0.03 to about half of that then the impact appreciation of E would switch to an impact depreciation of the currency in response to an increase in i^g (or, equivalently, a monetary tightening).

Finally, in our benchmark calibration we assumed that the wage-in-advance parameter ϕ was the same in developed and developing countries. This calibration implied that the strength of the output effect is the same across the two groups of countries, and thus does not contribute to their differing exchange rate dynamics. Arguably, the working capital requirements tend to be more important in developing countries, which would suggest a larger parameter ϕ for these economies. In this case, our model would imply a stronger output effect in developing countries and even more pronounced tendency for their exchange rate to depreciate following rises in i^g.

We should also point out that the size of the shocks to interest rates in developing countries is four-times larger than the size of interest rate shocks in developed countries. The impulse responses reported for the two sets of countries in Figure 4 reflect the tradeoffs amongst these offsetting effects.

6 Conclusions

The effect of monetary policy on the exchange rate has long been one of the fundamental concerns of academics and practitioners alike. A large preponderance of existing models predict that monetary policy tightening should induce an exchange rate appreciation. What does the evidence suggest though? In this paper we have used a cross-country dataset comprising of 74 countries between 1974 and 2009 to show that while most developed countries indeed exhibit exchange rate appreciations in response to interest rate increases, in developing countries the effect is the opposite: most of them exhibit depreciating currencies in response to interest rate increases. We call this puzzling new data fact the "exchange rate response puzzle".

We have provided an explanation for this puzzle using a simple open economy monetary model. Our explanation rests on the contrasts in the interplay between three key effects between developed and developing countries. Our model formalized three important effects of raising interest rates – a larger fiscal burden, a negative output effect and a positive effect on real money demand. While the first two effects tend to depreciate the currency, the last tends to appreciate it. Using a calibrated version of the model, we have shown that the differences in the relative importance of these three effects between the two groups of countries can account for the contrasting responses in the two groups. In particular, the fiscal burden is about 62 percent higher on average in developing countries while the reserve requirement ratio in developing countries is almost three times higher. These two effects can jointly account for the different impulse responses of exchange rate.

References

Altig, D., L. Christiano, M. Eichenbaum, and J. Linde (2011): "Firm-Specific Capital, Nominal Rigidities and the Business Cycle," *Review of Economic Dynamics*, 14(2), 225–247.

Arellano, M., and S. Bond (1991): "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," *Review of Economic Studies*, 58(2), 277–97.

Auernheimer, L. (2008): "Monetary Policy Rules, the Fiscal Theory of the Price Level, and (Almost) All that Jazz," in *Money, Crises, and Transition: Essays in Honor of Guillermo A. Calvo*, pp. 41–67. MIT Press.

Brock, P. L. (1989): "Reserve Requirements and the Inflation Tax," *Journal of Money, Credit and Banking*, 21(1), 106–21.

Calvo, G. A., and C. A. Vegh (1995): "Fighting Inflation with High Interest Rates: The Small Open Economy Case under Flexible Prices," *Journal of Money, Credit and Banking*, 27(1), 49–66.

Christiano, L. J., and M. Eichenbaum (1992): "Liquidity Effects and the Monetary Transmission Mechanism," *American Economic Review*, 82(2), 346–53.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113(1), 1–45.

Correia, I., J. C. Neves, and S. Rebelo (1995): "Business cycles in a small open economy," *European Economic Review*, 39(6), 1089–1113.

Diaz-Gimenez, J., E. C. Prescott, T. Fitzgerald, and F. Alvarez (1992): "Banking in Computable General Equilibrium Economies," *Journal of Economic Dynamics and Control*, 16(3-4), 533–559.

DORNBUSCH, R. (1976): "Expectations and Exchange Rate Dynamics," *Journal of Political Economy*, 84(6), 1161–76.

EDWARDS, S., AND C. A. VEGH (1997): "Banks and Macroeconomic Disturbances under Predetermined Exchange Rates," *Journal of Monetary Economics*, 40(2), 239–278.

EICHENBAUM, M., AND C. L. EVANS (1995): "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates," *The Quarterly Journal of Economics*, 110(4), 975–1009.

FISCHER, S., R. SAHAY, AND C. A. VEGH (2002): "Modern Hyper- and High Inflations," *Journal of Economic Literature*, 40(3), 837–880.

GREENWOOD, J., Z. HERCOWITZ, AND G. W. HUFFMAN (1988): "Investment, Capacity Utilization, and the Real Business Cycle," *American Economic Review*, 78(3), 402–17.

GRILLI, V., AND N. ROUBINI (1996): "Liquidity models in open economies: Theory and empirical evidence," *European Economic Review*, 40(3-5), 847–859.

HOLTZ-EAKIN, D., W. NEWEY, AND H. S. ROSEN (1988): "Estimating Vector Autoregressions with Panel Data," *Econometrica*, 56(6), 1371–95.

JUDD, K. L. (1998): *Numerical Methods in Economics*, vol. 1 of *MIT Press Books*. The MIT Press.

KIM, S., AND N. ROUBINI (2000): "Exchange Rate Anomalies in the Industrial Countries: A Solution with a Structural VAR Approach," *Journal of Monetary Economics*, 45(3), 561–586.

LAHIRI, A., AND C. A. VEGH (2003): "Delaying the Inevitable: Interest Rate Defense and Balance of Payments Crises," *Journal of Political Economy*, 111(2), 404–424.

LOVE, I., AND L. ZICCHINO (2006): "Financial development and dynamic investment behavior: Evidence from panel VAR," *The Quarterly Review of Economics and Finance*, 46(2), 190–210.

MENDOZA, E. G. (1991): "Real Business Cycles in a Small Open Economy," *American Economic Review*, 81(4), 797–818.

NEUMEYER, P. A., AND F. PERRI (2005): "Business Cycles in Emerging Economies: The Role of Interest Rates," *Journal of Monetary Economics*, 52(2), 345–380.

OBSTFELD, M., AND K. ROGOFF (1995): "Exchange Rate Dynamics Redux," *Journal of Political Economy*, 103(3), 624–60.

Rabanal, P. (2007): "Does inflation increase after a monetary policy tightening? Answers based on an estimated DSGE model," *Journal of Economic Dynamics and Control*, 31(3), 906–937.

Rebelo, S., and C. A. Vegh (1995): "Real Effects of Exchange-Rate-Based Stabilization: An Analysis of Competing Theories," in *NBER Macroeconomics Annual 1995, Volume 10*, NBER Chapters, pp. 125–188. National Bureau of Economic Research, Inc.

Reinhart, C. M., and K. S. Rogoff (2004): "The Modern History of Exchange Rate Arrangements: A Reinterpretation," *The Quarterly Journal of Economics*, 119(1), 1–48.

Schmitt-Grohe, S., and M. Uribe (2004): "Solving Dynamic General Equilibrium Models Using a Second-Order Approximation to the Policy Function," *Journal of Economic Dynamics and Control*, 28(4), 755–775.

Schmitt-Grohé, S., and M. Uribe (2006): "Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model," in *NBER Macroeconomics Annual 2005, Volume 20*, NBER Chapters, pp. 383–462. National Bureau of Economic Research, Inc.

Uribe, M., and V. Z. Yue (2006): "Country Spreads and Emerging Countries: Who Drives Whom?," *Journal of International Economics*, 69(1), 6–36.

Vegh, C. (2010): *Open Economy Macroeconomics in Developing Countries*chap. 5. Manuscript.