

# The Exchange Rate Response Puzzle<sup>1</sup>

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Draft: February 2012

<sup>1</sup>We would like to thank Paul Beaudry, Barbara Rossi and seminar participants at various universities and institutions for comments. Hnatkovska and Lahiri would like to thank SSHRC for research support.

## **Abstract**

Standard models in open economy macroeconomics predict that an expansionary (contractionary) monetary policy will lead to a currency depreciation (appreciation). The data, however, reveals an interesting twist to this prediction. In a sample of 25 industrial and 47 developing countries, we find that while the nominal exchange rate does indeed tend to appreciate in response to interest rate increases in developed countries, in 75 percent of the developing countries, 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 monetary model where interest rate changes have 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 as the outcome of differing intensities of these opposing effects in the two groups.

**JEL Classification:** F3, F4

**Keywords:** Monetary policy, interest rates, exchange rates

# 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.<sup>1</sup> 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.<sup>2</sup>

While the Dornbusch-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).<sup>3</sup> 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).<sup>4</sup> The nominal interest rate must fall for such agents to absorb the excess liquidity. In an open economy, the fall in the nominal interest rate will be associated with a currency depreciation.

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<sup>1</sup>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.

<sup>2</sup>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.

<sup>3</sup>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 have no effects on the nominal interest rate.

<sup>4</sup>See, for example, Christiano and Eichenbaum (1992) and Grilli and Roubini (1996).

(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.<sup>5</sup> 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 47 developing countries.<sup>6</sup> We first run 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 75 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 countries but depreciates in developing countries. Finally, we subject the data to a battery of alternative specifications and methods and find that the results are robust to them. We will refer to these contrasting findings in industrial versus developing countries as the “exchange rate response puzzle.”

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<sup>5</sup>See Calvo and Vegh (1995) and Lahiri and Vegh (2003).

<sup>6</sup>For several developing countries we have multiple episodes giving us a total of 55 developing country-episode pairs in our sample.

In order to provide an explanation for the puzzling data fact, we choose to focus on three key margins along which developed and developing countries are often viewed to be different. These differences arise mostly due to institutional reasons but also may be due to them being in different stages of the developmental process. The first is the fact that developed economies tend to have a larger money base possibly due to a more stable monetary history. This tends to primarily show up in a larger demand deposits to output ratio in developed countries. Second, developing economies tend to have weaker public finances which raises their dependence on the inflation tax for financing public expenditures. Third, developed countries tend to have more developed financial markets which lowers the dependence of firms on bank finance relative to firms in developing countries. We provide evidence on these patterns later in the paper. Crucially, we believe that these three features introduce differences in the monetary transmission channel between developed and developing countries.

We formalize these three features by presenting 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 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 effects will typically be 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 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 1974:1-2010:12 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. We note that for majority of countries in our sample we used the T-bill rate. This rate is the closest to the overnight interbank lending rates, which would be our preferred policy rate, but is not available for most of our countries.<sup>7</sup> In our analysis we focus on the interest rate differential between home and abroad computed as domestic interest rate minus

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<sup>7</sup>In what follows we show that our results are robust to using only countries for which the T-bill rate is available. We also verify that our results are not driven by the fact that our measures of interest rates may potentially contain information other than the monetary policy change, i.e. changes in expected inflation or in the perceived sovereign risk.

U.S. Federal Funds rate.

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  $\pm 2\%$  (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).<sup>8</sup> These correspond to their fine classification indices of 11, 12, 13, and 14, respectively.<sup>9</sup> 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. For the Eurozone countries, we used their national exchange rates before the introduction of the Euro as separate episodes. Since 1999:1 we included a separate episode for the Euro area, for which we used the Euro-dollar exchange rate and the ECB marginal lending facility rate as the policy rate. According to Reinhart and Rogoff (2004) regime classification, some countries had multiple episodes of flexible exchange rates. We considered each such episode separately. To be included in our sample we also require that an episode has at least 24 months of data in the flexible regime for each country. This selection gives us a sample of 25 industrial country-episode pairs and 55 developing country-episode pairs, for a total of 80 country-episode pairs. All country-episode pairs are listed in the Appendix A.1.<sup>10</sup>

To illustrate the relationship between interest rate and the exchange rate, we first report some simple time-series correlations between them. Panel A of Table 1 summarizes our results. We compute correlations on a country-by-country basis for both levels and first-differences of (log) exchange rate and interest rate variables, which are shown in the first column.<sup>11</sup> Column “full sample” reports the mean of all the time-series correlations obtained for the countries in our sample. Columns la-

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<sup>8</sup>These categories are generally used in the literature to represent floating exchange rate regimes (see Reinhart and Rogoff (2004)). In what follows we also check for robustness of our results with respect to the regime classification (see Section 2.1.1).

<sup>9</sup>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  $\pm 2\%$ ; (ii) de facto crawling band that is narrower than or equal to  $\pm 5\%$ ; (iii) moving band that is narrower than or equal to  $\pm 2\%$ ; (iv) managed floating; (v) freely floating; (vi) freely falling. These correspond to indices 3, 4, and 5 in Reinhart and Rogoff (2004).

<sup>10</sup>It is probably not surprising that the majority of flexible exchange rate episodes in developing countries included in our sample occur in the 1990s – the “globalization” decade.

<sup>11</sup>Using interest rates and exchange rate series in levels has been a conventional practice in the literature (see, for instance, Kim and Roubini (2000), Faust and Rogers (2003) among others). Such approach implicitly assumes that the two variables are integrated of the same order. We confirm this result in our sample of countries. We test for the presence of a unit root in the country exchange rate and interest rate differential series using augmented Dickey-Fuller test and Phillips-Perron test. We can not reject the presence of a unit root in the levels of both interest rate and (log) exchange rate for 90 percent of all country-episode pairs in our sample. Unit root is rejected in *all* country-episode pairs at 10 percent significance level when both variables are in first-differences.

belled “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, resulting in positive correlation between them.

To confirm the significance of these correlations we also estimate simple regression of the log exchange rate (or its first-difference) on a constant and domestic minus US interest rate differential (or its first-difference) on a country-by-country basis. We then report the average of the slope coefficients from these regressions and its 95% confidence interval for the full sample and separately for developed and developing countries in the Panel B of Table 1. These regressions confirm our findings from correlations: exchange rates and interest rates are negatively correlated in industrial countries; and they are positively correlated in developing countries. These results hold in both levels and first-differences and are highly statistically significant. Importantly, the confidence intervals for the slope coefficients in developed and developing countries do not overlap, indicating significant differences between them.

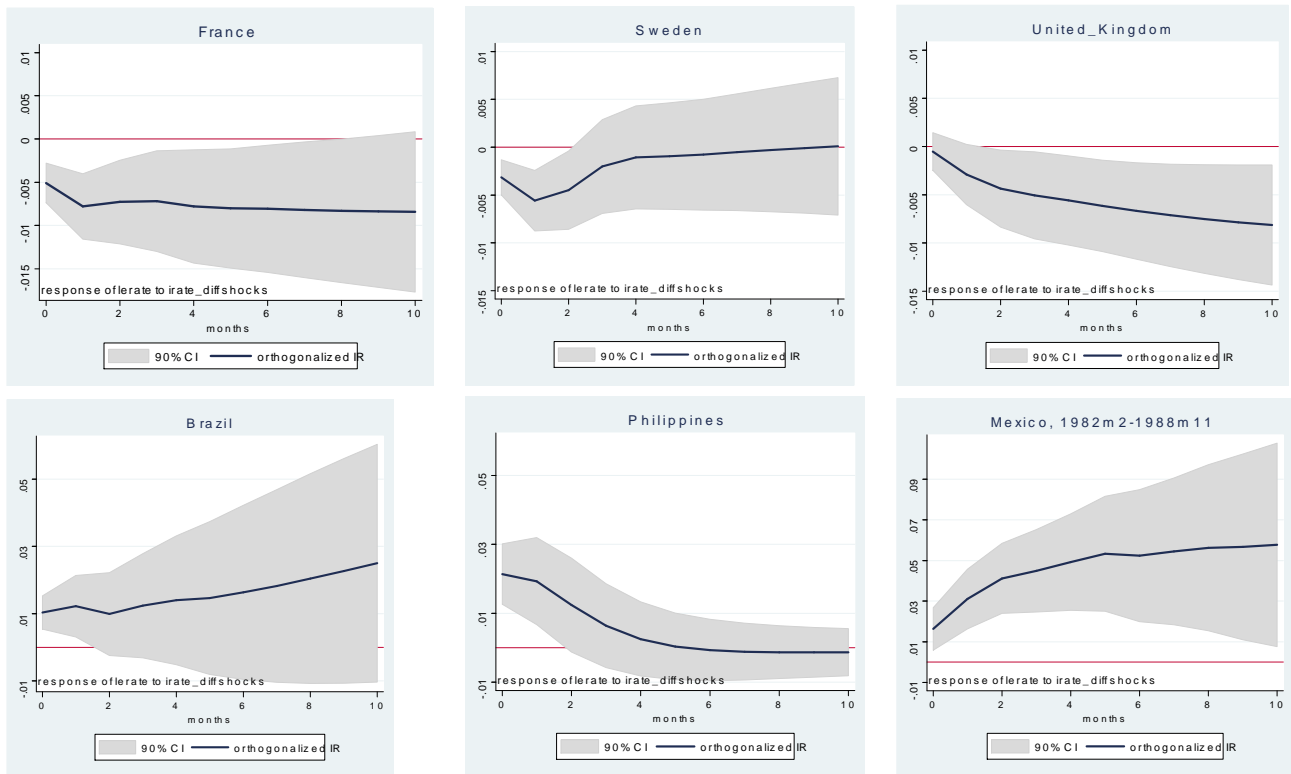
Table 1: Correlation between exchange rate and interest rate

	Full sample	Developed	Developing
		<i>Panel A</i>	
$corr(\ln E_t, i_t - i_t^{us})$			
mean	0.13	-0.09	0.24
median	0.10	-0.08	0.36
$corr(\Delta_t \ln E, \Delta_t (i - i^{us}))$			
mean	0.06	-0.10	0.13
median	0.03	-0.11	0.13
		<i>Panel B</i>	
$\ln E_t = \beta_0 + \beta_1(i_t - i_t^{us}) + \varepsilon_t$			
mean( $\hat{\beta}_1$ )	1.27	-0.74	2.19
95% c.i.( $\hat{\beta}_1$ )	[1.13; 1.42]	[-0.94; -0.54]	[1.99; 2.39]
$\Delta_t \ln E_t = \alpha_0 + \alpha_1 \Delta_t(i_t - i_t^{us}) + u_t$			
mean( $\hat{\alpha}_1$ )	0.02	-0.44	0.24
95% c.i.( $\hat{\alpha}_1$ )	[-0.08; 0.13]	[-0.57; -0.31]	[0.09; 0.38]

Note: Panel A of the Table reports the mean and median of the cross-sectional distribution of the correlation coefficient between (log) exchange rate and interest rate (and their first-differences) for our sample of countries. Panel B presents the mean of the estimated slope coefficients from the regression  $\ln E_t = \beta_0 + \beta_1(i_t - i_t^{us}) + \varepsilon_t$  in levels and first-differences. 95% confidence intervals are in parenthesis.

