The Exchange Rate Response to Monetary Policy Innovations

By Viktoria Hnatkovska, Amartya Lahiri, and Carlos A. Vegh

We present a new data fact: in response to a monetary tightening, the domestic currency tends to appreciate in developed countries but depreciate in developing countries. A model is developed to rationalize this contrasting pattern. It has three key channels of monetary transmission: a liquidity demand channel, a fiscal channel, and an output channel. The paper shows that a calibrated version of the model can explain the contrast between developed and developing countries. Using counterfactual experiments and empirical evidence, we identify differences in the liquidity demand effect as critical in explaining the contrasting responses generated by the model.

JEL: F3, F4
Keywords: Monetary policy, interest rates, exchange rates

We examine cross-country data on 72 countries to uncover an intriguing contrast between developed and developing countries in terms of the response of their nominal exchange rates to monetary policy shocks: developed countries appreciate in response to a monetary tightening while developing economies depreciate. This contrasting response is robust to controlling for the endogenous response of monetary policy to various types of exogenous shocks. This is a new data fact. We formalize a model to explain the contrast and show that a calibrated version of the model can explain the data patterns. The model identifies liquidity demand to be a key factor underlying the different responses of the two groups of countries. We provide independent evidence in support of this channel: controlling for the strength of liquidity demand in our sample of countries renders their development status an insignificant predictor of currency appreciations in response to monetary tightening.

Perhaps one of the oldest issues in international economics is about the relationship between monetary policy and the nominal exchange rate, specifically the question “what is the effect of tightening monetary policy on the exchange rate?” In the context of modern central banking practices, this question can be rephrased as “how does the nominal exchange rate respond when the central bank raises the interest rate?” Indeed, all undergraduate textbooks have a treatment of some version of it, policymakers (especially in smaller, more open economies) are extremely conscious of it, while practitioners and analysts have some priors about it when they debate the consequences of policy inter-
ventions on the economy.

Somewhat paradoxically, the evidence on this to date has been sparse and somewhat limited. Probably, the best-known study is due to 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 to look at non-US G-7 countries and reach the same conclusion. These results tend to provide support for the conventional wisdom which holds that exchange rates should appreciate in response to a monetary tightening.\textsuperscript{1}

In this paper we use a larger cross-country sample of 25 industrial and 47 developing countries with flexible exchange rates to argue that, contrary to the case of industrial countries, in developing countries the currency depreciates in response to an increase in interest rates.\textsuperscript{2} We start by computing simple correlations between interest rate and the exchange rate (defined in domestic currency units per U.S. dollar) and find that the two variables are negatively correlated in industrial countries, but are positively correlated in developing countries. Moreover, the differences are highly statistically significant. To isolate the effects of interest rate shocks on the exchange rate, we then turn to individual country VARs. We examine the impact of monetary policy shocks on the nominal exchange rate. The policy shocks are identified from the VAR system as innovations to the estimated policy rule. We find that for industrial countries, the domestic currency appreciates in response to a positive shock to interest rates in 84 percent of the cases. In sharp contrast, for developing countries the nominal exchange rate depreciates in response to higher interest rates in 73 percent of the cases. We also confirm this finding by estimating 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. We will refer to these contrasting findings in industrial versus developing countries as the “exchange rate response puzzle.”

One may argue that the differential responses are due to differences in the type of shocks in the two groups of countries. These could be expected inflation or output shocks which are often more pronounced in developing countries; or they could be country risk premium shocks, which too tend to be more volatile in developing countries. If such shocks in developing countries depreciate the exchange rate and induce policy makers to respond by raising the policy interest rate, we are likely to find a positive correlation between the two variables in this group of countries. In developed countries, on the other hand, such shocks may be less important, leading to a negative correlation between interest rates and exchange rate. We investigate this conjecture using recursive individual-country and panel VARs. We show that even after controlling for inflation, expected inflation, output, and risk premium shocks, the divergence in the response of

\textsuperscript{1}The conventional wisdom is probably grounded in the predictions of the older Mundell-Fleming family of open economy macroeconomic models based on sticky prices. However, the prediction that exchange rates should appreciate in response to a monetary tightening is shared by a broader group of models such as limited asset market participation, fiscal theory of the price level as well as the Obstfeld-Rogoff-type sticky-price models.

\textsuperscript{2}For several developing countries we have multiple episodes giving us a total of 55 developing country-episode pairs, and 80 country-episode pairs in total in our sample.
the exchange rate to identified interest rate shocks in developed and developing countries survives. The results suggest that differences in the nature of the shocks in developed and developing countries are unlikely to be the reason for the different responses.\footnote{Another explanation for the mixed results is that central banks in developed countries can precommit to not responding to exchange rate changes while developing country central banks cannot do so. An example of this is the well documented “fear of floating” syndrome amongst developing countries. However, we find that the different responses of developed and developing countries are robust to allowing for contemporaneous movements of exchange rate and the interest rate.}

We propose an alternative explanation for the observed divergence between developed and developing countries: monetary transmission mechanism. To this end, we develop a model of a small open economy which incorporates three key features which we believe are important aspects of the monetary transmission mechanism: a demand for liquidity channel, a fiscal channel, and an output channel. The liquidity demand channel raises the demand for domestic currency denominated liquid assets and hence has a strengthening effect on the local currency when monetary policy is tightened, i.e., when the policy controlled interest rate is raised. The other two channels tend to weaken the currency in response to a rate hike: the output channel – through a contractionary effect of higher interest rates on domestic activity; and the fiscal channel – through a greater fiscal burden of higher interest rates. Both effects imply a higher required inflation rate which has a weakening effect on the local currency. We identify necessary and sufficient conditions for the model to give rise to appreciations or depreciations in response to interest rate changes.

With the theoretical insights in hand, we then quantify the model by calibrating it. The calibration exercise is structured around trying to determine whether differences between developed and developing economies in the strengths of the three channels described above can account for the differences in the response of their exchange rates to monetary policy shocks. Accordingly, we undertake two calibrations: one for developed and another for developing economies. We keep all parameters identical for the two groups except for the parameters that control the liquidity demand, fiscal and output channels. We then examine the impulse response of exchange rates to interest rate shocks which we identify by estimating different interest rate rules for the two groups of countries. Amongst the monetary policy rules we study are exogenous interest rate rules and two different types of Taylor rules. The model impulse responses from all the different specifications yield the same result: developed country exchange rates appreciate in response to an increase in the policy interest rate while developing countries show depreciations. In other words, the impulse responses from the quantified model replicate the impulse response patterns from the data.

As a final check on the mapping between the model and the data, we look for independent evidence on the key mechanism that drives the differential response of exchange rates in developed and developing economies to monetary policy shocks. Using counterfactual experiments on the calibrated model, we identify the liquidity demand effect to be a key driver of the quantitative results. The strength of this effect is an increasing function of the money-to-GDP and the deposit-to-cash ratios. In the data, both these ratios are systematically higher in developed economies. As a result, for such countries, the
liquidity demand channel outweighs the indirect output and fiscal channels, and a monetary policy tightening leads to an exchange rate appreciation. For developing economies, with low money-output and deposit to cash ratios, the liquidity demand channel is substantially weaker, and indirect effects dominate. For such countries, a monetary policy tightening consequently leads to a currency depreciation rather than appreciation.

Simple regressions reveal that: (a) including the money-to-GDP and deposit-to-cash ratios as regressors significantly increases both the probability and the size of exchange rate appreciation in response to a rate hike; and (b) including these two ratios makes the development status of the country an insignificant predictor of currency appreciation. We interpret this as evidence in support of the key mechanism identified by the model for explaining the puzzle since differences in the exchange rate responses of developed and emerging economies to interest rate increases can be accounted for by differences in the strengths of the liquidity demand effect of these countries.

The importance of measures such as the money-to-GDP ratio and the deposits-to-cash ratio suggests that the transmission of monetary policy to the economy is likely to be fundamentally affected by factors such as the history of expropriation of interest bearing assets, the institutional strength of the monetary regime, the presence and duration of deposit insurance schemes, and the level of financial development. Hence, they need to be factored in explicitly when conducting monetary policy in developing countries since the outcomes may well be at odds with the established wisdom derived from developed country experiences.

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 impact effect of policy-induced changes in interest rates on the level of the exchange rate.

The next section presents 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 II presents the model, while Section III discusses how the model is calibrated and solved. Section IV presents the quantitative results while the last section concludes.

I. Empirical facts

We start off by empirically documenting our motivating issue. We use a large sample of countries over the period 1974:1-2010:12 for which monthly data on exchange rates and interest rates was available. Most of the data are 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. In the subset of country-episodes where the T-bill rate was not available, we used the discount rate, or the money market rate. The T-bill 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.\footnote{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.} In our analysis we focus on the interest rate differential between home and abroad computed as domestic interest rate minus U.S. Federal Funds rate.

For our data and sample selection, we follow the same approach as in Hnatkovska, Lahiri and Vegh (2013). In particular, our sample focuses on countries and time periods that are characterized by a flexible exchange rate regime. For the classification of exchange rate regimes we rely on the historical exchange rate classification in Reinhart and Rogoff (2004). A country is deemed to have a flexible exchange rate regime if, in a given year, its exchange rate was either (i) within a moving band that is narrower than or equal to +/-2\%; or (ii) was classified as managed floating; or (iii) was classified as freely floating; or (iv) was classified as freely falling in Reinhart and Rogoff (2004).\footnote{These categories are standard representations of floating exchange rate regimes and correspond to the fine classification indices (indices 11, 12, 13, and 14) in Reinhart and Rogoff (2004).} We focus only on the post-1974 period for all countries.\footnote{As in Hnatkovska, Lahiri and Vegh (2013), we also considered the coarse exchange rate classification (indices 3, 4 and 5) of Reinhart and Rogoff (2004) and found the results to be robust this.} For countries which had multiple episodes of flexible exchange rates during this period, we considered each episode separately subject to the restriction that there were at least 24 months of data in each episode. 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.\footnote{As noted in Hnatkovska, Lahiri and Vegh (2013), 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.}

A. Bilateral interest rate-exchange rate relationship

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 differential variables.\footnote{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.} Column “full

\[4\] 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.

\[5\] These categories are standard representations of floating exchange rate regimes and correspond to the fine classification indices (indices 11, 12, 13, and 14) in Reinhart and Rogoff (2004).

\[6\] As in Hnatkovska, Lahiri and Vegh (2013), we also considered the coarse exchange rate classification (indices 3, 4 and 5) of Reinhart and Rogoff (2004) and found the results to be robust this.

\[7\] As noted in Hnatkovska, Lahiri and Vegh (2013), 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.

\[8\] 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.

\[9\] Using interest rates and exchange rate series in levels has been a conventional practice in the literature (see, for instance, Kim and Roubini (2000) and Faust and Rogers (2003), among others). This implicitly assumes that the two variables are integrated of the same order. We test for the presence of a unit root in our country exchange rate and interest rate differential series using augmented Dickey-Fuller test and Phillips-Perron test. We cannot 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
sample” reports the mean and median of all the time-series correlations obtained for the countries in our sample. Columns labeled “developed” and “developing” compute 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 a 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 go together with currency depreciations, resulting in a positive correlation between them.

To confirm the significance of these correlations we also estimate a simple regression of the log exchange rate (or its first-difference) on a constant and the 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 Panel B of Table 1. These regressions confirm our findings from the correlations: exchange rates and interest rates are negatively correlated in industrial countries but positively correlated in developing countries. The 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.