We next turn to an analysis of the exchange rate-interest rate relationship using 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 the U.S..<sup>12</sup> Our VAR specification also includes a constant term.<sup>13</sup> We use the estimated 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.<sup>14</sup> Following Eichenbaum and Evans (1995) we compute the impulse responses using the ordering: interest rate differential, exchange rate.<sup>15</sup>

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



Note: These figures present impulse responses of exchange rate to a positive interest rate innovation from individual country VARs estimated on (log) exchange rate and interest rate differential between home and abroad. The following ordering is used:  $i - i^{US}, E$ .

We start by presenting the impulse responses of the nominal exchange rate to interest rate shocks

<sup>12</sup>In our benchmark VAR specification we focus on interest rate differential and exchange rate variables only. This allows us to use and draw inference from the largest possible sample of countries. In section 2.1.2 we extend our benchmark VAR specification to include a broad set of other macroeconomic variables, such as output, prices, inflation, risk-premium, etc. Due to data limitations such analysis can only be conducted for a much smaller sample of countries. Nevertheless it allows us to provide robustness checks for the results in this section.

<sup>13</sup>We also tried a VAR specification with a trend and have found that the results remained largely unchanged.

<sup>14</sup>In each individual VAR we used the Akaike criterion to choose the lag length. The results remain unchanged when Schwarz's Bayesian information criterion (BIC) is used for selecting the lag length as the two criteria choose the same lag length in 97 percent of all cases.

<sup>15</sup>We conduct robustness checks with respect to the ordering of the variables in Section 2.1.3.

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 – France, 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.<sup>16</sup>

To check the generality of this differing relationship between interest rates and the exchange rate in developed and developing countries, we ran individual country level VARs for all countries in our sample.<sup>17</sup> We adopted several approaches to classifying a country as exhibiting appreciation: (i) if the response of its exchange rate after an interest rate shock is negative on impact; (ii) if the response of its exchange rate to an interest rate shock is negative at the end of the 1st month; and (iii) if the 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. Table 2 summarizes the results from the individual country VARs, where we estimated a bivariate specification with variables ordered as  $i - i^{US}, \ln E$ . 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 positive shock to the interest rate differential between home and abroad, based on level VARs.

Table 2: Individual country VARs: Summary

	(a). Levels			(b). First-differences		
	impact	1 month	3 months	impact	1 month	3 months
<i>Bivariate VAR: <math>i - i^{US}, \ln E</math></i>						
Industrial countries: appreciation	84%	88%	84%	84%	88%	52%
Developing countries: depreciation	75%	75%	75%	70%	62%	60%

Note: The table reports the fraction of developed (developing) countries that experience an appreciation (depreciation) of their exchange rate following a positive 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. The ordering used to obtain the orthogonalized impulse responses to interest rate shocks is  $i - i^{US}, E$ .

The results clearly indicate that an overwhelming majority of industrial economies see their

<sup>16</sup>Notice that some of these impulse responses have a hump-shaped pattern, which came to be known as the “delayed overshooting” result (see, for instance, Sims (1992), Eichenbaum and Evans (1995), among others). While there is ongoing debate as for the reasons for such “delayed overshooting” pattern in exchange rate responses to monetary policy shocks (Faust and Rogers (2003), Bacchetta and van Wincoop (2010), Engel (2011)), our interest is on the immediate response of the exchange rate. Thus when presenting results, we focus on the immediate responses.

<sup>17</sup>One may be concerned that the use of a linear VAR specification is not warranted in countries that experienced large jumps in the level of the exchange rate or crisis episodes. We check the robustness of our results with respect to crisis episodes and periods of high inflation in Section 2.1.1.

exchange rate appreciating after a positive interest rate shock both on impact (84 percent of all industrial countries), as well as one month (88 percent of all industrial countries) and three months after (84 percent of all industrial countries). For developing countries on the other hand, 75 percent of countries show a depreciation following a positive interest rate shock on impact, after 1 month, and the proportion remains at 75 percent if the cutoff is raised to the end of the 3rd month. If we restrict our sample of countries to only those with T-bill data available, we find that our results for developing countries become even stronger. In particular, in that subsample 83 percent of all developing countries experienced an impact depreciation after an interest rate shock, and 80 percent saw their currency depreciate one month later.

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 from this estimation and associated impulse responses are summarized in panel (b) of Table 2. Our earlier results remain robust. In particular, we find that among industrial economies, 84 percent have experienced exchange rate appreciation after an interest rate shock on impact, 88 percent still saw their currency appreciate after the 1st month and 52 percent did so by the end of the first quarter. For the developing countries, the corresponding numbers were 70 percent, 62 percent and 60 percent, respectively.<sup>18</sup>

We further confirm our empirical findings by running unrestricted, bivariate *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 106 months in developing countries and 324 months in developed economies. While this does not eliminate the bias in the estimates, it lends credibility to our level-based results.<sup>19</sup> An alternative transformation that eliminates the fixed effects is the first-difference transformation. We present the results from the panel VARs on the first-differenced data below.

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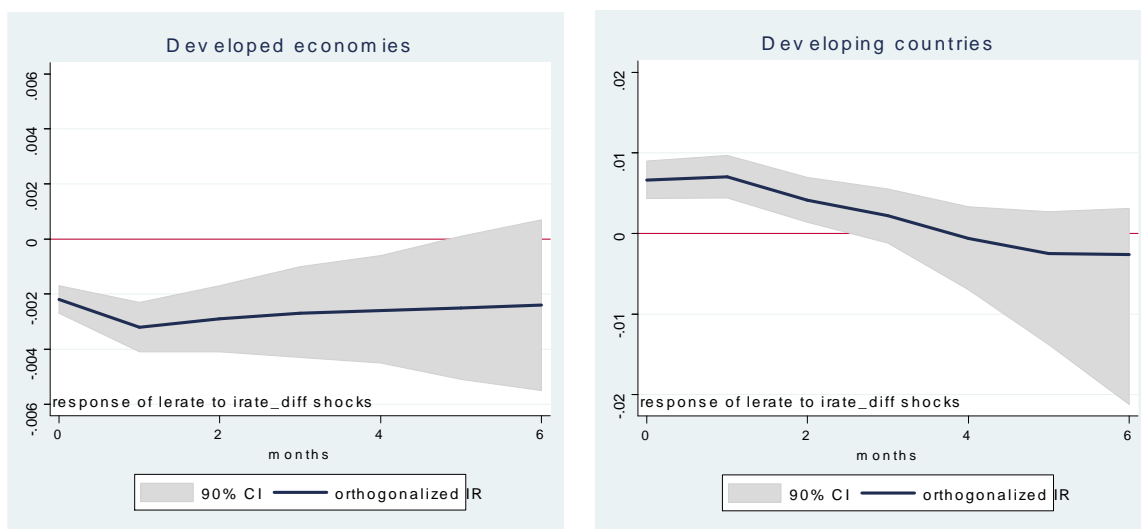
<sup>18</sup>We should note that when the model is estimated in first-differences, the exchange rate in the third month is the difference between the exchange rate levels in months three and four. Hence, it is not surprising that the differences in the responses of the groups to temporary shocks in the third month appear to be much smaller in first-differences than in levels since the first-difference observation reflects an additional period.

<sup>19</sup>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.

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 a positive interest rate innovation 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 2: Panel VAR: Impulse responses of exchange rate to interest rate shock (levels)



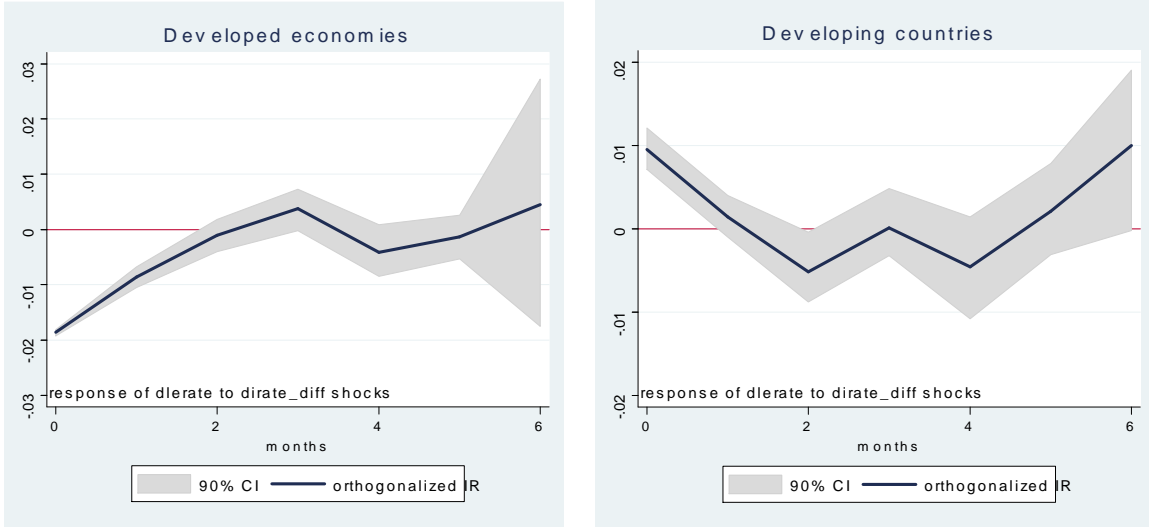
Note: Figures present the impulse responses of the exchange rate to a positive interest rate differential shock from panel VARs estimated for developed and developing countries. Estimation uses (log) exchange rates and interest rates in levels. Both series are de-meaned and linearly de-trended.

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.

## 2.1 Robustness of empirical results

In this section we present a battery of additional robustness checks of our key empirical result: interest rates and exchange rates are negatively related in industrial countries, but are positively

Figure 3: Panel VAR: Impulse responses of exchange rate to interest rate shock (1st differences)



Note: Figures present the impulse responses of the exchange rate to a positive interest rate differential shock from panel VARs estimated for developed and developing countries. Estimation uses (log) exchange rates and interest rates in first differences.

related in developing countries.