B. Bivariate VAR results

We next turn to an analysis of the exchange rate-interest rate relationship using vector autoregressions (VARs) in order to isolate the effects of interest rate shocks on the exchange rate. The monetary policy shocks are identified as innovations to the estimated interest rate rule. In this sub-section we consider bivariate VARs, while in sub-section I.D we turn to multivariate VARs. We estimate VARs on a country-by-country basis for our sample using the log exchange rate and interest rate differential between home and the U.S..\(^\text{10}\) Our VAR specification also includes a constant term. We use the estimated VARs to calculate the impulse response of the exchange rate to an orthogonalized one unit (i.e. percent) innovation in the interest rate differential for each country.\(^\text{11}\) Following Eichenbaum and Evans (1995), we compute the impulse responses using the ordering: interest rate differential, exchange rate.\(^\text{12}\)

\(^\text{10}\)The simple bi-variate specification allows us to use and draw inference from the largest possible sample of countries. In section I.D we extend our benchmark VAR specification to include a broader set of other macroeconomic variables, such as output, prices, and risk-premium. Due to data limitations, such an analysis can only be conducted for a much smaller sample of countries.

\(^\text{11}\)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. The results are also robust to using fixed lag length across all countries (6 lags in the bivariate analysis and 4 lags in the multivariate analysis).

\(^\text{12}\)We also tried a specification with a trend and found that the results remained largely unchanged.
We start by presenting the impulse responses of the nominal exchange rate to interest rate shocks in several selected countries in our sample to illustrate the more general data fact. Figure 1 presents the impulse responses in six of the G-7 economies. The picture shows that in all countries, except Canada, 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). Figure 2 shows impulse responses in the six largest developing countries in our sample. For this group the effect is the opposite – a positive innovation in the interest rate differential between home and the U.S. induces a significant depreciation of the currency. The only exception is Korea, for which the exchange rate response is not statistically significant.\footnote{Notice that some of these impulse responses have a hump-shaped pattern, which is known as the “delayed overshooting” result (see, for instance, Sims (1992) and Eichenbaum and Evans (1995), among others). While there is an ongoing debate on the reasons for such “delayed overshooting” (Faust and Rogers (2003), Bacchetta and van Wincoop (2010), and Engel (2011)), our interest is in the immediate response of the exchange rate. Thus when presenting results, we focus on the immediate responses.}

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.\footnote{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.} We adopted several approaches to classifying...
Note: These figures present impulse responses of exchange rate to a 1% 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: $i - i^U S, \ln E$. Confidence bands are computed from parametric bootstrap over 1000 repetitions.

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. Based on the VARs we compute the share of developed and developing countries that have experienced appreciations of their exchange rates following a 1% positive shock to the interest rate differential. For each country we also record the size of the (log) exchange rate response and report the mean, median, the top and bottom quartiles of these responses for developed and developing countries separately. Table 2 summarizes the results.

The results clearly indicate that an overwhelming majority of industrial economies see their exchange rate appreciating after a positive interest rate shock both on impact (84% episodes and periods of high inflation in Section I.C.
Note: These figures present impulse responses of exchange rate to a 1% 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: $i - i^{US}$, ln $E$. Confidence bands are computed from parametric bootstrap over 1000 repetitions. The results for Mexico are for 1995m1-2007m12 episode.

How big are the resulting responses of the exchange rate? We find that for the developed countries, on average, the exchange rate appreciates by 11% on impact, reaches

$^{15}$The also estimated individual VARs on the first difference of the (log) exchange rate and the interest rate differential. They confirm our findings from the level VARs.
Table 2—Bivariate country VARs: Results

<table>
<thead>
<tr>
<th>Bivariate VAR: $i - i^{US}$, ln $E$</th>
<th>Developed countries</th>
<th>Developing countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>impact</td>
<td>1 month</td>
</tr>
<tr>
<td>share with appreciation</td>
<td>84%</td>
<td>88%</td>
</tr>
<tr>
<td>size of ln $E$ response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>-0.121</td>
<td>-0.212</td>
</tr>
<tr>
<td>median</td>
<td>-0.134</td>
<td>-0.235</td>
</tr>
<tr>
<td>25th percentile</td>
<td>-0.200</td>
<td>-0.292</td>
</tr>
<tr>
<td>75th percentile</td>
<td>-0.061</td>
<td>-0.118</td>
</tr>
<tr>
<td>std.error of the mean</td>
<td>0.024</td>
<td>0.035</td>
</tr>
</tbody>
</table>

Note: The table reports the fraction of developed and developing countries that experience an appreciation of their exchange rate following a 1% positive shock to the interest rate differential; and the size of the (log) exchange rate responses. The impulse responses on the impact, 1st month and 1st quarter (3 months) are reported based on a country-by-country VAR analysis. The ordering used to obtain the orthogonalized impulse responses to interest rate shocks is $i - i^{US}$, ln $E$.

-19% after one month and declines slightly to -17% after 3 months. The median responses are slightly larger (more negative). Even the top 25% of all developed countries in our sample experienced appreciation after a rise in the interest rate. On the contrary, the exchange rate responses are positive in developing countries. The mean depreciation is 12% on impact, rises to 18% after one month, and to 22.5% after the first quarter. The median responses are marginally smaller, suggesting a longer right tail in the distribution of the responses. The exchange rate responses switch to appreciation for the bottom quartile of the developing countries. Also note that the standard errors of the mean responses are rather small in both groups and imply that the mean responses are statistically different at conventional significance levels.

We confirm our findings above by running a bivariate panel VARs for industrial and developing countries separately. In the panel VAR analysis, country heterogeneity is likely to be important due to 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. We also included a

16Note that the exchange rate appears with a log in the VAR, so we are working with a log-linear regression.

17Alternative transformations that eliminate the fixed effects are the forward mean differencing (the Helmert proce-
set of year dummies in the panel VARs to control for common shocks.

To further address the issue of the correlation between the lagged dependent variable and the error term, we estimate the model coefficients by an instrumental variable (IV) method. Specifically, we apply the system generalized method of moments (GMM) of Arellano and Bond (1991) that uses lagged regressors as instruments.

**Figure 3. Bivariate panel VAR: Impulse responses of exchange rate to interest rate shock**

Note: Figures present the impulse responses of the exchange rate to a 1% positive interest rate differential shock from panel VARs estimated for developed and developing countries. The following ordering is used: $i - i^{US}$, ln $E$. Both series are de-meaned and linearly de-trended. The VAR also includes a full set of year dummies. Confidence bands are computed based on Monte Carlo simulations.

Figure 3 presents the impulse response of the exchange rate to a positive 1% interest rate shock together with the 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 developed countries but depreciates in developing countries.

**C. Exchange rate classification, crisis and high inflation episodes**

How robust are our results with respect to the floating exchange rate classification we used? As noted above, we used the definition of the floating exchange rate regime (as in Holtz-Eakin, Newey and Rosen (1988) and Love and Zicchino (2006) or taking the first-differences of the variables. We find our results to be robust to these transformations.
in Reinhart and Rogoff (2004) and the existing literature. This classification included, among others, the “freely falling” category consisting of (i) countries that have experienced inflation rates above 40 percent over a 12 month period; and (ii) 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 periods, 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.

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

<table>
<thead>
<tr>
<th></th>
<th>Full sample</th>
<th>Developed</th>
<th>Developing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$corr(\ln E_t, i_t - i_t^{**})$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>0.15</td>
<td>-0.09</td>
<td>0.33</td>
</tr>
<tr>
<td>median</td>
<td>0.11</td>
<td>-0.08</td>
<td>0.42</td>
</tr>
<tr>
<td>$corr(\Delta_t \ln E_t, \Delta_t (i - i_t^{**}))$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>0.00</td>
<td>-0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>median</td>
<td>-0.03</td>
<td>-0.11</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Panel B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\ln E_t = \beta_0 + \beta_1(i_t - i_t^{**}) + \epsilon_t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean($\beta_1$)</td>
<td>1.21</td>
<td>-0.74</td>
<td>2.69</td>
</tr>
<tr>
<td>95% c.i.($\beta_1$)</td>
<td>[1.05; 1.37]</td>
<td>[-0.94; -0.54]</td>
<td>[2.45; 2.93]</td>
</tr>
<tr>
<td>$\Delta_t \ln E_t = a_0 + a_1\Delta_t (i_t - i_t^{**}) + u_t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean($a_1$)</td>
<td>-0.06</td>
<td>-0.44</td>
<td>0.22</td>
</tr>
<tr>
<td>95% c.i.($a_1$)</td>
<td>[-0.16; 0.04]</td>
<td>[-0.57; -0.31]</td>
<td>[0.08; 0.37]</td>
</tr>
</tbody>
</table>

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 $\ln E_t = \beta_0 + \beta_1(i_t - i_t^{**}) + \epsilon_t$ in levels and first-differences. 95% confidence intervals are in parenthesis.

We also verify our individual country VARs and panel VARs for this restricted sample of countries 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 a depreciation on impact of a positive shock to the interest rate differential, 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. The panel VAR results also go through unchanged.

\[ D. \ \text{Multivariate VAR results} \]

One concern that may arise in the bivariate VAR specification estimated above is related to the endogeneity of the interest rate and the exchange rate to various exogenous shocks, such as shocks to output, prices, and country risk. To account for this possibility we now turn to multivariate VAR analysis. As before, the monetary policy shocks are identified from the VARs as innovations to the estimated interest rate rules, except that here such rules are endogenous to economic conditions.

We consider a specification in which policy interest rates react to the price level, industrial production and a measure of risk premium. We assume the following ordering for the variables: risk-premium, (log) industrial production, (log) consumer price index (CPI), interest rate differential, (log) exchange rate. This specification, excluding the risk-premium variable, and ordering of the variables are very close to that used in Eichenbaum and Evans (1995). We add the risk-premium to the analysis to account for the possibility that the joint dynamics of exchange rates and interest rates are driven by changes in country risk-premia. 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. Unfortunately, country-specific risk-premia 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. 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.\[18\]

Our identification strategy implies that innovations to interest rates have effects on domestic real activity, prices 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 macroeconomic

---

\[18\] We also examined country-specific measures of the risk-premium for a few countries for which such data are available. Specifically, for a subsample of countries that includes Brazil, Mexico, South Africa, Thailand, Turkey, Indonesia, Iceland, Japan, Sweden, and United Kingdom we were able to obtain historical country credit default swap (CDS) spreads over their respective flexible exchange rate episodes. These findings are supportive of using the Baa spread. First, CDS spreads are highly positively correlated with the Baa spread, with the average correlation in this subsample of over 0.65. Second, when we estimate individual country VARs with CDS spreads, we find that the impact responses of the exchange rate to a positive interest rate shock remain qualitatively unchanged relative to the impulse responses that we obtained when the Baa spread was used to proxy for the risk-premium in all countries. CDS spreads are from Bloomberg. We also used J. P. Morgan’s EMBI+ country spreads as a measure of risk-premium. For five developing countries for which data were available (Brazil, Mexico, Nigeria, South Africa and Turkey), we found that the VAR results remained largely unchanged relative to the VARs with Baa spread.
variables percolates only with a lag. The ordering of the first three variables assumes that risk-premium shocks are the most exogenous. The assumption that output shocks affect prices immediately is standard in the literature (see, for instance, Bernanke and Blinder (1992)).