### 2.1.1 Exchange rate classification and crisis episodes

We begin by checking the robustness of our results with respect to the exchange rate classification. As we noted above, we used the definition of the floating exchange rate regime following Reinhart and Rogoff (2004) and the existing literature. This classification included the following categories: exchange rate in a given year was (i) within a moving band that is narrower than or equal to  $\pm 2\%$  (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. The latter “freely falling” category included countries in the following circumstances. First, it included countries that have experienced inflation rates above 40 percent over the 12 month period. Second, it included periods during the six months immediately following a currency crisis and accompanied by a regime switch from a fixed or quasi fixed regime to a managed or independently floating regime.

To verify that our results are not driven by the high-inflation countries or crisis episodes, we exclude these “freely falling” country-episodes from our benchmark sample. This leaves us with a selection of 58 country-episode pairs in total, of which 25 are developed country-episode pairs and 33 are developing country-episode pairs. Table 3 reports correlation and regression results for this modified sample. As is easy to see, all results remain practically unchanged and highly significant.

We also verify our individual country VARs and panel VARs for this restricted sample of countries

Table 3: Correlation between exchange rate and interest rate: No crisis or high inflation episodes

	Full sample	Developed	Developing
<i>Panel A</i>			
$corr(\ln E_t, i_t - i_t^{us})$			
mean	0.15	-0.09	0.33
median	0.11	-0.08	0.42
$corr(\Delta_t \ln E, \Delta_t (i - i^{us}))$			
mean	0.00	-0.10	0.08
median	-0.03	-0.11	0.05
<i>Panel B</i>			
$\ln E_t = \beta_0 + \beta_1(i_t - i_t^{us}) + \varepsilon_t$			
mean( $\hat{\beta}_1$ )	1.21	-0.74	2.69
95% c.i.( $\hat{\beta}_1$ )	[1.05; 1.37]	[-0.94; -0.54]	[2.45; 2.93]
$\Delta_t \ln E_t = \alpha_0 + \alpha_1 \Delta_t (i_t - i_t^{us}) + u_t$			
mean( $\hat{\alpha}_1$ )	-0.06	-0.44	0.22
95% c.i.( $\hat{\alpha}_1$ )	[-0.16; 0.04]	[-0.57; -0.31]	[0.08; 0.37]

Note: Panel A of the Table reports the mean and median of the cross-sectional distribution of the correlation coefficient between (log) exchange rate and interest rate (and their first-differences) for our sample of countries. Panel B presents the mean of the estimated slope coefficients from the regression  $\ln E_t = \beta_0 + \beta_1(i_t - i_t^{us}) + \varepsilon_t$  in levels and first-differences. 95% confidence intervals are in parenthesis.

and episodes. Our results change only marginally for developing countries. For instance, in bivariate VARs estimated on the levels of (log) exchange rate and interest rate differential we find that 71 percent of developing countries experienced depreciation after a positive shock to the interest rate differential on impact, 74 percent saw their currency depreciating 1 month after the shock, and exchange rate continued to depreciate 3 months after the shock in 76 percent of developing countries.<sup>20</sup> The panel VAR results also go through unchanged.

### 2.1.2 VAR specification

One concern that may arise in the bivariate VAR specification we estimated above is related to inflation. In particular, developing countries often experience higher inflation rates and may be more susceptible to inflationary shocks. Hence, their interest rate innovations might be endogenous policy responses to inflationary shocks which also tend to depreciate the currency. To account for this possibility we amend our VAR specification to include monthly CPI. There are two specifications that are popular in the literature. We examine both.

*Specification (1): Price level shocks.* First, following Eichenbaum and Evans (1995), for every country we estimate a three-variable VAR that includes its (log) consumer price index (CPI), its interest

<sup>20</sup>Note that no industrial country is classified as “freely falling” in Reinhart and Rogoff (2004).

rate differential with the U.S., and its (log) exchange rate. This is the same as our benchmark specification except that we have now also included the domestic *price level*. To obtain orthogonalized impulse responses we use the same ordering as in Eichenbaum and Evans (1995): Price level, interest rate differential, exchange rate. The data on all three variables, however, is available only for a subsample of our countries. Thus, our subsample with CPI consists of 59 country-episode pairs, of which 17 are for developed economies and 42 are for developing countries. We find that our results remain robust under this extended model specification. As shown in panel (1) of Table 4, among developed countries, 82 percent exhibit a currency appreciation on impact after a positive interest rate innovation. In contrast, 76 percent of developing countries saw their currency depreciating on impact after a positive interest rate shock. By the end of the first month, 82 percent of developed countries saw an appreciation of their currency, while 67 percent of developing countries experienced depreciations. By the end of the third month, the corresponding numbers were 82 percent and 74 percent. When estimated in growth rates, our VAR analysis suggests an impact exchange rate appreciation following a positive shock to the interest rate differential in 82 percent of developed countries and an exchange rate depreciation in 73 percent of all developing countries.

*Specification (2): Inflation shocks.* Second, we try another specification that is common in the literature which uses the inflation rate rather than the price level (see, for instance, Grilli and Roubini (1995, 1996)). Hence, we estimate a three-variable VAR that includes the domestic CPI *inflation rate* differential over the U.S. CPI inflation rate, the interest rate differential between home and the US, and the (log) exchange rate. We obtain orthogonalized impulse responses using the ordering: Inflation rate differential, interest rate differential, exchange rate. As can be seen in panel (2) of Table 4, under this specification, an orthogonalized interest rate shock led to an impact appreciation of the exchange rate in 82 percent of all developed countries but a depreciation in 67 percent of developing countries. At the end of the first and third month, the corresponding numbers were 82 percent for developed countries and 69 percent for developing economies.<sup>21</sup>

*Specification (3): Expected inflation shocks.* Inflation may matter for interest rate-exchange rate relationship in another important way. It may be the case that interest changes reflect endogenous policy responses to expected inflationary shocks. To account for this possibility, we estimate another modified VAR in which we include one month ahead inflation differential between home and the U.S. We order variables as follows: Forward CPI inflation differential, interest rate differential, exchange rate. The results are presented in Panel (3) and confirm that our earlier findings remain unchanged for developed countries and in fact become stronger for developing countries.

*Specification (4): Risk premium shocks.* Another potential concern is that the joint dynamics of

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<sup>21</sup>Note that we do not run this specification in first-differences since CPI inflation is already the first-difference of the log price level.

Table 4: Individual country VARs: Robustness

	(a). Levels			(b). First-differences		
	impact	1 month	3 months	impact	1 month	3 months
<i>(1) With CPI level: <math>\ln P, i - i^{US}, \ln E</math></i>						
Industrial countries: appreciation	82%	82%	82%	82%	82%	52%
Developing countries: depreciation	76%	67%	74%	73%	65%	68%
<i>(2) With inflation differential: <math>\pi - \pi^{US}, i - i^{US}, \ln E</math></i>						
Industrial countries: appreciation	82%	82%	82%	–	–	–
Developing countries: depreciation	67%	69%	69%	–	–	–
<i>(3) With forward inflation differential: <math>\pi_{t+1} - \pi_{t+1}^{US}, i_t - i_t^{US}, \ln E_t</math></i>						
Industrial countries: appreciation	82%	82%	82%	–	–	–
Developing countries: depreciation	71%	69%	71%	–	–	–
<i>(4) With risk-premium: <math>rp, i - i^{US}, \ln E</math></i>						
Industrial countries: appreciation	72%	84%	84%	–	–	–
Developing countries: depreciation	72%	72%	69%	–	–	–
<i>(5) With output: <math>\ln y, i - i^{US}, \ln E</math></i>						
Industrial countries: appreciation	84%	89%	84%	–	–	–
Developing countries: depreciation	64%	73%	64%	–	–	–
<i>(6) With output, CPI and risk-premium: <math>rp, \ln y, \ln P, i - i^{US}, \ln E</math></i>						
Industrial countries: appreciation	83%	92%	92%	–	–	–
Developing countries: depreciation	70%	60%	70%	–	–	–

Note: The table reports the fraction of developed (developing) countries that experience an appreciation (depreciation) of their exchange rate following a positive 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.

exchange rates and interest rates are driven by the changes in country risk-premiums. For instance, if the country risk-premium rises, its currency may depreciate. At the same time, its Central Bank may be compelled to raise domestic interest rates to counterweight the effect of the rising risk-premium. To account for such a possibility, we control for the risk-premium in the country VARs. Unfortunately, country-specific measures of risk-premium are available only for a very small group of developing countries. Instead we proxy developing country risk premia with junk bond spreads that are known to be highly correlated with the sovereign bond spreads – a standard measure of the country risk-premium (see Uribe and Yue (2006)). More precisely, we use Moody’s Seasoned Baa Corporate Bond Yield spread over the U.S. T-bill rate as a measure of risk-premium.<sup>22</sup> We re-run

<sup>22</sup>Blanchard (2004) also uses Baa spread and shows that it is a good instrument for risk-premium in Brazil.

our VARs and obtain orthogonalized impulse responses using the ordering: Risk-premium, interest rate differential, exchange rate. The proportions of appreciating developed countries and depreciating developing countries are reported in panel (4) of Table 4. As is easy to see, an overwhelming majority of all industrial countries in our sample still see their exchange rate appreciating following shocks to the interest rate, even after controlling for changes in the risk-premium. In contrast, in the majority of developing countries in our sample, exchange rates depreciate in response to interest rate shocks. We also use the Merrill Lynch High Yield Master II bond yield spreads to measure the risk-premium and find that the results remain robust.<sup>23</sup> Both series are available from the Board of Governors of the Federal Reserve System.

*Specification (5): Taylor rules.* Our policy-controlled interest rates may also be driven by endogenous policy responses to changes in domestic business cycles due to a Taylor rule. To account for this possibility we include industrial production (index, 2000 base year) in our baseline VAR specification. This would be our preferred VAR specification, but industrial production data is only available for less than a half (30 country-pairs to be precise, of which 19 belong to developed countries and 11 belong to developing countries) of all country-episode pairs in our sample.<sup>24</sup> The results for this subsample are reported in Panel (5) of Table 4. Importantly, our results are confirmed again: on impact, 84 percent of developed countries showed appreciation after an orthogonalized shock to interest rate, while developing countries showed depreciation in 64 percent of all cases. One month later 89 percent industrial countries currencies continued to appreciate, while 73 percent of developing countries saw depreciation. Three months later the proportions were 84 percent and 64 percent, respectively.