The impulse responses from the multivariate VAR specification for the sample of six developed and six developing countries are presented in Figures 4 and 5. These are the counterparts of Figures 1 and 2 for the multivariate specification. Consistent with our findings from the bivariate VARs, here we again find that exchange rate appreciates in developed countries and depreciates in developing countries following a 1% rise in the interest rate, even after conditioning on risk-premium, domestic output and prices.

Turning to the full sample of countries, due to limited data availability, this extended VAR can only be estimated for 24 country-pairs, of which 13 are industrial country-pairs and 11 are developing country-pairs. The results for this VAR specification are presented in Table 4. A shock to the interest rate that is orthogonal to domestic output, price level, and risk-premium, leads to currency appreciation on impact in 85% of developed countries, with the share increasing to 92% one month and three months following the shock. The corresponding numbers for developing countries are 27%, on impact, 36% after 1 month and 27% percent after 3 months. The majority of developing countries, thus, saw a depreciation of their currencies after an interest rate rise. Turning to the size of the exchange rate responses, we find the patterns arising from the multivariate VARs to be very similar to our findings from the bivariate VAR specification, with the main difference being their smaller size. For instance, the average response of the exchange rate to a 1% rise in the interest rate in developed countries is -0.8%, becomes -1.4% after 1 month and appreciates further to -1.6% after the first quarter. In developing countries the corresponding responses are 2.7% on impact, 3.5% after 1 month and 3.1% after 3 months.

This extended VAR also allows us to examine the responses of output, prices and the risk-premium to monetary policy shocks as one may be suspicious as to whether the shocks we identified are indeed monetary policy shocks for developing countries. We find that the rest of the variables show quite standard responses. Industrial production falls in a majority of developing countries (55% to 73% depending on the horizon) following an increase in the interest rate. The price level increases after a monetary policy tightening in a majority of developing countries (64% to 82% depending on the horizon). This is the well known price puzzle which has been documented for developed countries

---

19 We also tried an alternative ordering where the risk-premium variable is placed after output and the price level, and found that the results remain unchanged.
20 We also estimated an extended VAR with inflation rate differential between home and the U.S. instead of price level and found very similar results. See online appendix.
21 One may also be concerned that our recursive VAR identification strategy rules out potential simultaneity effects between interest rates and exchange rates in identifying interest rate shocks. Such a contemporaneous feedback between the two variables may be important in developing countries, as emphasized in the “fear of floating” literature (see Calvo and Reinhart (2002)). To address this question we estimate a structural VAR (SVAR) in which we allow for a contemporaneous correlation between the 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. We find that our results remain robust to this alternative specification. More details are presented in the online appendix.
Figure 4. Developed Country Multivariate VARs: Impulse Responses of Exchange Rate to Interest Rate Shock

Note: These figures present impulse responses of exchange rate to a 1% positive interest rate innovation from individual country VARs estimated on risk-premium, (log) industrial production, (log) CPI level, (log) exchange rate and interest rate differential between home and abroad. The following ordering is used: $r_p$, $\ln y$, $\ln P$, $i - i^{US}$, $\ln E$. Confidence bands are computed from parametric bootstrap over 1000 repetitions.

Our results provide evidence of the price puzzle in developing countries as well. Lastly, the risk-premium rises after a tightening in developing countries.²²

Our results are further confirmed by the multivariate panel VAR. Figure 6 shows the impulse responses of the exchange rate to a 1% positive innovation to the interest rate differential resulting from such a VAR estimated separately for developed and developing countries. The responses are very similar to those obtained from the bivariate panel VARs, except that they are a bit smaller.

²²We find that the increase in risk-premium after a positive interest rate shock is also characteristic of developed countries in our sample.
FIGURE 5. DEVELOPING COUNTRY MULTIVARIATE VARs: IMPULSE RESPONSES OF EXCHANGE RATE TO INTEREST RATE SHOCK

Note: These figures present impulse responses of exchange rate to a 1% positive interest rate innovation from individual country VARs estimated on risk-premium, (log) industrial production, (log) CPI level, (log) exchange rate and interest rate differential between home and abroad. The following ordering is used: $rp$, $\ln y$, $\ln P$, $i - i^{US}$, $\ln E$. Unfortunately, monthly industrial production data is not available for Brazil, Philippines, Indonesia and South Africa, so the VAR is estimated without it for these countries. Confidence bands are computed from parametric bootstrap over 1000 repetitions. The results for Mexico are for 1995m1-2007m12 episode.

**E. Additional tests: Case studies**

The empirical exercises in the paper have focused on lower frequency monthly data on exchange rate and interest rate as it is available for a large set of countries. The shortcoming of such an approach is that it introduces some temporal aggregation of adjustments in the two variables. An alternative approach would be to conduct event studies which utilize high-frequency exchange rate and interest rate data in studying their inter-relation. Some studies along these lines do exist for a few countries and, importantly, their findings support our basic conclusions. For instance, using intraday data for three developed
Table 4—Multivariate country VARs: Results

<table>
<thead>
<tr>
<th></th>
<th>Developed countries</th>
<th>Developing countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>impact 1 month 3 months</td>
<td>impact 1 month 3 months</td>
</tr>
<tr>
<td>share with appreciation</td>
<td>85% 92% 92%</td>
<td>27% 36% 27%</td>
</tr>
<tr>
<td>size of ln E response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>-0.008 -0.014 -0.016</td>
<td>0.027 0.035 0.031</td>
</tr>
<tr>
<td>median</td>
<td>-0.005 -0.011 -0.013</td>
<td>0.012 0.009 0.032</td>
</tr>
<tr>
<td>25th percentile</td>
<td>-0.007 -0.011 -0.015</td>
<td>0.004 -0.003 -0.007</td>
</tr>
<tr>
<td>75th percentile</td>
<td>-0.001 -0.005 -0.005</td>
<td>0.064 0.075 0.044</td>
</tr>
<tr>
<td>std.error of the mean</td>
<td>0.003 0.005 0.008</td>
<td>0.011 0.015 0.021</td>
</tr>
</tbody>
</table>

Note: The table reports the fraction of developed and developing countries that experience an appreciation of their exchange rate following a 1% positive shock to the interest rate differential; and the size of the (log) exchange rate responses. The impulse responses on the impact, 1st month and 1st quarter (3 months) are reported based on a country-by-country VAR analysis. The ordering used to obtain the orthogonalized impulse responses to interest rate shocks is \( r, p, \ln y, \ln P, i - i^{US}, \ln E \).

countries (Australia, Canada, and New Zealand) Zettelmeyer (2004) finds that an unanticipated monetary tightening leads to a rapid appreciation the exchange rate in these countries in the 1990s. Kearns and Manners (2006) refine the analysis in Zettelmeyer (2004) by adding the United Kingdom to the sample of countries, extending the time period, and restricting the sample to a period in which the central banks in the four countries did not explicitly respond to the exchange rate and confirm the findings of Zettelmeyer (2004). Using the same approach, Kohlscheen (2014) focuses on three developing countries (Brazil, Mexico and Chile) and shows that their exchange rates depreciate on impact following monetary policy tightening rather than appreciate as in the developed country sample of Zettelmeyer (2004). This evidence provides confirmation of our contrasting findings for developed and developing countries in higher frequency data as well.

The evidence from the high-frequency estimation also allows us to affirm our VAR-based identification approach. Specifically, we ask whether for the three countries (Brazil, Mexico and Chile) for which the high-frequency analysis shows the exchange rate depreciation after a monetary policy tightening, our VAR-based approach makes the same prediction. For this exercise we revisit our multivariate VAR specification for the three developing countries using the same time period as in Kohlscheen (2014). We find that the exchange rate indeed depreciates in these countries following an identified monetary policy shock.

We then refine this analysis further by providing a more precise measure of unanticipated shocks to monetary policy. More precisely, for Brazil and Chile we collected the monthly forecasts of policy interest rates from the Banco Central do Brasil and Banco Central de Chile. For both countries we have current month forecasts of policy interest
Note: Figures present the impulse responses of the exchange rate to a 1% positive interest rate differential shock from panel VARs estimated for developed and developing countries. The following ordering is used: $r_p$, $\ln y$, $\ln P$, $i - i^{US}$, $\ln E$. All series are de-meaned and linearly de-trended. Confidence bands are computed based on Monte Carlo simulations.
II. The Model

We propose an alternative explanation for the differing exchange rate responses in developed and developing countries. Our explanation relies on the differences in the transmission mechanism of monetary policy in developed and developing countries. In particular, we argue that a higher policy interest rate has three effects on the economy: (i) a "liquidity demand" channel which raises the demand for domestic currency denominated liquid assets and strengthens the local currency; (ii) a "fiscal" channel which weakens the currency due to a greater fiscal burden of higher interest rates; and (iii) an "output" channel which also leads to currency depreciation due to a contractionary effect of higher interest rates on domestic activity. The strength of these effects differs in developed and developing countries, thus potentially implying different responses of their exchange rates to interest rate shocks.

The model we use is essentially the same as that developed in Hnatkovska, Lahiri and Vegh (2013) but with two key modifications: (a) we introduce physical capital; and (b) we introduce stochastic shocks to productivity and policy variables. We consider a one-good, small open economy inhabited by an infinitely-lived representative household. The economy has unrestricted access to world goods markets so that the law of one price holds. The world price of the good is constant and, with no loss of generality, set equal to unity in terms of the foreign currency. The good is produced by a representative firm which uses capital and labor to produce. However, the firm is subject to a working capital requirement which it finances by borrowing from 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 detail below.

Before proceeding we should note that the one-good environment and perfect goods mobility imply that the model’s implications for the exchange rate and the price level are identical. This tight link though is easily broken under very small modifications of the basic structure of the model. An online appendix expands on this using an extension of the model to non-traded goods. Consequently, we view the model as predicting exchange rate behavior rather than the price level.