*Specification (6): All shocks.* Finally, we estimate an extended VAR specification, where we include CPI level, industrial production and risk-premium into the benchmark specification. We assume the following ordering for the variables: risk-premium, industrial production, price level, interest rate differential, exchange rate. This identification strategy implies that innovations to interest rates have effects on domestic real activity, the price level and the risk-premium with a one-period lag, but, as before, can affect exchange rates contemporaneously. This identification scheme also implies that shocks to output, prices and the risk-premium can affect domestic interest rates contemporaneously. This ordering reflects the standard assumption in the literature that macroeconomic variables react to monetary policy shocks with a lag, while monetary policy can respond to macroeconomic shocks immediately. A similar structure is assumed for the relationship between the exchange rate and macroeconomic variables: exchange rate can respond immediately to all shocks, but its effect on

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<sup>23</sup>We prefer to report the results for the BAA spread because it is available for a longer period thus allowing us to estimate VARs for a larger sample of countries (79 country-episode pairs, as opposed to 44 country-episode pairs if we use high-yield spread instead).

<sup>24</sup>The ordering follows Eichenbaum and Evans (1995), where industrial production appears first, followed by interest rate differential and (log) exchange rate.

macroeconomic variables percolates only with a lag. The ordering of the first three variables assumes that risk-premium shocks are the most exogenous.<sup>25</sup> The assumption that output shocks affect prices immediately is standard in the literature (see, for instance, Bernanke and Blinder (1992)).

Due to limited data availability, this extended VAR can only be estimated for 22 country-pairs, of which 12 are industrial country-pairs and 10 are developing country-pairs. The results for this VAR specification are presented in Panel (6). A shock to interest rate that is orthogonal to domestic output, the price level, and risk-premium, leads to currency appreciation on impact in 83 percent of developed countries, the share increases to 92 percent of all developed countries after one month, and 92 percent see their currency appreciating three months following the shock. The corresponding numbers for developing countries are 70 percent, on impact, 60 percent after 1 month and 70 percent after 3 months.

### 2.1.3 Structural VAR

In our VAR analysis so far we obtained identification of interest rate shocks by placing zero contemporaneous restrictions on the interaction between interest rates and the exchange rate. This assumption, while standard in the literature, rules out potential simultaneity effects between interest rates and exchange rates in identifying interest rate shocks. However, contemporaneous feedback between interest rates and exchange rates may be important in developing countries, as emphasized in the “fear of floating” literature (see Calvo and Reinhart (2002)). This literature documents the tendency of monetary authorities, especially in developing countries, to respond to fluctuations in the exchange rate. Furthermore, since the exchange rate is a forward looking variable, it may contain information about the future prospects of the economy to which the monetary authority may want to react. Both these concerns raise the question of whether our results are sensitive to the identifying restrictions we used?

To address this question we estimate a structural VAR (SVAR) in which we allow for a contemporaneous correlation between interest rate and the exchange rate. Identification is obtained by imposing a long-run restriction that interest rates have no long-run effects on the *real* exchange rate. This is a standard neutrality assumption that holds in a number of theoretical monetary models (see Clarida and Gali (1994)) and has been recently used in several empirical studies (see Bjørnland (2009)).<sup>26</sup> Thus, we estimate a structural VAR containing interest rate differential,  $i - i^{US}$ , and the first difference of the log real exchange rate  $\Delta \ln r_{er}$ , imposing long-run neutrality restriction described above.<sup>27</sup> We find that our results remain largely unchanged. Based on structural impulse responses,

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<sup>25</sup>We also try an alternative ordering where risk-premium variable is placed after output and price level, and find that results remain unchanged.

<sup>26</sup>This restriction is also satisfied by the model we develop in this paper.

<sup>27</sup>We estimate the SVAR on the first differenced (log) real exchange rate so that, in the spirit of Blanchard and

we find that 73 percent of all developing countries in our sample experienced impact depreciations following an interest rate shock, 69 percent depreciated 1 month after the shock while 55 percent experienced depreciations 3 months after the shock. We interpret these results as not necessarily suggesting that the contemporaneous feedback between interest rates and exchange rate is not important. Instead we think that the exchange rate classification scheme of Reinhart and Rogoff (2004) that we used to identify flexible exchange rate countries, by being based on the de-facto exchange rate regime, allowed us to focus on the countries and episodes for which “fear of floating” was less of a concern.

Overall, based on the variety of samples and 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 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 model of a small open economy that is perfectly integrated with the rest of the world in both goods and capital markets. It is populated by four types of agents: households, firms, banks and the government. The infinitely-lived representative 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 representative firm combines capital and labor to produce final goods, and is subject to a working capital requirement. As a result, it must borrow from the banks. The representative bank acts as an intermediary between households and firms, but also lends to the government. The latter is comprised of a fiscal and monetary authority. We describe the problem of each agent in details next.

#### 3.1 Households

Household’s lifetime welfare is given by

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

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Quah (1989), the effects of the interest rate shock on the level of the exchange rate add up to zero. See Appendix A.2 for econometric details.

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

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

Here  $\sigma$  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.<sup>28</sup>

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

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

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-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:

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

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

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

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<sup>28</sup>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)). The key analytical simplification introduced by GHH preferences is that there is no wealth effect on labor supply.

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  $\rho$  denote the wage and rental rates.  $\tau$  denotes lump-sum transfers received from the government.  $\Omega^f$  and  $\Omega^b$  represent dividends from firms and banks respectively.  $\kappa$  denotes capital adjustment costs

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

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

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

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

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

where  $\Omega^f$  and  $\Omega^b$  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  $t$ . We define the nominal interest rate as

$$1 + i_{t+1} = R\mathbb{E}_t(1 + \pi_{t+1}). \quad (6)$$

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

$$y_t = F(k_{t-1}, A_t l_t) = A_t k_{t-1}^\alpha l_t^{1-\alpha}, \quad (7)$$

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  $\phi$  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.<sup>29</sup>

<sup>29</sup> 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

Formally, this constraint is given by

$$N_t = \phi P_t w_t l_t, \quad \phi > 0, \quad (8)$$

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

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

where  $i^l$  is the lending rate charged by bank for their loans and  $\Omega^f$  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

$$b_{t+1}^f - n_t = R b_t^f - \left( \frac{1 + i_t^l}{1 + \pi_t} \right) n_{t-1} + y_t - w_t l_t - \rho_t k_{t-1} - \Omega_t^f.$$

Define

$$a_{t+1}^f \equiv b_{t+1}^f - \frac{(1 + i_{t+1}^l)}{R(1 + \pi_{t+1})} n_t.$$

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

$$a_{t+1}^f + \Omega_t^f = R a_t^f + y_t - \rho_t k_{t-1} - w_t l_t \left[ 1 + \phi \left\{ \frac{1 + i_{t+1}^l - R(1 + \pi_{t+1})}{R(1 + \pi_{t+1})} \right\} \right]. \quad (9)$$

Note that  $\phi \left\{ \frac{1 + i_{t+1}^l - R(1 + \pi_{t+1})}{R(1 + \pi_{t+1})} \right\} w_t l_t = \left\{ \frac{1 + i_{t+1}^l - R(1 + \pi_{t+1})}{R(1 + \pi_{t+1})} \right\} n_t$  is the additional resource cost that is incurred by firms due to the credit-in-advance constraint.<sup>30</sup>

The firm chooses a path of  $l$  and  $k$  to maximize the present discounted value of dividends subject to equations (7), (8) and (9). 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.

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additional insights.

<sup>30</sup>We should note that the credit-in-advance constraint given by equation (8) holds as an equality only along paths where the lending spread  $1 + i^l - R(1 + \pi)$  is strictly positive. We will assume that if the lending spread is zero, this constraint also holds with equality.

### 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,  $Z$ .<sup>31</sup> It also holds required cash reserves,  $\theta D$ , where  $\theta > 0$  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  $\phi^n$  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.<sup>32</sup> The nominal flow constraint for the bank is

$$N_t + Z_t - (1 - \theta) D_t + P_t q_t - P_t d_{t+1}^b = \left(1 + i_t^l - \phi^n\right) N_{t-1} + (1 + i_t^g) Z_{t-1} - \left(1 + i_t^d\right) D_{t-1} + \theta D_{t-1} - P_t R d_t^b - P_t \Omega_t^b, \quad (10)$$

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:

$$q_t = q\left(d_{t+1}^b\right), \quad q' > 0, \quad q'' > 0.$$

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:

$$q_t = \frac{\gamma}{2} \left(d_{t+1}^b - \bar{d}^b\right)^2, \quad (11)$$

where  $\gamma > 0$  and  $\bar{d}^b$  are constant parameters.<sup>33</sup>

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

$$\Omega_t^b = \left[ \frac{R(1 + \pi_t) - 1}{1 + \pi_t} \right] [(1 - \theta) d_{t-1} - n_{t-1} - z_{t-1}] + \frac{i_t^l - \phi^n}{1 + \pi_t} n_{t-1} + \frac{i_t^g}{1 + \pi_t} z_{t-1} - \frac{i_t^d}{1 + \pi_t} d_{t-1} - q_t, \quad (12)$$

<sup>31</sup>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 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).

<sup>32</sup>We should note that this cost  $\phi^n$  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  $\phi^n = 0$ .

<sup>33</sup>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:  $P_t d_{t+1}^b = N_t + Z_t - (1 - \theta) D_t$ . 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  $d_{t+1}^b = \frac{N_t + Z_t - (1 - \theta) D_t}{P_t}$ .

The representative bank chooses sequences of  $N$ ,  $Z$ , and  $D$  to maximize the present discounted value of profits subject to equations (10) taking as given the paths for interest rates  $i^l$ ,  $i^d$ ,  $i^g$ ,  $i$ , and the value of  $\theta$  and  $\phi^n$ . We assume that the bank uses the household's stochastic discount factor to value its profits. Note that  $i_{t+1}^g, i_{t+1}^l$  and  $i_{t+1}^d$  are all part of the information set of the household at time  $t$ .

The bank optimality conditions imply that we must have

$$i_{t+1}^l = i_{t+1}^g + \phi^n, \quad (13)$$

$$i_{t+1}^d = (1 - \theta) i_{t+1}^g. \quad (14)$$

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  $\phi^n$  of monitoring loans to private firms. Hence, equation (13) says that the interest rate charged by banks on private loans should equal the rate on loans to the government plus  $\phi^n$ . 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  $\theta$  of deposits as required reserves. Hence, equation (14) shows that at an optimum the deposit rate must equal the interest on government bonds net of the resource cost of holding required reserves.