A. Households

The representative household derives utility from consumption and disutility from working. The household’s periodic flow utility is given by

\[
U(c, x) = \frac{1}{1 - \sigma} (c - \zeta x^\nu)^{1-\sigma}, \quad \zeta > 0, \quad \nu > 1.
\]
where \( c \) is consumption and \( x \) denotes labor supply. The household’s expected lifetime welfare is

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

where \( \beta (> 0) \) is the exogenous and constant rate of time preference, \( \sigma \) is the intertemporal elasticity of substitution and \( \nu - 1 \) is the inverse of the elasticity of labor supply with respect to the real wage.\(^{24}\)

In order to introduce a demand for nominal assets we assume that households face costs in carrying out transactions which can be reduced through holdings of cash, \( H \), and nominal demand deposits, \( D \). The transactions costs technology is assumed to be

\[
s_t = \nu \left( \frac{H_t}{P_t} \right) + \psi \left( \frac{D_t}{P_t} \right),
\]

where \( P \) is the nominal price of goods in the economy. We assume that the transactions technology is strictly convex with the functions \( \nu(h) \) and \( \psi(d) \), defined for \( h \in [0, \tilde{h}] \), \( \tilde{h} > 0 \), and \( d \in [0, \tilde{d}] \), \( \tilde{d} > 0 \), respectively, satisfying: \( \nu \geq 0 \), \( \nu' \leq 0 \), \( \nu'' > 0 \), \( \nu'(\tilde{h}) = 0 \), and \( \psi \geq 0 \), \( \psi' \leq 0 \), \( \psi'' > 0 \), \( \psi'(\tilde{d}) = 0 \). This specification implies that households can reduce the transactions costs by increasing the real value of cash and deposits. However, the marginal reduction in transactions costs declines as cash and deposit holdings become larger.\(^{25}\)

Households earn wage income by supplying labor to firms, consume the single good in this economy, and save by investing in four alternative instruments: foreign real bonds, physical capital, nominal cash holdings and nominal deposits. The household’s nominal flow budget constraint is thus given by

\[
P_t b_{t+1} + D_t + H_t + P_t (c_t + I_t + s_t + \kappa_t) = P_t \left( Rb_t + w_t x_t + \rho j_{t-1} + \tau_t + \Omega^f_t + \Omega^k_t \right) + (1 + i^d_t) D_{t-1} + H_{t-1}.
\]

where \( b \) denote foreign bonds (these are real and denominated in terms of the good) and \( R (= 1 + r) \) is the constant gross world interest factor on these foreign bonds. \( I \) denotes investment in physical capital, \( \rho \) is the rental rate on capital \( k \), while \( \kappa \) denotes capital adjustment costs. \( i^d_t \) denotes the deposit rate contracted in period \( t - 1 \) and paid in period \( t \). The wage is denoted by \( w \) while \( \tau \) is the fiscal transfer made to households by the government. \( \Omega^f \) and \( \Omega^k \) are the dividend payments made by firms and banks to the households, who are the owners of these entities.

\(^{24}\)These preferences are well-known as GHH preferences since they were developed in Greenwood, Hercowitz and Huffman (1988).

\(^{25}\)In the following we shall denote real cash balances and real demand deposits by \( h (= H/P) \) and \( d (= D/P) \), respectively.
Capital evolves in this economy according to the standard transition relation:

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

However, the capital adjustment process is subject to a convex adjustment cost so that:

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

We shall define the gross inflation rate between \( t-1 \) and \( t \) to be \( 1 + \pi_t = \frac{P_t}{P_{t-1}}. \) Using this definition, we can also define the nominal interest rate as

\( 1 + i_{t+1} = R E_t (1 + \pi_{t+1}). \)

Using the definition of the gross inflation factor, we can rewrite the household’s nominal flow constraint in real terms as:

\[
\begin{align*}
b_{t+1} + h_t + d_t + c_t + I_t + s_t + \kappa_t &= R b_t + w_t x_t + \rho_t k_{t-1} + \left( \frac{h_{t-1}}{1 + \pi_{t-1}} + \frac{1 + i_t^d}{1 + \pi_t} \right) d_{t-1} + \tau_t + \Omega_t^f + \Omega_b^f. \\
\end{align*}
\]

Households maximize their lifetime welfare given by equation (1) subject to equations (2), (4), (3) and (6).

**B. Firms**

Firms produce the good by combining capital \( k \) and labor \( l \) using the technology

\( y_t = A_t k_{-\alpha}^\alpha I_t^{1-\alpha}, \quad \alpha > 0 \)

where \( A_t \) denotes productivity at date \( t \) and is stochastic. Firms make production plans after observing the stochastic shocks for the period. However, firms face a working capital requirement at the beginning of the period since a fraction \( \phi \) of the wages to workers have to be paid before the realization of output for the period. Firms borrow this working capital from banks. Hence, loan demand by firms \( N \) is given by

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

The firm’s flow constraint in real terms is given by

\[
b_{t+1}^f - n_t = R b_t^f - \left( \frac{1 + i_t^f}{1 + \pi_t} \right) n_{t-1} + y_t - w_t l_t - \rho_t k_{t-1} - \Omega_t^f. 
\]
where \( n = N / P \) is real loan demand, \( i_l \) is the lending rate on loans while \( b^f \) are the foreign bonds held by firms. Using the definition \( a^f_{t+1} = b^f_{t+1} - \frac{(1+i^f_{t+1})}{r(1+\pi_{t+1})} n_t \) along with equation (8) allows us to rewrite the firm’s flow constraint as

\[
(9) \quad a^f_{t+1} + \Omega_t^f = Ra^f_t + y_t - \rho_t k_{t-1} - w_t l_t \left[ 1 + \phi \left\{ \frac{1 + i^f_{t+1} - R (1 + \pi_{t+1})}{R (1 + \pi_{t+1})} \right\} \right].
\]

The term \( \phi \left\{ \frac{1 + i^f_{t+1} - R (1 + \pi_{t+1})}{R (1 + \pi_{t+1})} \right\} w_t l_t \) above gives the resource cost to firms due to the credit-in-advance constraint.\(^{26}\)

The firm chooses paths of \( l \) and \( k \) to maximize the present discounted value of dividends subject to equations (7), (8) and (9). This problem yields two static optimality conditions dictating optimal labor and capital employment as well as an Euler equation which is identical to the household’s Euler equation (since households own the firms in this economy).

\[ C. \text{ Banks} \]

Banks lend to firms, \( N \), and the government though purchases of government bonds, \( Z \). They also hold cash reserves, \( \theta D \), where \( \theta > 0 \) is the reserve-requirement ratio imposed by the central bank. The bank’s liabilities are deposits from consumers and real foreign debt, \( d^b \).\(^{27}\) The bank’s balance sheet identity is thus \( P_t d^b_{t+1} = N_t + Z_t - (1 - \theta) D_t \). The nominal flow constraint for the bank is

\[
N_t + Z_t - (1 - \theta) D_t + P_t q_t - P_t d^b_{t+1} = (1 + i^f_t - \phi^a) N_{t-1} + (1 + i^g_t) Z_{t-1} - (1 + i^d_t) D_{t-1} - \theta D_{t-1} - P_t R d^b - P_t \Omega_t^b,
\]

where \( i^g_t \) is the interest rate on government bonds. \( q \) are banking costs of managing its portfolio. We assume that banking costs are a convex function of the foreign debt held by the bank: \( q_t = q (d^b_{t+1}) \), and \( q' > 0, q'' > 0 \).\(^{28}\) \( \phi^a \) is a per unit cost of managing loans which we assume to be a constant. Our qualitative results do not depend on the presence of this cost \( \phi^a \). We introduce it here since we use it later for our quantitative exercises.

\(^{26}\) As is well known, the wage-in-advance constraint given by equation (8) binds along paths where the lending spread \( 1 + i^f - R (1 + \pi) \) is strictly positive. In the rest of the paper we shall restrict attention to parameter ranges where this is true.

\(^{27}\) Commercial bank lending to governments is widespread in developing countries. Systematic evidence on this kind of lending in developing countries can be found in Rodriguez (1991) and Druck and Garibaldi (2000).

\(^{28}\) The assumption that \( q > 0 \) implies that there is no interest parity between foreign bonds and domestic government bonds. This opens up an independent role for interest rate policy in an otherwise standard open economy model with capital mobility, i.e., it avoids the well known policy "trilemma". A similar treatment of banking costs can be found in Edwards and Vegh (1997).
Using the balance sheet identity one can rewrite equation (10) in real terms as:

\[
\Omega_t^b = \left[ \frac{R(1 + \pi_t) - 1}{1 + \pi_t} \right] \left[ (1 - \theta) d_{t-1} - n_{t-1} - z_{t-1} \right] + \left( i^i_t - \phi^a \right) n_{t-1} + \frac{i^g_{t-1}}{1 + \pi_t} z_{t-1} - \frac{i^d_t}{1 + \pi_t} d_{t-1} - q_t,
\]

where we have used the bank’s balance sheet identity: \( P_t d_{t+1}^b = N_t + Z_t - (1 - \theta) D_t \).

The banking sector is competitive so that banks take the paths of all the interest rates \((i^i, i^d, i^g, i)\) and \(\theta\) and \(\phi^a\) as given. They choose sequences of \(N, Z, D\) to maximize the present discounted value of profits subject to equation (10). We assume that the bank uses the household’s stochastic discount factor to value its profits. The bank optimality conditions are

\[
i^i_{t+1} = i^g_{t+1} + \phi^a,
\]

\[
i^d_{t+1} = (1 - \theta) i^g_{t+1}.
\]

Equation (12) says that the interest rate on private loans should equal the rate on government bonds plus \(\phi^a\). This is intuitive since the only difference between loans to firms and government bonds are the additional cost \(\phi^a\) of managing loans. Equation (13) says that the deposit rate must equal the interest on government bonds net of the resource cost of holding required reserves. This too is obvious since each unit of deposit requires a payment of the deposit rate \(i^d\) but only a fraction \(1 - \theta\) of it can be lent out which earns the interest \(i^g\). Under a competitive banking sector zero profits require that these two must be equal.

\[\]\

**D. Government**

The government in this economy consists of a fiscal and a monetary authority. The consolidated government issues high powered money and domestic bonds, sets the reserve requirement ratio on bank deposits, and makes lump-sum transfers to households which are fixed and exogenous. The consolidated government’s nominal flow constraint is

\[
P_t \bar{\tau} + (1 + i^g_t) Z_{t-1} = M_t - M_{t-1} + Z_t.
\]

where \(\bar{\tau}\) denotes the exogenously fixed level of government transfers while \(M\) and \(Z\) are high powered money and government bonds, respectively.\(^{29}\) Dividing by the price level and suitably rearranging the result yields the government’s flow constraint in real terms:

\[
\bar{\tau} + \frac{1 + i^g_t}{1 + \pi_t} z_{t-1} = m_t + z_t - \frac{1}{1 + \pi_t} m_{t-1}.
\]

\(^{29}\)Note that we are assuming that the monetary authority does not hold any foreign reserves. This is with no loss of generality since we are studying an economy with a flexible exchange rate which implies that the central bank does not intervene in foreign exchange markets. Consequently, setting government holdings of international reserves to zero is just a convenient normalization.
We use $\mu$ to denote the rate of growth of the nominal money supply. Specifically,

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

The government in our model economy has three policy instruments: the money growth rate $\mu$, the interest rate on government bonds $i^g$, and fiscal transfers $\tau$. Only two out of these three instruments are free since the third would get determined as a function of the other two from the government’s consolidated budget constraint. Given our focus on interest rate policy, we shall assume that $i^g$ is chosen exogenously along with $\tau$ leaving the rate of money growth $\mu$ to be endogenously determined from equation (14).

E. 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 $N$ and $i^g$. We denote the entire state history of the economy till date $t$ by $s = (s_0, s_1, s_2, ..., s_t)$. An equilibrium for this economy is defined as:

**DEFINITION 1:** Given a sequence of realizations $A(s^t), i^g(s^t), r$ and $\tilde{\tau}$, an equilibrium is a sequence of state contingent allocations $\{c(s^t), x(s^t), l(s^t), h(s^t), d(s^t), k(s^t), b(s^t), b^l(s^t), d^b(s^t), n(s^t), z(s^t)\}$ 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 these prices the allocations solve the problems faced by households, firms and banks; (b) factor markets clear; and (c) the government budget constraint (equation (14)) is satisfied.

It is useful at this stage to clarify the process of nominal exchange rate determination in our model. Recall that $m = M/P$ and nominal money is $M = H + \theta D$. The optimality conditions for cash and deposit holdings, along with the definition for the nominal interest rate $1 + i_{t+1} = R_{t+1} (1 + \pi_{t+1})$, yield the equilibrium cash and deposit demands in the model as

$$
\begin{align*}
  h_t &= \tilde{h} \left( \frac{i_{t+1}}{1 + i_{t+1}} \right) \quad \text{and} \\
  d_t &= \tilde{d} \left( \frac{i_{t+1} - (1 - \theta) i^g_{t+1}}{1 + i_{t+1}} \right),
\end{align*}
$$

where both functions are decreasing in their arguments. Derivations are provided in Appendix C. Therefore, the money market equilibrium condition can be written implicitly as $h_t + \theta d_t = L (i_{t+1}, i^g_{t+1})$ where $L$ denotes the implicit aggregate demand for cash and deposits. At any date $t$, $M_t$ is known while its growth rate $\mu_{t+1}$ is endogenous. Money market equilibrium dictates that at date $t$ the nominal exchange rate is given by

$$
E_t = \frac{M_t}{L (i_{t+1}, i^g_{t+1})},
$$

30 Instead of setting $i^g$ the government could choose the composition of $m$ and $z$. This would entail the government allowing the market to determine the interest rate $i^g$. 

\[\text{RAW TEXT END}\]
Note that by combining the consolidated government flow constraint with the commercial bank balance sheets we get:

\[ \bar{\pi} = h_t - \left( \frac{1}{1 + \pi_t} \right) h_{t-1} + \theta \left( d_t - \frac{d_{t-1}}{1 + \pi_t} \right) + z_t - \left( \frac{1 + \pi_t}{1 + \pi_t} \right) z_{t-1}. \]

For any given policy rate \( i^{\text{g}}_{t+1} \), the nominal interest rate \( i^{\text{g}}_t \) (and the expected inflation rate between \( t \) and \( t + 1 \)) is determined from the government budget constraint (18). From equation (17), knowledge of \( i^{\text{g}}_{t+1} \) and \( i^{\text{g}}_t \) are sufficient to determine the real money demand \( L(i^{\text{g}}_{t+1}, i^{\text{g}}_t) \), and nominal exchange rate \( E_t \) 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 \( t \) from equation (14). Hence, \( M_{t+1} \) gets determined at date \( t \).\(^{31}\)

From equations (18) and (17) it is easy to see that the effect of an interest rate increase on the equilibrium nominal 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. Interest rate changes impact these fundamentals in often opposing ways. This is likely to make their end effect on the exchange rate non-linear and possibly non-monotonic. We explore these possibilities quantitatively below.\(^{32}\)

### III. 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 liquidity 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.

\(^{31}\)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 \( i^{\text{g}} \). While \( i^{\text{g}} \) 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 \( \bar{\pi} \).

\(^{32}\)In this paper we focus on the time series behavior of this model. Elsewhere, in Hnatkovska, Lahiri and Vegh (2013) we have examined the cross-sectional steady state properties of a simplified, deterministic version of this model without capital.
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 the 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 B. The model calibration is such that one period in the model corresponds to one quarter.

A. Functional forms and parameters

We assume that the capital adjustment cost technology is given by

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

with \( \zeta \) being the level parameter.

As in Rebelo and Vegh (1995), we assume that the transactions costs functions \( \nu(.) \) and \( \psi(.) \) are quadratic:

$$s_{\kappa} \left( \chi^2 - \phi_{\kappa} \chi + \left( \frac{\phi_{\kappa}}{2} \right)^2 \right),$$

where \( \kappa \) represents cash or demand deposits, \( \kappa = \{h, d\} \), while \( s_{\kappa} \) and \( \phi_{\kappa} \) are the level parameters.

We assume that the transactions technology for the banks is also quadratic and given by

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

where \( d_{t+1} = \frac{N_t + Z_t - (1 - \theta) D_t}{P_t} \). Here \( \gamma \) is a constant and \( \bar{d} \) is a steady state level of banks’ debt to GDP ratio. Note that as banking costs become infinitely large, the bank will choose to maintain a constant portfolio of external assets or liabilities, i.e., \( \lim_{\gamma \to \infty} d_{t+1} = \bar{d} \).

We begin by discussing parameters that are set to be common to both developed and developing countries. Most of these parameter values are taken from Neumeyer and

---

33 Clearly there are a number of other differences between developed and developing economies such as the prevalence of trend shocks in developing countries, the predominance of foreign currency debt in developing countries as well as their greater exposure to risk premium shocks. We also abstract from any sticky prices considerations and instead focus on a frictionless price setting world. These choices do not presuppose that the omitted factors are unimportant. We abstract from all of these other factors in order to cleanly assess the explanatory power of just the three margins that we have formalized in this model.
Perri (2005) and Mendoza (1991). In particular, we set the coefficient of relative risk aversion, $\sigma$, to 5, while the curvature of labor, $\nu$, is set to 1.6. This value is within the range used in the literature, and implies that the elasticity of labor demand with respect to the real wage, $\frac{1}{\nu}$, is 1.67, which is consistent with the estimates for the U.S. We set the labor weight parameter, $\zeta$, to 2.48 so as to match the average working time of 1/5 of total time. Following Uribe and Yue (2006), we set the subjective discount factor, $\beta$, to 0.97. The capital income share, $\alpha$, is chosen to be equal to 0.38, while the depreciation rate for capital, $\delta$, is set to 4.4% per quarter. The capital adjustment costs parameter, $\xi$, is calibrated to replicate the volatility of investment relative to the volatility of output in our sample. Table 5 summarizes the calibration for parameters that are common across the two groups of countries.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>discount factor</td>
<td>$\beta$</td>
</tr>
<tr>
<td>risk-aversion</td>
<td>$\sigma$</td>
</tr>
<tr>
<td>labor curvature</td>
<td>$\nu$</td>
</tr>
<tr>
<td>labor weight</td>
<td>$\zeta$</td>
</tr>
<tr>
<td>capital income share</td>
<td>$\alpha$</td>
</tr>
<tr>
<td>depreciation rate</td>
<td>$\delta$</td>
</tr>
<tr>
<td>capital adjustment costs</td>
<td>$\xi$</td>
</tr>
<tr>
<td>banks cost technology</td>
<td>$\gamma$</td>
</tr>
</tbody>
</table>

The remaining parameters are calibrated to developed and developing countries separately using the sample of 6 developed and 6 developing countries discussed above. Table 6 summarizes targeted data moments and values for parameters in the two groups of countries that minimize the distance between these moments in the data and in the model.

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 $\theta$ equal to 0.03 in developed countries and 0.10 in developing economies over our sample period. The reserve requirement ratio $\theta$, together with $s_\kappa$ and $\lambda_\kappa$, $\kappa = \{h, d\}$, 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

Note that all of these common parameters are almost the same in Neumeyer and Perri (2005) who calibrate to Argentina and Mendoza (1991) who calibrates to Canada.
Table 6—Benchmark targets and parameter values: Country-specific

<table>
<thead>
<tr>
<th></th>
<th>DEVELOPED</th>
<th>DEVELOPING</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA TARGETS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reserve requirement ratio</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>M1/GDP</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Deposits/Cash</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Cash interest elasticity</td>
<td>-0.04</td>
<td>-0.04</td>
</tr>
<tr>
<td>Bank reserves interest elasticity</td>
<td>-0.04</td>
<td>-0.04</td>
</tr>
<tr>
<td>Net lending/borrowing by the general government/GDP</td>
<td>-0.013</td>
<td>-0.021</td>
</tr>
<tr>
<td>Spread of nominal lending rate over money market rate</td>
<td>0.05</td>
<td>0.09</td>
</tr>
<tr>
<td>Net foreign assets/GDP</td>
<td>-0.26</td>
<td>-0.33</td>
</tr>
<tr>
<td>MODEL PARAMETERS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \theta ): reserve requirement</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>( s_k, \kappa = {h, d} ): transaction cost</td>
<td>( s_h = 24.55, s_d = 0.097 )</td>
<td>( s_h = 100, s_d = 4.8 )</td>
</tr>
<tr>
<td>( \lambda_k, \kappa = {h, d} ): transaction cost</td>
<td>( \lambda_h = 0.244, \lambda_d = 1.303 )</td>
<td>( \lambda_h = 0.125, \lambda_d = 0.138 )</td>
</tr>
<tr>
<td>( \tau ): lump-sum transfers</td>
<td>1.3% of GDP</td>
<td>2.1% of GDP</td>
</tr>
<tr>
<td>( \phi ): share of wage-in-advance</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>( \phi^n ): per unit loans costs</td>
<td>0.05</td>
<td>0.09</td>
</tr>
<tr>
<td>( \bar{d}^b ): debt to GDP ratio</td>
<td>-0.26</td>
<td>-0.33</td>
</tr>
</tbody>
</table>

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. Third, since estimates for the interest elasticities of deposits and cash are not separately available, we discipline our calibration by picking parameters such that elasticities of cash demand and the reserve fraction of deposit demand (which is bank reserves) are equalized within each group of countries and across the two groups of countries in the steady state. Furthermore, the parameters are picked to match interest elasticity of money demand equal to –0.04 annually. This number was estimated by Mulligan and Sala-i-Martin (1992) for the U.S. and is in line with the estimate obtained by Ball (2001).³⁵ This value is also in the mid-range of estimates reported in the literature for various countries, time-periods, and methodologies (see Kumar, Chowdhury and Rao (2010) for a recent overview and summary of the estimates of interest rate elasticities of money demand).³⁶

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 sam-

³⁵Mulligan and Sala-i-Martin (1992) estimated the interest elasticity of money for both M1 and M0. The two estimates were very similar. Our interest lies in the interest elasticities of the individual components of M0 for which we do not have disaggregated estimates. Hence, we impose the neutral assumption of setting the elasticities of cash and bank reserves equal to each other.

³⁶Total transaction costs implied by the model are very small in our calibration: they are 0.04% of GDP in developed countries, and 0.48% of GDP in developing countries.
ple period, 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 to calibrate our key parameters are systematic. For instance, all developing countries in our calibration sample have higher reserve requirement ratios, lower ratios of M1 to GDP, lower ratios of deposits to cash, and larger negative fiscal imbalances (with the exception of Korea). Based on this 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 the 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 et al. (2011)). Schmitt-Grohe and Uribe (2005) 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 for their model to match the empirical impulse responses of several macroeconomic aggregates.

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.

Lastly, we calibrate parameters $\gamma$ and $\bar{d}_b$ to match the average net foreign asset position to GDP ratios equal to -26% in developed economies and -33% in developing countries over our sample period. The proportional cost parameter $\phi^b$ in the banking sector problem is chosen to match the average spread of the nominal lending rate over the money market rate equal 9% in developing countries and 5% in developed economies over our sample period.

$^{37}$In fact, we restrict $\gamma$ to be the same in the two groups of countries to reduce the number of free parameters. The resulting banking costs, $q$, in the steady state are very small, equal to less than 0.00086% of GDP.
B. 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. When characterizing business cycles properties of the model, we set the volatility of productivity shocks in developed and developing countries calibrations such that the simulated volatility of output in the model matches the volatility of output in the data for the two groups of countries.

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

We consider three interest rate rules which differ in their exogeneity or endogeneity to macroeconomic conditions.

(i) Exogenous interest rate rule: The first rule we consider is an exogenous interest rate rule, where we estimate the first-order autoregressive process for $i^g$ as

\begin{equation}
\hat{i}^g_{t+1} = \rho_i \hat{i}^g_t + \varepsilon^g_{t+1},
\end{equation}

with $\varepsilon^g_{t+1}$ being i.i.d. normal innovations.\(^{38}\) While this rule is not very realistic, it allows us to flesh out the mechanism of the model.