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  $\lim_{\gamma \rightarrow \infty} d_{t+1}^b = \bar{d}^b$ . 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,  $\tau$ , to the public, and sets the reserve requirement ratio,  $\theta$ , 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

$$\bar{\tau} + \frac{1 + i_t^g}{1 + \pi_t} z_{t-1} = m_t + z_t - \frac{1}{1 + \pi_t} m_{t-1}. \quad (15)$$

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

$$\frac{M_{t+1}}{M_t} = 1 + \mu_{t+1}, \quad M_0 \text{ given.} \quad (16)$$

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  $\tau$ . 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 (15)). 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  $\mu$  adjusts endogenously so that equation (15) is satisfied.

### 3.5 Resource constraint

By combining the flow constraints for the consumer, the firm, the bank, and the government (equations (5), (9), (12) and (15)) and using equations (7) and (8), we get the economy's flow resource constraint:

$$a_{t+1} = Ra_t + y_t - c_t - I_t - \kappa_t - s_t - q_t, \quad (17)$$

where  $a = b + b^f - d^b$ . Note that the right hand side of equation (17) 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  $s^t = (s_0, s_1, s_2, \dots, s_t)$ . An equilibrium for this economy is defined as:

*Given a sequence of realizations  $A(s^t)$ ,  $i^g(s^t)$ ,  $r$  and  $\bar{\tau}$ , an equilibrium is a sequence of state contingent allocations  $\{c(s^t), x(s^t), l(s^t), h(s^t), d(s^t), k(s^t), b(s^t), b^f(s^t), d^b(s^t), n(s^t), z(s^t)\}$  and prices  $\{P(s^t), \pi(s^t), i(s^t), i^d(s^t), i^l(s^t), w(s^t), \rho(s^t)\}$  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 (15)) is satisfied.*

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

$$\bar{\tau} = h_t - \left( \frac{1}{1 + \pi_t} \right) h_{t-1} + \theta \left( d_t - \frac{d_{t-1}}{1 + \pi_t} \right) + z_t - \left( \frac{1 + i_t^g}{1 + \pi_t} \right) z_{t-1}. \quad (18)$$

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 that  $i^d$  is linked one-for-one with  $i^g$ . At any date  $t$ ,  $M_t$  is known while its growth rate  $\mu_{t+1}$  is endogenous. Money market equilibrium then dictates that at date  $t$  the nominal exchange rate is given by

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

For any given policy rate  $i_t^g$ , the inflation rate  $\pi_t$  (and hence the nominal interest rate  $i_t$ ) is determined from the government budget constraint (18). 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  $\mu$  between dates  $t$  and  $t + 1$  also gets determined at date from equation (15). Hence,  $M_{t+1}$  gets determined at date  $t$ .<sup>34</sup>

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<sup>34</sup>It is important to note that there is no nominal indeterminacy in this model despite the policy rate being chosen exogenously. Essentially, the real money demand  $L$  is a function of both  $i$  and  $i^g$ . While  $i^g$  is exogenous,  $i$  is determined endogenously within the model from the government budget constraint through the inflation tax that is required to finance the exogenous level of public spending  $\bar{\tau}$ .

### 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  $i^l$  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.

Our basic approach is to keep the majority of the parameters of the model common to both sets of countries. The parameters that we calibrate separately for developed and developing countries are those that control the three key features that we have introduced in the model: the money demand effect, the fiscal effect and the output effect. By restricting the differences between the two groups of countries, we feel that this approach allows us to better ascertain the quantitative power of the margins we have introduced in the model. Clearly, the more parameters we calibrate separately for the two groups the greater our ability to explain differences in the data patterns since developed and developing countries differ along many more margins than the three that we have chosen to focus on here.

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 the 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 A.3. 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

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

with  $\xi$  being the level parameter.

As in Rebelo and Vegh (1995), we assume that the transactions costs functions  $v(\cdot)$  and  $\psi(\cdot)$  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

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

where  $d_{t+1}^b = \frac{N_t + Z_t - (1-\theta)D_t}{P_t}$ . Here  $\gamma$  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) and Mendoza (1991).<sup>35</sup> In particular, we set the coefficient of relative risk aversion,  $\sigma$ , to 5, while the curvature of the labor,  $v$ , is set to 1.6. This value is within the range of values used in the literature.<sup>36</sup> This implies the elasticity of labor demand with respect to real wage,  $\frac{1}{v-1}$ , equal to 1.67, consistent with the estimates for the U.S. Labor weight parameter  $\zeta$  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,  $\beta$ , is set to 0.97, as in Uribe and Yue (2006). Capital income share,  $\alpha$ , is chosen to be equal to 0.38, while a depreciation rate for capital,  $\delta$ , of 4.4% per quarter. Capital adjustment costs parameter  $\xi$  is calibrated to replicate the volatility of investment relative to the volatility of output in our sample.

The remaining parameters are calibrated to developed and developing countries separately using the sample of 6 developed and 6 developing countries discussed above. Parameter  $\theta$  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  $\theta$  equal to 0.03 in developed countries and 0.10 in developing economies over our sample period. Reserve requirement ratio  $\theta$ , together with  $s_{\varkappa}$  and  $\lambda_{\varkappa}$ ,  $\varkappa = \{h, d\}$  parameters in the transactions costs technology for banks, 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,  $\tau$ , are measured as the net lending/borrowing by the general government as a share of GDP. Over our sample period,

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<sup>35</sup>Note that all of these common parameters are almost the same in the two papers – Neumeyer and Perri (2005) who focus on Argentina and in Mendoza (1991) who calibrates to Canada.

<sup>36</sup>For example, Mendoza (1991) uses  $v$  equal to 1.455 for Canada, while Correia, Neves, and Rebelo (1995) set  $v$  to 1.7 for Portugal.

this ratio is equal to -1.3% in developed economies, and -2.1% in developing countries.

It is important to note that the differences in the moments between developed and developing countries that we relied on so far to calibrate our key parameters are systematic. For instance, all developing countries in our calibration sample have higher reserve requirement ratios, significantly lower ratio of M1 to GDP and ratio of deposits to cash, as well as larger negative fiscal imbalances.<sup>37</sup> Based on these evidence, we believe that our key parameters are correlated with the level of income and can be used to distinguish developed and developing countries.

The share of wage bill paid in advance,  $\phi$ , is a difficult parameter to calibrate. Most of the existing studies that incorporate such working capital constraints 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 the 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  $\phi$  equal to 1, while Uribe and Yue (2006), find that a value of  $\phi$  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  $\phi$  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  $\phi$  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  $\phi$  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.

We calibrate parameters  $\gamma$  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.<sup>38</sup> The proportional cost parameter  $\phi^n$  in the banking sector’ problem is chosen to match the average

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<sup>37</sup>The only exception is Korea, whose fiscal balance to GDP ratio is positive, on average.

<sup>38</sup>In fact, we restrict  $\gamma$  to be the same in the two groups of countries to reduce the number of the free parameters. The resulting banking costs,  $q$ , in the steady state are very small, equal to less than 0.00086% of GDP.

spread of nominal lending rate over money market rate equal 9% in developing countries and 5% in developed economies over our sample period. Table 5 summarizes parameter values under our benchmark parametrization.<sup>39</sup>

Table 5: Benchmark parameter values

PREFERENCES		DEVELOPED	DEVELOPING
discount factor	$\beta$	0.971	0.971
risk-aversion	$\sigma$	5	5
labor curvature	$\nu$	1.6	1.6
labor weight	$\zeta$	2.48	2.48
TECHNOLOGY			
capital income share	$\alpha$	0.38	0.38
depreciation rate	$\delta$	0.044	0.044
share of wage-in-advance	$\phi$	0.15	0.15
capital adjustment costs	$\xi$	4.5	4.5
MONEY			
reserve requirement	$\theta$	0.03	0.10
transaction cost technology	$\lambda_{\varkappa}, \varkappa = \{h, d\}$	$\lambda_h = 0.24, \lambda_d = 0.98$	$\lambda_h = 0.125, \lambda_d = 0.138$
banks cost technology	$\gamma$	100	100
per unit loans costs	$\phi^n$	0.05	0.09
lump-sum transfers	$\tau$	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,  $\rho_A$ , equal to 0.95. The innovations,  $\varepsilon^A$ , to this process are assumed to be independent and identically normally distributed with the standard deviation,  $\sigma(\varepsilon^A)$ , 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 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

<sup>39</sup>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.

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  $\hat{i}^g$  as a differential between a country interest rate and the U.S. Federal Funds rate, and then estimate the first-order autoregressive process for  $\hat{i}^g$  as

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

where  $\varepsilon_t^g$  are i.i.d. normal innovations.<sup>40</sup> 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  $\hat{i}_t^g$  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  $\hat{i}_t^g$  is 1.53% in developed countries and 4.50% in developing economies.<sup>41</sup> We also get  $\sigma(\varepsilon_t^g) = 0.0049$  in developed countries and  $\sigma(\varepsilon_t^g) = 0.0216$  in developing countries, on average.<sup>42</sup>

Once the shock processes and other parameter values are set, we solve the model by linearizing the equations characterizing equilibrium around the steady state and solving the resulting system of linear difference equations.<sup>43</sup>

## 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,  $\pi_t$ , 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

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<sup>40</sup> Measuring  $\hat{i}^g$  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 de-trend of the interest rate data.

<sup>41</sup> In the estimation of the process for  $\hat{i}^g$  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.