(ii) Generalized Taylor (GT) rule: The second rule we consider is the well-known Taylor rule due to Taylor (1993) where the interest rate responds to current output and inflation. We also allow for inertia in the interest rate. Such rules are typically referred to as Generalized Taylor rules in the literature. More precisely, we estimate Generalized Taylor rules of the form:

\begin{equation}
i^g_{t+1} = \rho_i i^g_t + \alpha_1 (\pi_t - \pi^*) + \alpha_2 y^{gap}_t + \varepsilon^g_{t+1},\end{equation}

where $y^{gap}$ is the output gap measured as the deviation of industrial production in a given

\(^{38}\)We also considered a differential between a country interest rate and the U.S. Federal Funds rate in our interest rate rules and found that the results remained practically unchanged.
country from its Hodrick-Prescott trend.\textsuperscript{39} $\pi_t$ is inflation measured as the (annualized) CPI growth rate, while $\pi^*$ is the time-independent inflation target.

(iii) Inflation-Forecast-Based (IFB) monetary rule: Our third rule is a “forward looking” version of the Taylor rule as it assumes that policy rate responds to a forecast of future inflation rather than the current inflation. We estimate simple IFB rules of the following form:

\begin{equation}
    i_{t+1}^g = \rho_i i_t^g + \alpha_1 \mathbb{E}_t (\pi_{t+1} - \pi^*) + \alpha_2 \gamma_{t+1}^{gap} + \varepsilon_{i_t+1}^g.
\end{equation}

$\mathbb{E}_t (\pi_{t+1} - \pi^*)$ is measured as the one period ahead forecast of inflation from the VAR estimated on (log) output, inflation and policy interest rate for each country in our calibration sample.

We estimate the equations above separately for a panel of developed and developing countries.\textsuperscript{40} This approach is intended to capture the dynamics of $i_t^g$ in an average emerging market economy and an average industrial country. Coefficient estimates in the three interest rate rules are presented in Table 7.\textsuperscript{41}

We find a substantial degree of policy inertia in the interest rate rules in both developed and developing countries, with the persistence being slightly higher in developed countries. In our estimation, the weight on inflation, either contemporaneous or expected future, tends to be somewhat higher in developing countries, while the weight on output is comparable in the two groups of countries. These results are in line with the findings in a number of studies: for instance, Levin, Wieland and Williams (2003) evaluate the performance of IFB rules in various monetary models and estimate the degree of policy inertia to be quite high - around 1.\textsuperscript{42} Laxton and Pesenti (2003) confirm their results for emerging market economies. Our estimates are also in line with Clarida, Gali and Gertler (2000).\textsuperscript{43}

We also find interest rates in developing countries to be significantly more volatile - the average standard deviation of $i_t^g$ is 1.42% in developed countries and 5.21% in developing economies (see row labeled $\sigma (i^g)$ in Table 7).\textsuperscript{44} The same differences extend to the volatility of innovations to interest rates in the two countries (row labeled $\sigma (\varepsilon_{i+t+1}^g)$). For instance, we get $\sigma (\varepsilon_{i+t+1}^g) = 0.48\%$ in developed countries and $\sigma (\varepsilon_{i+t+1}^g) = 2.15\%$ in developing countries in the simple exogenous rule, on average.\textsuperscript{45}

Once the shock processes and other parameter values are set, we solve the model by linearizing the equations characterizing the equilibrium around the steady state and

\textsuperscript{39}If industrial production at quarterly frequency was not available, we used GDP volume instead.

\textsuperscript{40}Note that we do not include country-specific intercepts in our regressions. Adding such intercepts changes the estimates very marginally.

\textsuperscript{41}We also considered Taylor rules with the real exchange rate as discussed in Taylor (2001), but find that the estimates remain mostly unchanged as the coefficients on the real exchange rate and its lags are insignificant.

\textsuperscript{42}We should note that any inference from our IFB regressions should be performed with caution since the variance-covariance matrix is subject to the generated regressor problem (Pagan (1984)).

\textsuperscript{43}Note that out estimates also satisfy the Taylor principle in both groups of countries.

\textsuperscript{44}In the estimation of the process for $i^g$ 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 calibration sample.

\textsuperscript{45}We also estimated country-specific processes for $i^g$, and found them to be along the lines of the aggregate estimates.
TABLE 7—Estimated interest rate rules

<table>
<thead>
<tr>
<th>Developed countries</th>
<th></th>
<th>Developed countries</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(i)</td>
<td>(ii)</td>
</tr>
<tr>
<td>Exogenous</td>
<td></td>
<td>GT</td>
<td></td>
<td>(iii)</td>
<td>(iv)</td>
</tr>
<tr>
<td></td>
<td>i_t^g</td>
<td>0.982***</td>
<td>0.918***</td>
<td>0.897***</td>
<td>0.959***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.007)</td>
<td>(0.018)</td>
<td>(0.024)</td>
<td>(0.023)</td>
</tr>
<tr>
<td></td>
<td>y_t^gap</td>
<td>0.054***</td>
<td>0.069***</td>
<td>0.116***</td>
<td>0.063***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.012)</td>
<td>(0.013)</td>
<td>(0.031)</td>
<td>(0.019)</td>
</tr>
<tr>
<td></td>
<td>\pi_t - \pi^*</td>
<td>0.076***</td>
<td></td>
<td>0.382***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.026)</td>
<td></td>
<td>(0.138)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E_t (\pi_{t+1} - \pi^*)</td>
<td>0.107***</td>
<td></td>
<td>0.128***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.030)</td>
<td></td>
<td>(0.075)</td>
<td></td>
</tr>
<tr>
<td>\sigma (i_t^g)</td>
<td>1.416</td>
<td>0.479</td>
<td>0.407</td>
<td>5.209</td>
<td></td>
</tr>
<tr>
<td>\sigma (\pi_{t+1})</td>
<td>0.040</td>
<td>0.405</td>
<td>2.150</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.470</td>
<td>0.754</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Column (i) and (iv) present estimation results for equation (20); columns (ii) and (v) are for equation (21), while columns (iii) and (vi) are for equation (22). We obtain y_t^gap in each country as deviations of industrial production from its Hodrick-Prescott trend. Due to the presence of lagged dependent variable, all equations are estimated with instrumental variables, where we used lagged values of interest rate as instruments. Rows \sigma (i_t^g) and \sigma (\pi_{t+1}) report standard deviations of interest rate and innovations to interest rates, respectively. Robust standard errors are in parentheses. *,**, and *** indicate significance at 10%, 5%, and 1%, respectively.

46 In our economy, international bonds follow a unit root process. To account for this non-stationarity (which is a standard feature, of course, of textbook small open economy models) and render the model stationary for numerical purposes, we impose a quadratic bond holding cost of the form \Phi(a_t) = \frac{\theta}{2} N \left( \frac{a_t - \tilde{a}}{N} \right)^2, where \tilde{a} denotes the steady state ratio of bond holdings to GDP, and \theta is a level parameter.
compute the level of nominal exchange rate in the model as follows. First, from the money market equilibrium condition in conjunction with PPP, \( M_0/E_0 = m^d(i^g, i_1) \), 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, \( \pi_1 \), predicted by the model. Clearly, the exchange rate is non-stationary in our model. We transform \( E_t \) into stationary terms by dividing it by the model-implied \( M_t \). This is a standard transformation used in the literature to normalize nominal non-stationary variables in monetary models. We should 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 7 presents impulse responses of the exchange rate to a temporary positive 1% shock to the policy-controlled interest rate \( i^g \) in the model under the three interest rate rules. Panel (a) is based on the model parameterized for a developed country, while panel (b) is for the model calibrated to a developing country.

**Figure 7. Impulse responses following 1% shock to \( i^g \)**

(a). Developed countries

(b). Developing countries

Note: The figures present the responses of nominal exchange rate to a 1% positive shock to policy-controlled interest rate, \( i^g \), under three interest rate rules: exog–exogenous rule given in equation (20); GT–Generalized Taylor rule given in equation (21); and IFB–Inflation-Forecast-Based rule given in equation (22). Panel (a) presents impulse responses from the model calibrated to developed countries, while panel (b) does the same for developing countries.

A 1% increase in \( i^g \) is associated with about a 3.93% appreciation of the exchange rate on impact in developed countries and a 2.75% depreciation of exchange rate on impact in emerging market economies under an exogenous interest rate rule. When endogenous interest rate rules are considered, the model predicts a larger appreciation in developed countries and a slightly larger depreciation in developing countries. These differences in the quantitative responses of the exchange rate are primarily due to differences in
the estimated persistence of shocks in the three interest rate rules. Not only do these responses match very well the signs of the empirical impulse responses, they are also within the range of the quantitative estimates of those responses in section I.

What is behind the contrasting response of the exchange rate in developed and developing countries? The impact response of the exchange rate to the policy shock depends on the response of real money demand. Recall that $m = h + \theta d$ and $E_0 = \frac{M_0}{m_0}$. Since $M_0$ is predetermined at date 0, an increase in real money demand $m$ will appreciate the currency while a decrease will have the opposite effect. We thus turn to the response of real money demand to a positive shock to $i_e$.

An increase in $i_e$ will raise the interest rate on deposits $i_d$, which, ceteris paribus, will reduce the deposit spread and consequently raise deposit demand $d$ and real money demand. This is the direct effect of $i_e$ on real money demand and we refer to it as the "liquidity demand" effect. Changes in $i_e$ also have indirect effects on the real money demand which are brought about by the effects of $i_e$ on the market interest rate $i$. Specifically, a higher $i_e$ raises the fiscal burden on the government and consequently raises expected inflation and $i$. This is the "fiscal" effect. A higher $i_e$ also raises the interest rate on loans $i_l$ and consequently lowers the demand for loans and output. This is the "output" effect. In response to the higher $i_e$ banks demand more government bonds which raises the expected fiscal burden on the government. The consequence of this is higher expected inflation and a higher market interest rate $i$. An increase in $i$ triggered by the indirect effects of higher $i_e$ raises the opportunity cost of holding cash and deposits, reducing the demand for them. Whether the overall demand for money increases or decreases depends on the relative strength of the direct and indirect effects.

We illustrate these adjustments by plotting the impulse responses of the key variables to a positive 1% shock to $i_e$. Since the steady states are different for developed and developing countries, to facilitate the comparison across calibrations we present all impulse responses as deviations from the steady state (multiplied by 100). Results are in Figure 8.

Panel (a) shows that inflation, $\pi$, rises in both developed and developing countries in response to the rise in $i_e$. The symmetric inflation effect implies that the increase in the market nominal interest rate $i$ is also symmetric in developed and developing countries. Panel (b) of Figure 8 shows that deposits rise in both groups in response to an increase in $i_e$. Crucially though, deposits respond much more in developed countries. Panel (c) shows that cash holding $h$ declines in both groups but, again, the decline is larger for developed countries. Overall, panel (d) shows that aggregate money demand rises in developed countries but falls in developing countries in response to a shock to $i_e$. This implies that the indirect effect of lower cash and deposits demand due to a higher $i$ swamps the direct effect on deposits from higher $i_d$ in developing countries whereas in developing countries it does not.

To develop some intuition for the differences in money demand responses in the two groups of countries, consider the money demand equation:

$$m_t = h_t + \theta d_t$$
Totally differentiating this expression with respect to $i^g$ and evaluating the derivative around the steady state gives

$$\eta_m = \frac{i^g}{1+i} \left[ - (1-a) \eta_h \frac{1}{i} - \frac{a}{\theta} \eta_d \left( \frac{1+i_d}{i-i_d} \right) \right] \frac{\partial i}{\partial i^g} + \frac{a}{\theta} \eta_d \left( \frac{i_d}{i-i_d} \right) \frac{\partial d}{\partial i^g}$$

direct effect on $h$ and $d$  
indirect effect on $h$ and $d$

where $\eta_m = \frac{dm}{d^g y^d}, \eta_h = -\frac{dh}{d^g y^d} > 0, \eta_d = -\frac{dd}{d^g y^d} > 0$, and $a = \frac{\theta d_d}{\theta d_d + \theta d_h}$ with $d_d$ and $h_d$ denote steady state values of $d_d$ and $h_d$. Note that in deriving the above we have used the definitions $I \equiv \frac{i}{1+i}$ and $I^d \equiv \frac{i^d}{1+i}$. Equation (23) gives the response of $m^g$ to changes in $i^g$ around the steady state. The first two terms on the right-hand-side of equation (23) give the indirect effect of $i^g$ on $m$. It is easy to see that that effect is always negative, since $\frac{\partial i}{\partial i^g} > 0$. The last term in equation (23) gives the direct effect of $i^g$ on $m$ and that effect is always positive. The relative strengths of the two effects will determine the net effect on $m$.

In our calibration, $\eta_h$ and $\eta_d$ are the same in developed and developing countries. Moreover, the coefficient $a$ turns out to be very similar in developed (0.107) and developing (0.091) countries as does $\frac{\partial i}{\partial i^g}$. Hence, the strength of the direct and indirect effects boils down to the relative magnitudes of $i^g, i$ and $\theta$ in the two groups of countries. With $i^g, i$ and $\theta$ all being smaller in developed countries, we find that the direct effect is stronger in this group. Similarly, the indirect effect is also stronger in developed countries. However, the net of the two effects is positive in developed countries and negative in developing, leading to opposite responses of money demand and the exchange rate in the two groups.

A. Counterfactual experiments

What determines the relative strength of the fiscal effect, the output effect, and the liquidity demand effect in the model? More specifically, would changing the relative strengths of any one of these margins change the result on whether the currency appreciates or depreciates? We emphasized that the strength of the three effects in the model could be summarized by a few key parameters that distinguish developed and developing countries in our model. To see this more formally, consider again the government budget constraint (equation (14)) which is used to pin down the expected inflation rate and nominal market interest rate $i$. In the steady state this equation becomes:

$$\frac{\bar{\tau}}{y} + \left( \frac{i^g - \pi}{1+\pi} \right) \frac{\bar{z}}{y} = \left( \frac{\pi}{1+\pi} \right) \frac{m}{y},$$

where we have normalized all variables by output $y$ to control for scale. Hence, all else equal, the higher the money base $\frac{m}{y}$, the lower is the required inflation rate $\pi$ to finance a given amount of government spending $\bar{\tau}$. Similarly, the lower is the fiscal spending to GDP ratio $\frac{z}{y}$, the lower is the required $\pi$ to finance the budget. Lastly, note that the
impact of the "output" effect on $\pi$ comes through $z$ since government bonds are linked to loans to the private sector $n$ through the commercial bank balance sheets. A higher $\phi$ raises private sector loans which reduces $z$. Since $\frac{z}{1 + z}$ and $\frac{z - \phi}{1 + z}$ are both increasing in $\pi$, the fall in $z$ necessitates a higher $\pi$ in order to finance government spending. This gives us three key parameters – $\tau$, $\phi$, and those governing $\frac{m}{v}$ in the steady state – determining the strength of the three effects in the model. In the impulse response analysis we also showed that the composition of money demand in the steady state ($d$ and $h$) also matter for the results (see equation (23)). So we add $\frac{d}{h}$ to the list.

To study the importance of each parameter, we carry out counterfactual experiments
VOL. NO. ISSUE EXCHANGE RATE AND MONETARY POLICY 37

wherein we sequentially vary parameters that control the three main channels while keeping the other parameters unchanged and examine the effect on the impulse response of the exchange rate to shocks to $i^g$. More precisely, for different values of the parameters we compute the impact effect of an increase in $i^g$ on the exchange rate (expressed as percent deviation from the steady state).

The parameters that control the strength of the fiscal and output effects in the model are $\tau$ and $\phi$, respectively. The first important result to emerge was that our baseline impulse response behavior in developed and developing countries were robust to varying $\tau$ and $\phi$. Hence, the different responses in the two groups of countries are not sensitive to small changes in the measured fiscal and wage-in-advance parameters. These results are available in the Appendix D.

The factors that control the strength of the liquidity demand effect in the model are parameters that pin down the steady state $m_y$ and $d_h$ ratios. Panel (a) of Figure 9 shows the effect of reducing the $d_h$ ratio for developed countries while keeping all other developed country targets unchanged. A lower $d_h$ ratio makes the impact appreciation of the exchange rate smaller in developed countries. In fact, for all $d_h$ less than 1.15, the exchange rate response to a rise in $i^g$ switches from appreciation to depreciation. Panel (b) of Figure 9 shows the corresponding effect of raising the $d_h$ ratio for emerging economies keeping all their other parameters unchanged. The picture here is different. While raising the $d_h$ ratio does tend to reduce the impact depreciation initially, the response never switches to an appreciation. In fact, for $d_h$ ratios greater than 7.2 the size of the exchange rate depreciation begins to rise again. This exercise suggests that the relatively high $d_h$ ratio in developed countries is important for their currency appreciations in response to increases in $i^g$. The low $d_h$ ratio in emerging economies however was not, by itself, the reason for their currency depreciation.

To examine the importance of the $m_y$ ratio, we lower the baseline target of $m_y = 0.20$ for developed countries while keeping all other developed country targets unchanged. For emerging economies, we raise the $m_y$ ratio from their baseline value of 0.10. Figure 10 shows the results. Panel (a) of Figure 10 shows that reducing the $m_y$ ratio in developed countries makes their impact appreciation smaller. For all values of $m_y$ less than 0.07, the appreciation in developed countries switches to a depreciation in response to an increase in $i^g$. Correspondingly, starting from the baseline level of 0.10, we find that raising the target $m_y$ above 0.22 for emerging economies switches their exchange rate impact response to an appreciation. Clearly, the differential results between developed and developing countries do depend on the $m_y$ ratio.

Our conclusion from these results is that the liquidity demand effect appears to be a key aspect of understanding the differences between developing and developed economies since varying the target variables $d_h$ and $m_y$ tend to switch the exchange rate responses

47 More precisely, we adjust parameters $s_x$ and $x_{xx}, x = [h, d]$ such that $d_h$ target ratio changes to a new level, while $m_y$ ratio is kept at its benchmark target of 0.2 and the interest elasticities at their benchmark target of -0.04 annually in developed countries. A symmetric exercise is performed for developing countries using their respective targets. The same approach is used when varying the $m_y$ ratio.
FIGURE 9. COMPARATIVE STATICS FOR DEPOSITS-TO-CASH RATIO

(a). Developed countries
(b). Developing countries

Note: The figure presents the responses of nominal exchange rate to a positive 1% shock to \( i^e \) for various levels of the \( \frac{d}{h} \) ratio. The developed country calibration is shown in the left panel while the right panel shows the developing country calibration. Dashed vertical line indicates the level of \( \frac{d}{h} \) under our benchmark calibration in each country group.

predicted by the model.

B. Independent evidence on mechanism

Does the data provide any independent evidence supporting the importance of the liquidity demand channel, in particular, the roles played by the \( \frac{d}{h} \) and \( \frac{m}{y} \) ratios? More generally, can the differences in the empirical results between developed and developing countries just be proxied by the differences in the strengths of the liquidity demand channels in appreciating and depreciating countries, without reference to their developed or developing economy status?

To examine this, we start by estimating a probit regressions to predict the probability of a country’s currency appreciating or depreciating in response to an interest rate increase. For our left hand side variable, we construct a binary variable for whether or not the currency appreciated (1) or depreciated (0) on impact in our VAR estimations reported in Section I. We regress this appreciation event on several explanatory variables. Table 8 reports the marginal effects of these explanatory variables for different specifications. The first specification includes only a country income dummy: \( developing = 1, developed = 0 \) as determined by the World Bank Income Classification. As column (i) of the Table shows, developing country status has a significant negative effect on the probability of an exchange rate appreciation in response to an interest rate increase. However, columns (ii) and (iii) show that the income dummy becomes
insignificant when we include as additional regressors either the \( \frac{d}{h} \) ratio or the \( \frac{m}{y} \) ratio. The last specification (column (iv) of the Table) includes all three: the income dummy, the \( \frac{d}{h} \) ratio and the \( \frac{m}{y} \) ratio. The income dummy continues to remain insignificant. Importantly, the \( \frac{m}{y} \) ratio enters positively and significantly. We view these results as: (a) indicating support for the liquidity demand channel as measured by the money-to-GDP ratio; and (b) confirming the result from the model that the \( \frac{d}{h} \) ratio is likely less important than the overall \( \frac{m}{y} \) ratio in a country in order to determine the exchange rate response from a rise in \( i^R \).

We also verify that the \( \frac{m}{y} \) ratio has explanatory power for the size of the exchange rate responses to the interest rate shocks. To this effect, we regress the actual exchange rate responses at different horizons obtained from the bivariate individual country VARs on \( \frac{m}{y} \) ratio. The results are summarized in Table 9. Columns (i), (iii) and (v) present the results from the regression of the exchange rate response on an income dummy. Developing country status has a positive effect on the size of the exchange rate change in response to an interest rate increase, and this effect is strongly significant 1 and 3 months after the shock. Adding the \( \frac{m}{y} \) ratio to the regression wipes out the significant of the income

\[\text{Note: The figure presents the responses of nominal exchange rate to a positive 1% shock to } i^R \text{ for various levels of the } \frac{m}{y} \text{ ratio. The developed country calibration is shown in the left panel while the right panel shows the developing country calibration. Dashed vertical line indicates the level of } \frac{m}{y} \text{ under our benchmark calibration in each country group.} \]
TABLE 8—PROBIT REGRESSION FOR EXCHANGE RATE RESPONSES

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-developing, 0-developed</td>
<td>-0.407***</td>
<td>-0.184</td>
<td>0.036</td>
<td>0.245</td>
</tr>
<tr>
<td></td>
<td>(0.166)</td>
<td>(0.276)</td>
<td>(0.258)</td>
<td>(0.347)</td>
</tr>
<tr>
<td>$d/h$</td>
<td></td>
<td>0.044</td>
<td></td>
<td>0.046</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.034)</td>
<td></td>
<td>(0.050)</td>
</tr>
<tr>
<td>$m/y$</td>
<td></td>
<td></td>
<td>0.055***</td>
<td>0.055***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.016)</td>
<td>(0.017)</td>
</tr>
</tbody>
</table>

N 36  36  36  36

Note: This table shows marginal effects from the probit regressions of a binary variable identifying impact appreciation of exchange rate in each country-episode pair on several controls. The variable identifying impact exchange rate appreciation is obtained from the VARs, the results for which are summarized in Table 2. Right-hand-side variables are developing country dummy variable (1-developing, 0-developed); deposit-to-cash ratio ($d/h$); and money to GDP ratio ($m/y$). N refers to the number of observations. Standard errors are in parenthesis. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

dummy at all horizons (columns (ii), (iv), and (vi)). The effect of $m/y$ ratio on the size of the exchange rate response is negative and always significant, implying that an increase in the $m/y$ ratio reduces the size of the exchange rate depreciation after a positive interest rate shock.