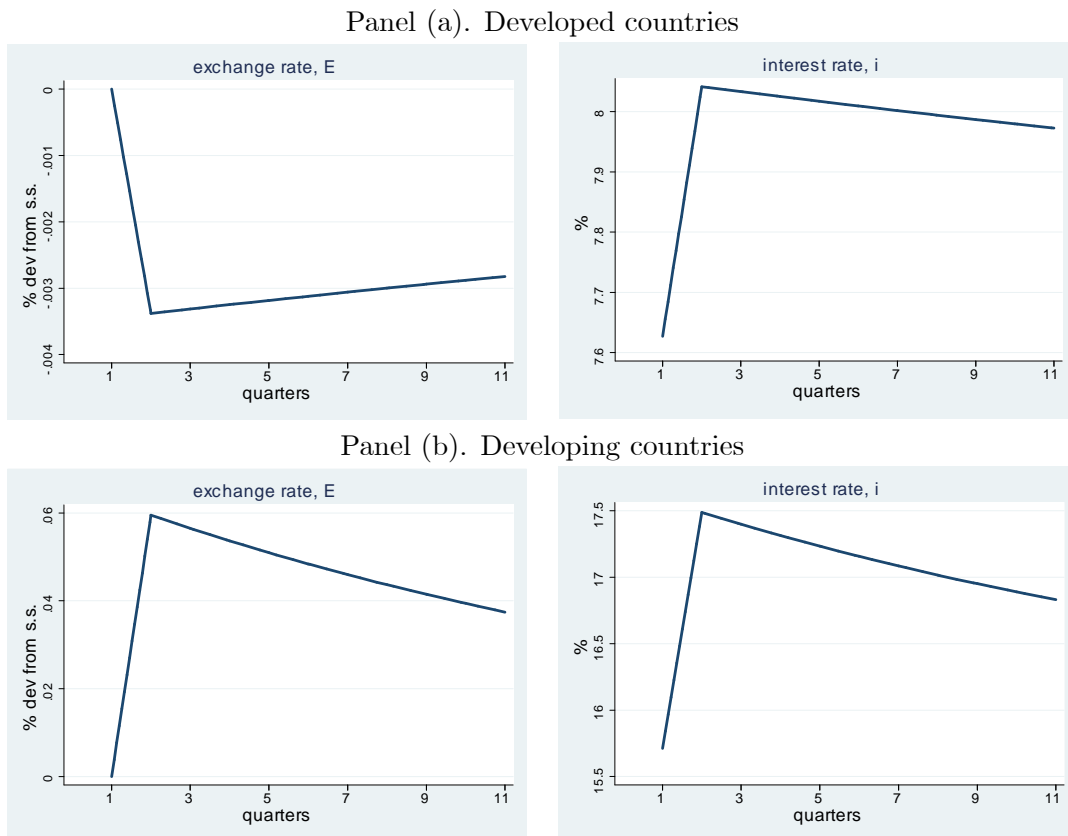
<sup>42</sup> We also estimated country-specific processes for  $\hat{i}^g$ , and found them to be along the lines of the aggregate estimates.

<sup>43</sup> In our economy, international bonds follow a unit root process. To account for this 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 holdings to GDP, and  $\vartheta$  is a level parameter.

the literature to normalize nominal non-stationary variables in monetary models. Before proceeding, it is important to note that only nominal variables are non-stationary in the model. All real variables, including real money demand, in our model are stationary in that temporary shocks leave their long run levels unchanged.

Figure 4 presents impulse responses of the exchange 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. We also report the impulse responses of the market interest rate,  $i$ , to the same  $i^g$  shock in developed and developing countries on Figure 4.

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



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.

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. Note that these responses not only match the signs of the empirical impulse responses, but are also in line with the quantitative estimates of those responses in Figures 1 and 2. The market interest rate,  $i$ , increases after the shock to  $i^g$  in both countries.

The impulse responses in Panels (a) and (b) of Figure 4 highlight the inherent non-monotonicities in the relationship between interest rates and the exchange rate present in our model. One might argue that the interest rates measured in the data and used in our empirical analysis might not be fully controlled by the policymakers. Our theoretical impulse responses above highlight the fact that the differing relationship between exchange rate and interest rate for developed and developing countries also holds more generally for market interest rates, not just policy-controlled interest rate. There is a positive comovements between the market interest rate and exchange rate in developing countries but negative comovement in developed countries rather than a systematic relationship for all.<sup>44</sup>

## 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 “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.,  $d^b = \bar{d}^b$ . From expression (19), the exchange rate at any date  $t$  is given by  $E_t = \frac{M_t}{h_t + \theta d_t}$  where  $M_t$  is given. Log differentiating this relationship gives

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

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 cash holdings,  $h$ , and interest-bearing demand

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<sup>44</sup>Note that following the shock, market interest rates remains above their steady state value for a prolonged period of time in both developed and developing country calibrations. Since uncovered interest parity holds in our model, this implies a depreciating path for the exchange rate in both countries immediately following the differing impact response. This is indeed in the case in our model. However, while panel (a) in Figure 4 is consistent with this pattern in that the exchange rate exhibits a depreciating path after the impact appreciation, the response of developing countries shown in panel (b) appears to contradict it. The exchange rate in developing countries seem to be appreciating after an impact depreciation. This pattern is an artefact of the normalization by  $M$  that we used. Because  $M$  is also increasing after the shock, but does so at a faster rate than the exchange rate for developing countries, the ratio of  $E/M$  is falling.

deposits,  $d$ , 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  $d_t = \tilde{d}\left(\frac{i_{t+1} - (1-\theta)i_{t+1}^g}{1+i_{t+1}}\right)$  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

$$\bar{\tau} + \frac{1 + i_t^g}{1 + \pi_t} z_{t-1} = h_t - \frac{h_{t-1}}{1 + \pi_t} + \theta d_t - \frac{\theta d_{t-1}}{1 + \pi_t} + z_t \quad (21)$$

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  $\pi_t$  and  $i_{t+1}$ . Note that  $i_t$  and  $i_t^g$  are given at any date  $t$  while  $\pi_t$  and  $P_t$  are determined within the period. Since  $P_{t-1}$  is given, pinning down  $\pi_t$  ( $= \frac{P_t}{P_{t-1}}$ ) and is equivalent to determining  $P_t$ .<sup>45</sup>

In light of these linkages, how does one understand the differences in the calibrated responses of developed and developing countries? The discussion above makes clear that the opposing responses of the exchange rate in these two groups of countries to interest rate shocks must be due to differences in the responses of cash and demand deposits. But what factors explain the differences in the response of these two variables? We illustrate the key factors at play by using impulse responses of various variables to a positive shock to  $i^g$ . To facilitate the comparison across developed and developing countries calibrations we use the same size of the shock (equal to developed country standard deviation of  $i^g$ ) in both calibrations. Also, since the steady states are different in the two calibrations, we present all impulse responses as deviations from the steady state (multiplied by 100). Results are in Figure 5.

An increase in  $i^g$  leads to a fall in the demand for loans, and therefore output, due to a working capital constraint. Since parameter  $\phi$ , which governs the tightness of this constraint, is calibrated to be the same across developed and developing countries, the impact response of output is symmetric for

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<sup>45</sup>It is important to note that pinning down  $i_{t+1}$  is not equivalent to determining  $P_{t+1}$ . To see this, note that  $1 + i_{t+1} = R\mathbb{E}_t(1 + \pi_{t+1}) = R\mathbb{E}_t\left(1 + \frac{P_{t+1}}{P_t}\right)$ . Clearly, this is not equivalent to determining  $P_{t+1}$  which is free to deviate from  $\mathbb{E}_t(P_{t+1})$  in response to shocks that hit the economy after the formation of expectations about period  $t + 1$ .

the two groups.<sup>46</sup> The response is more long-lived in developed countries due to a higher persistence of the process for  $i^g$  in that group of countries. All else equal, a smaller loan portfolio of banks raises the amount of government bonds that banks buy, i.e.,  $z$  rises. In combination with the higher interest rate on these bonds, the interest burden on the government rises. Financing this higher level of fiscal spending thus requires a higher inflation rate,  $\pi$ . This, in turn, leads to a higher interest rate  $i$  following the shock to  $i^g$ .

How do money demand and its components respond to a rise in  $i^g$  and  $i$ ? Not surprisingly, demand for cash declines in both groups, since a rise in  $i$  unambiguously leads to a rise in the opportunity cost of holding cash,  $\frac{i_{t+1}}{1+i_{t+1}}$ . This effect is larger for developing country calibration, leading to a larger drop in cash holdings. On the other hand, demand for deposits rises in both calibrations. This is because the opportunity cost of holding deposits,  $\frac{i_{t+1} - (1-\theta)i_{t+1}^g}{1+i_{t+1}}$ , declines. On the one hand, higher  $i^g$  lowers this opportunity cost while on the other, an increase in  $i$  works in the opposite direction. Quantitatively, the first effect dominates under both calibrations, leading to higher deposit demand in both groups of countries. Turning to aggregate money demand,  $m = h + \theta d$ , we see opposing responses in the two calibrations: money demand increases in the developed country calibration, but declines in the developing country. This reflects the fact that, following the shock, the increase in deposits is larger than the fall in cash holdings in developed countries but not so in developing countries. Why is this the case? The key reason for the difference is that the steady state level of deposits to cash is four-times higher in developed economies than in developing countries in our calibration, reflecting the same difference in the data. This implies that deposits constitute a significantly larger fraction of total money demand in developed countries.<sup>47</sup> Hence, money demand in developed countries is more sensitive to changes in deposits than in developing countries (where cash holdings occupy a larger weight in money demand). As a result, after a positive shock to  $i^g$ , money demand increases in developed countries leading to an appreciation in  $\hat{E}$  as shown in equation (20). However, the same shock leads to a fall in money demand in developing countries and to a currency depreciation for them.

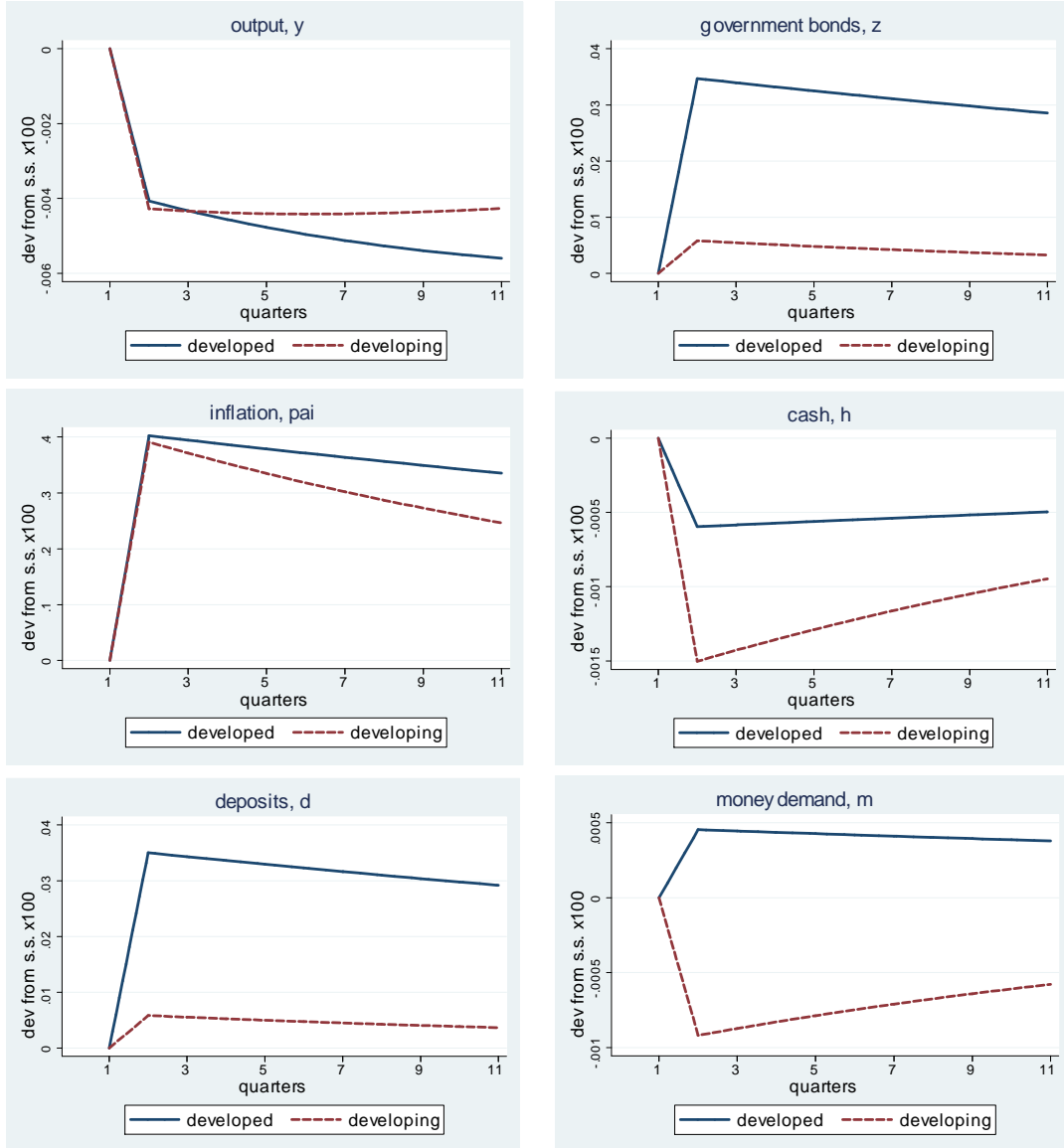
Next, we evaluate the sensitivity of our results with respect to several key parameters that distinguish developed and developing countries in our calibration. These parameters also affect the strength of the three effects – fiscal, output, and money demand effects – that we focused on in the model.

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<sup>46</sup>Note that the loan to output ratio is  $\frac{\phi w l}{y}$ . Under the Cobb-Douglas specification for technology,  $\frac{w l}{y} = 1 - \alpha$  is the same for both groups. Hence, under our maintained parameterization of a common  $\phi$ , the loan-output ratio is the same across countries. This is the reason for the symmetric output effect on impact for developed and developing countries in 5.

<sup>47</sup>Note, however, that the parameter  $\theta$  is higher in the developing country calibration, thus increasing the weight of deposits in total money demand in this group. This effect, however, is not too strong under our benchmark calibration. We investigate the robustness of our results with respect to parameter  $\theta$  in the next sub-section.

Figure 5: Impulse responses following 1 std dev shock to  $i^g$



Note: The figures present the responses of various variables to a 1 std. dev. positive shock to policy-controlled interest rate,  $i^g$ , in the versions of the model calibrated to developed and developing countries. The shock is set to be the same in the two groups of countries equal to the std. dev. of  $i^g$  in developed economies. All responses are presented in deviation from the steady state multiplied by 100.

## 5.2 Varying key parameters

The first of our three effects is the *fiscal effect*. The size of the fiscal burden in the model 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  $\pi_t$  (or

equivalently,  $P_t$ ) and  $i_{t+1}$ .<sup>48</sup> Consider equation (21) in a perfect foresight steady state:

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

where we have used the steady state relation  $1 + i = R(1 + \pi)$ . Keeping everything else constant, 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. Thus, the model predicts that the higher is  $\bar{\tau}$  the more depreciated the country's currency.

Figure 6 shows the fiscal effect in play for both developed countries (left panel) and emerging economies (right panel). In 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  $\tau$  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 6 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 developed countries, a higher  $i^g$  induces an impact currency appreciation for the entire range of  $\bar{\tau}$ 's plotted. For developing 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  $\tau$  becomes larger, reflecting partly the fact that the exchange rate changes are in percent deviations from the steady state and the higher  $\tau$  raises the steady state level of  $E$  itself for both groups.

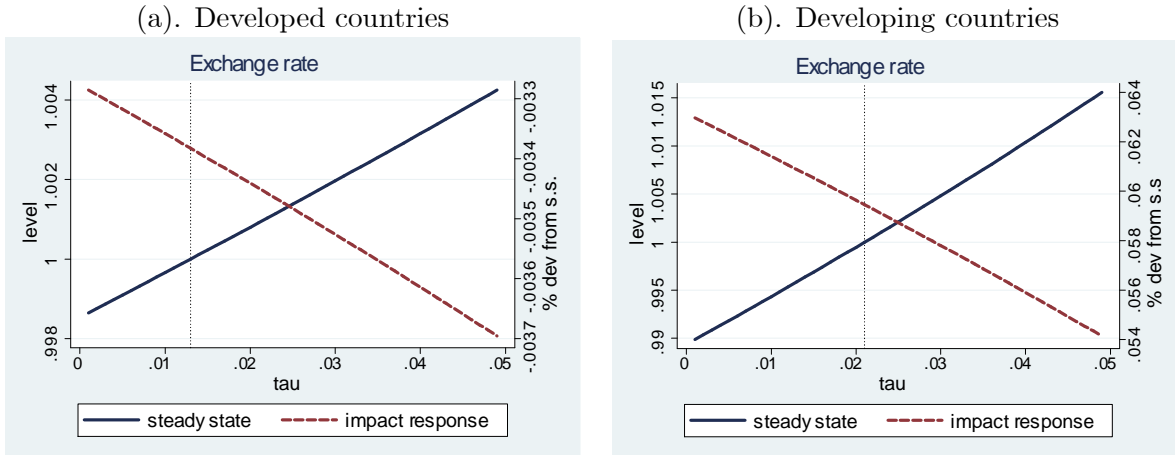
We draw two main conclusions from these results. First, for any given level of nominal money supply, a higher  $\tau$ , which is partially responsible for the strength of the fiscal effect, always leads to a more depreciated currency in the steady state. Second, the difference between developed and emerging economies that we found in Figure 4 is robust to changes in the level of  $\bar{\tau}$  since changes in  $\tau$  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. One of the key parameters that controls the strength of this effect is  $\theta$  which is the share of deposits that comprises the money base (bank reserves). In the model, the higher is  $\theta$  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

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<sup>48</sup>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 6: Comparative statics for parameter  $\tau$



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

equivalently a lower  $\pi$ ) 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  $\pi$  and  $i$ . However, for a given  $i^g$  a higher  $\theta$  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.

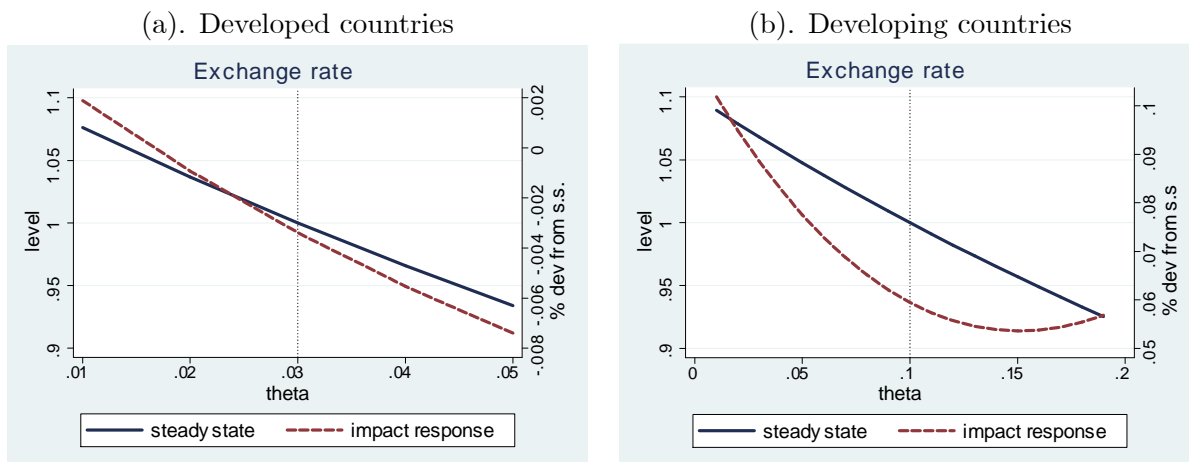
Figure 7 shows the effect of the parameter  $\theta$  on the exchange rate. The figure is symmetric to the one for the fiscal spending parameter  $\tau$  above. The solid lines depict the effect of  $\theta$  on the initial level of the exchange rate for a constant initial nominal money supply. The dashed 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  $\theta$ . 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 7 show that the initial value of the exchange rate is a decreasing function of  $\theta$ , 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  $\theta$ '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  $\theta$ . More generally, for

developed countries a higher domestic interest rate would depreciate the currency for very low levels of  $\theta$  but begin to appreciate it for higher  $\theta$ 's.

The switch in the impact response of  $E$  to  $i^g$  shock in developed countries from depreciation to appreciation as one changes  $\theta$  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  $\theta$ .

Figure 7: Comparative statics for parameter  $\theta$



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

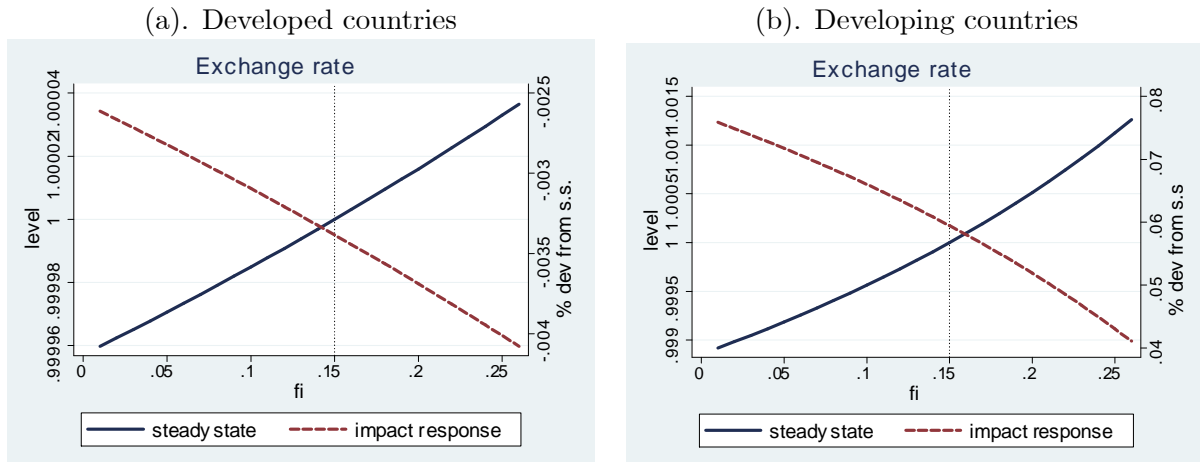
Our third effect is the output effect. The size of this effect is captured by the wage-in-advance parameter  $\phi$ . The higher is  $\phi$  the greater is the wage-in-advance requirement and hence the demand for loans. All else equal, a higher loan portfolio of banks reduces the amount of government 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  $\pi$  (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  $\phi$ . Figure 8 shows the effects of varying  $\phi$  in our model. The figure is symmetric to the ones for  $\tau$  and  $\theta$ . The upward sloping solid lines in the two panels of Figure 8 demonstrate that the higher is  $\phi$  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  $\phi$ .

Given that Figure 8 consistently reveals a depreciation for developing countries and an apprecia-

tion for developed economies for a broad range of values for  $\phi$  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  $\phi$ .

Figure 8: Comparative statics for parameter  $\phi$



Note: The top panel presents the responses of nominal exchange rate to changes in  $\phi$ . The developed country calibration is shown in the left panel while the right panel shows the developing country calibration. Dotted vertical line indicates the level of  $\phi$  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  $\tau$  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 bank reserves as a share of deposits 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  $\theta$  and make the money demand effect substantially weaker in developing countries relative to developed economies. As panel (a) of Figure 7 shows, if bank reserves in developed economies were lowered from the benchmark level of 0.03 to about 0.015, then the impact appreciation of  $E$  in developed countries in response to an

increase in  $i^g$  would switch to an impact depreciation of the currency.

Finally, in our benchmark calibration we assumed that the wage-in-advance parameter  $\phi$  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  $\phi$  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 panel dataset comprising of 72 countries between 1974 and 2010 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.

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## A Appendix

### A.1 Empirical evidence

In this Appendix we describe our data sources used in the empirical sections of the paper. Our primary data sources are the International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF) and the World Development Indicators (WDI) compiled by the World Bank. In our analysis we considered all countries in the IFS and WDI datasets for which monthly data on exchange rates and interest rates was available for any fraction of the 1974-2010 period.

Data description and sources are summarized in Table A1.

Table A1: Data description and sources

Variable	Definition	Source
Exchange rate	official exchange rate, period average	IFS by IMF
	market exchange rate, period average	IFS by IMF
	principal exchange rate, period average	IFS by IMF
	commercial exchange rate, period average	IFS by IMF
Interest rate	T-bill rate, period average	IFS by IMF
	discount rate, period average	IFS by IMF
	money market rate, period average	IFS by IMF
Output	Industrial production index	IFS by IMF
	2000 base year	
CPI	Consumer price index	IFS by IMF
Risk premium	BofA Merrill Lynch US High Yield Master II Option-Adjusted Spread	BofA Merrill Lynch
	Moody's Seasoned Baa Corporate Bond Yield	Board of Governors of the Federal Reserve System

As we mentioned in the main text, in our empirical analysis we restrict the sample to only 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. In particular, 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  $\pm 2\%$  (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. 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. Table A2 contains the list of country-episode pairs that are included in our sample.

Table A2: Sample used in the empirical work

No	from	to	country	No	from	to	country
1	1994m7	2001m12	Albania	41	1990m1	1998m12	Luxembourg
2	1988m1	1995m1	Algeria	42	2002m10	2007m12	Madagascar
3	2002m1	2005m5	Angola	43	1983m1	1994m12	Malawi
4	1974m1	2010m11	Australia	44	1997m8	2003m8	Malawi
5	1974m1	1998m12	Austria	45	1987m11	2000m12	Malta
6	1994m1	2002m10	Belarus	46	1982m2	1988m11	Mexico
7	1974m1	1998m12	Belgium	47	1995m1	2007m12	Mexico
8	1999m2	2007m12	Brazil	48	1991m1	1994m1	Myanmar
9	1992m1	1996m12	Bulgaria	49	1996m8	1999m1	Myanmar
10	1974m1	2010m11	Canada	50	1974m1	1990m8	Netherlands
11	1999m9	2001m12	Chile	51	1978m1	2010m11	New Zealand
12	1990m3	1992m7	China, P.R. (Mainland)	52	1991m7	2007m12	Nigeria
13	1994m7	2004m2	Congo, Dem. Rep. of	53	1974m1	2009m5	Norway
14	1980m10	1983m10	Costa Rica	54	1990m1	1993m10	Peru
15	1997m6	2001m12	Czech Republic	55	1997m7	1999m11	Philippines
16	1981m5	1988m12	Denmark	56	1982m4	1998m5	Portugal
17	2003m11	2007m12	Dominican Republic	57	1994m3	2001m3	Romania
18	1999m1	2010m11	Euro Area	58	2003m4	2007m12	Serbia, Rep. of
19	1974m1	1998m12	Finland	59	2002m1	2005m6	Sierra Leone
20	1974m1	1998m12	France	60	1974m1	2007m12	Singapore
21	1986m1	1991m9	Gambia, The	61	1974m1	1985m8	South Africa
22	1975m7	1998m12	Germany	62	1995m3	2007m12	South Africa
23	1985m4	2001m3	Ghana	63	1979m1	1998m12	Spain
24	1983m1	2000m12	Greece	64	1974m1	2010m11	Sweden
25	2000m5	2002m6	Guinea	65	1980m1	2010m11	Switzerland
26	1988m1	1991m12	Guyana	66	1982m6	1987m12	Syrian Arab Rep.
27	1994m10	2007m12	Haiti	67	1998m10	2002m10	Tajikistan
28	1987m6	2010m11	Iceland	68	2001m2	2007m12	Thailand
29	1997m8	2007m12	Indonesia	69	1991m12	1996m5	Turkey
30	1977m1	1979m10	Iran, I.R. of	70	2001m2	2007m12	Turkey
31	1974m1	1998m12	Ireland	71	1980m1	1986m8	Uganda
32	1977m3	1998m12	Italy	72	1989m10	1992m12	Uganda
33	1990m10	1992m12	Jamaica	73	1992m12	1996m9	Ukraine
34	1974m1	2010m11	Japan	74	1974m1	2010m10	United Kingdom
35	1994m4	1996m5	Kazakhstan	75	1991m12	1995m9	Uruguay
36	1987m1	1995m12	Kenya	76	2002m5	2005m5	Uruguay
37	1997m12	2007m12	Korea, Republic of	77	1984m3	1996m6	Venezuela, Rep. Bol.
38	1994m1	1999m11	Kyrgyz Republic	78	1978m1	1983m7	Zambia
39	1997m9	2000m3	Lao People S Dem.Rep	79	1985m11	2007m12	Zambia
40	1984m3	1991m7	Lebanon	80	1991m10	1999m3	Zimbabwe

## A.2 Structural VAR: Details

Let  $y_t$  be a (2x1) vector consisting of interest rate differential and (log) exchange rate:  $y_t = [i_t - i_t^{US}, \ln E_t]$ . The VAR can be written as:

$$y_t = (I - A_1L - \dots - A_pL^p)^{-1}u_t,$$

where  $u_t$  is a (2x1) vector of reduced-form residuals, assumed to be i.i.d., with zero mean and  $E u_t u_t' = \Sigma$ .  $L$  is a lag operator, while  $A_1, \dots, A_p$  are (2x2) matrices. Following the literature we assume that orthogonal structural shocks,  $\varepsilon_t$ , are linear combinations of  $u_t$ :  $u_t = B\varepsilon_t$ , where  $\varepsilon_t$  are i.i.d. with mean zero and the variance-covariance matrix equal to the identity matrix. The VAR can

then be written in terms of structural shocks as

$$y_t = (I - A_1L - \dots - A_pL^p)^{-1} B\varepsilon_t. \quad (\text{A1})$$

Parameters in  $A_1, \dots, A_p$  and  $\Sigma$  can be estimated from the data. Thus, to obtain structural interpretation from the reduced form VAR we need to identify matrix  $B$ . Matrix  $B$  satisfies  $\Sigma = BB'$ . To obtain identification in our structural VAR we impose a long-run neutrality restriction as discussed in the text. Specifically, we assume that interest rate shocks cannot have long-run effects on the real exchange rate. This is achieved by setting the values of the relevant lag coefficients in equation (A1) to zero. For instance, if we redefine

$$(I - A_1L - \dots - A_pL^p)^{-1} B = C(L)$$

and write the long-run expression of  $C(L)$  as  $C^* = \sum_{j=0}^{\infty} C_j$ , then our long-run neutrality restriction reduces to  $C_{21}^* = 0$ . As we discussed in the text, this identification scheme allows for contemporaneous link between interest rates and exchange rate, while maintaining comparability with the Cholesky ordering results.

### A.3 Calibration: Data sources

In this Appendix we describe data and sources used in model calibration. We focused on a sample of 6 industrial economies – Australia, Canada, Netherlands, New Zealand, Sweden and UK and 6 developing countries – Argentina, Brazil, Korea, Mexico, Philippines, and Thailand – during 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.

*Monetary variables:* M1 (in local currency) for all countries comes from World Development Indicators (WDI) and Global Development Finance (GDF) datasets compiled by the World Bank. GDP (in local currency) was obtained from the same dataset. Reserve ratio was computed for each country following Brock (1989) as the ratio of monetary base less currency outside banks to M2 less currency outside banks. All series used in the computation were obtained from the International Financial Statistics (IFS) by the International Monetary Fund (IMF). To obtain the ratio of deposits to cash holdings we computed the level of deposits in each country as M1 minus currency outside banks. Cash holdings were measured by the currency outside banks. Consumer price (CPI) data is from the IFS database.

*Fiscal variables:* We used general government net lending/borrowing as a share of GDP to

calibrate parameter  $\tau$ . This data is from the World Economic Outlook (WEO) dataset of the IMF.

*Other:* We obtained average net foreign asset position (NFA) from Lane and Milesi-Ferretti (2007) dataset. 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. This data is from the IFS database.