The importance of the deposit-to-cash and money-to-GDP ratios in rationalizing the different exchange rate responses in the two groups of countries raises a fundamental question: why are these ratios so much higher in developed countries relative to developing economies? The answer is likely related to a multitude of factors such as the history of expropriation of interest bearing deposits, the institutional strength of the monetary regime, the presence and duration of deposit insurance schemes, and the level of financial development. More generally, our results suggest that the transmission of monetary policy to the economy is likely to be fundamentally affected by these factors. Hence, they need to be factored in explicitly when conducting monetary policy in developing countries since the outcomes may well be at odds with the established wisdom derived from developed country experiences.

V. Conclusions

The effect of monetary policy on the exchange rate has long been one of the fundamental concerns of academics and practitioners alike. A number of existing models predict that a 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 72 countries between 1974 and 2010 and show that while most developed countries indeed exhibit exchange rate appreciations in response to interest rate increases, in devel-
Table 9—OLS regression for exchange rate responses

<table>
<thead>
<tr>
<th></th>
<th>impact</th>
<th>1 month</th>
<th>3 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(i)</td>
<td>(ii)</td>
<td>(iii)</td>
</tr>
<tr>
<td>1-developing, 0-developed</td>
<td>0.096</td>
<td>-0.019</td>
<td>0.220***</td>
</tr>
<tr>
<td></td>
<td>0.066</td>
<td>0.083</td>
<td>0.080</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.107</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.103</td>
<td></td>
</tr>
<tr>
<td>( m/y )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.007**</td>
<td>-0.007*</td>
<td>-0.007*</td>
</tr>
<tr>
<td></td>
<td>0.003</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>constant</td>
<td>-0.037</td>
<td>0.173**</td>
<td>-0.100**</td>
</tr>
<tr>
<td></td>
<td>0.026</td>
<td>0.083</td>
<td>0.041</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.113</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.126</td>
</tr>
</tbody>
</table>

N | 36  | 36  | 36  | 36  | 36  | 36  |

Note: This table shows the regression coefficients from the OLS regressions of the size of the (log) exchange rate response following a 1% rise in the interest rate on several controls. The responses are obtained from the bivariate VARs estimated for each country-episode pair. Right-hand-side variables are developing country dummy variable (1-developing, 0-developed); and money to GDP ratio (\( m/y \)). N refers to the number of observations. Standard errors are in parenthesis. *,**, and *** indicate significance at 10%, 5%, and 1%, respectively.

Developing countries the effect is the opposite: most of them exhibit depreciating currencies in response to interest rate increases. Importantly, the differing responses in developing and developed countries is not due simply to differences in the nature of expected inflation shocks or in the types of policy rules or in the nature of exogenous shocks in the two groups. This is a new data fact.

We have provided an explanation for this fact using a simple open economy monetary model. Our explanation rests on the contrast in the interplay of 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 liquidity 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. Lastly, we have provided independent evidence for the mechanism identified by the model and its ability to explain the data puzzle.

Our proposed resolution of the empirical findings is by no means the only possible explanation. However, given that we have shown empirical support for the mechanism underlying our explanation, we believe that alternative explanations are likely to be complementary rather than substitutes for our rationalization of the puzzling data fact.

REFERENCES


Appendix

A. 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>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchange rate</td>
<td>official exchange rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td></td>
<td>market exchange rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td></td>
<td>principal exchange rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td></td>
<td>commercial exchange rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td>Interest rate</td>
<td>T-bill rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td></td>
<td>discount rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td></td>
<td>money market rate, period average</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td>Output</td>
<td>Industrial production index</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td></td>
<td>2000 base year</td>
<td></td>
</tr>
<tr>
<td>CPI</td>
<td>Consumer price index</td>
<td>IFS by IMF</td>
</tr>
<tr>
<td>Risk premium</td>
<td>BoA Merrill Lynch US High Yield Master II Option-Adjusted Spread</td>
<td>BoA Merrill Lynch</td>
</tr>
<tr>
<td></td>
<td>Moody’s Seasoned Baa Corporate Bond Yield</td>
<td>Board of Governors</td>
</tr>
<tr>
<td></td>
<td>Credit Default Swap (CDS) spreads, weekly</td>
<td>Bloomberg</td>
</tr>
<tr>
<td></td>
<td>EMBI+ spread, daily</td>
<td>Bloomberg</td>
</tr>
</tbody>
</table>

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 +/-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.
B. 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 are from the IFS database.

Fiscal variables: We used general government net lending/borrowing as a share of GDP to calibrate parameter $\tau$. The data are 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. These data are from the IFS database.

C. Deriving money demand

Household’s first order conditions are

\begin{align}
(A1) & \quad U_c(c_t, x_t) = \beta R \mathbb{E}_t U_c(c_{t+1}, x_{t+1}), \\
(A2) & \quad v_c x_{t-1} = w_t, \\
(A3) & \quad U_c(c_t, x_t) (1 + \nu'(h_t)) = \beta \mathbb{E}_t \left[ U_c(c_{t+1}, x_{t+1}) \frac{P_t}{P_{t+1}} \right], \\
(A4) & \quad U_c(c_t, x_t) (1 + \psi'(d_t)) = \beta \mathbb{E}_t \left[ U_c(c_{t+1}, x_{t+1}) (1 + i^d_{t+1}) \frac{P_t}{P_{t+1}} \right], \\
(A5) & \quad U_c(c_t, x_t) = \beta \mathbb{E}_t \left[ \left( \frac{\rho_{t+1} + (1 - \delta) (1 + \kappa_l (t + 1) - \kappa_k (t + 1))}{1 + \kappa_l (t)} \right) U_c(c_{t+1}, x_{t+1}) \right]
\end{align}
Equation (A1) is the standard intertemporal Euler equation for optimal consumption. Under our maintained assumption of $\beta = 1/R$ it says that the household should equate the expected marginal utilities across time. Equation (A2) shows that labor supply depends only on the real wage. Moreover, the assumption $\nu > 1$ implies that labor supply $x$ is an increasing function of the real wage, $w$. Equation (A5) dictates the optimal capital accumulation decision by households. Note that by combining equations (A1) and (A5) one can derive a modified no-arbitrage condition which determines the optimal portfolio composition between bonds and physical capital.

Equations (A3) and (A4) implicitly define the demand for cash and demand deposits as a decreasing function of their respective opportunity costs. To see this apply the functional forms for transaction costs functions $v(h_t)$ and $\psi(d_t)$ specified in (19) and substitute in the definition of the nominal interest rate in (5) to the first order conditions for cash and deposit demand to obtain their implicit demand functions:

$$
(A6) \quad h_t = \tilde{h} \left( \frac{i_{t+1}}{1 + i_{t+1}} \right), \quad \tilde{h}' < 0.
$$

$$
(A7) \quad d_t = \tilde{d} \left( \frac{i_{t+1} - i_{t+1}^d}{1 + i_{t+1}} \right), \quad \tilde{d}' < 0.
$$

Explicit solutions for $h_t$ and $d_t$ can be derived under perfect foresight.

D. Counterfactual experiments with $\tau$ and $\phi$

Figure A1 shows the “fiscal” effect in play for both developed countries (left panel) and emerging economies (right panel). The figure depicts the impact effect of an increase in $i^g$ on the exchange rate (expressed as percent deviation from the steady state) for different values of $\tau$. For developed countries, a higher $i^g$ induces an impact currency appreciation, i.e. a fall in $E$, for the entire range of $\tau$’s plotted. For developing economies however, a higher $i^g$ induces a depreciation of the currency on impact, i.e., a rise in $E$, for the entire range of $\tau$. Therefore, the difference between developed and emerging economies that we found in Figure 7 is robust to changes in the level of $\tau$ since changes in $\tau$ do not appear to qualitatively change the impact effect of $i^g$ on the exchange rate.

The size and importance of the “output” effect is captured by the wage-in-advance parameter $\phi$. Figure A2 shows the effects of varying $\phi$ in our model. The figure shows that the impact effect of a temporary increase in $i^g$ on the exchange rate is an appreciation in developed countries and a depreciation in developing countries for a broad range of values for $\phi$. Therefore, we conclude that the differences in the impulse responses for the two groups to interest rate shocks highlighted in Figure 7 are robust to variations in the wage-in-advance parameter $\phi$. 
Note: The figure presents the responses of nominal exchange rate to a positive shock to $i^d$ for various levels of $\tau$. 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.

Note: The top panel presents the responses of nominal exchange rate to a positive shock to $i^d$ for various levels of $\phi$. 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.
### Table A2—Sample Used in the Empirical Work

<table>
<thead>
<tr>
<th>No</th>
<th>from to</th>
<th>country</th>
<th>No</th>
<th>from to</th>
<th>country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1994m7</td>
<td>2001m12</td>
<td>41</td>
<td>1990m1</td>
<td>1998m12</td>
</tr>
<tr>
<td>2</td>
<td>1988m1</td>
<td>1995m1</td>
<td>42</td>
<td>2002m10</td>
<td>2007m12</td>
</tr>
<tr>
<td>3</td>
<td>2002m1</td>
<td>2005m5</td>
<td>43</td>
<td>1983m1</td>
<td>1994m12</td>
</tr>
<tr>
<td>4</td>
<td>1974m1</td>
<td>2010m11</td>
<td>44</td>
<td>1997m8</td>
<td>2003m8</td>
</tr>
<tr>
<td>5</td>
<td>1974m1</td>
<td>1998m12</td>
<td>45</td>
<td>1987m11</td>
<td>2000m12</td>
</tr>
<tr>
<td>6</td>
<td>1994m1</td>
<td>2002m10</td>
<td>46</td>
<td>1982m2</td>
<td>1988m11</td>
</tr>
<tr>
<td>7</td>
<td>1974m1</td>
<td>1998m12</td>
<td>47</td>
<td>1995m1</td>
<td>2007m12</td>
</tr>
<tr>
<td>8</td>
<td>1999m2</td>
<td>2007m12</td>
<td>48</td>
<td>1991m1</td>
<td>1994m1</td>
</tr>
<tr>
<td>9</td>
<td>1992m1</td>
<td>1996m12</td>
<td>49</td>
<td>1996m8</td>
<td>1999m1</td>
</tr>
<tr>
<td>10</td>
<td>1974m1</td>
<td>2010m11</td>
<td>50</td>
<td>1974m1</td>
<td>1990m8</td>
</tr>
<tr>
<td>11</td>
<td>1999m9</td>
<td>2001m12</td>
<td>51</td>
<td>1978m1</td>
<td>2010m11</td>
</tr>
<tr>
<td>12</td>
<td>1990m3</td>
<td>1992m7</td>
<td>52</td>
<td>1991m7</td>
<td>2007m12</td>
</tr>
<tr>
<td>13</td>
<td>1994m7</td>
<td>2004m2</td>
<td>53</td>
<td>1974m1</td>
<td>2009m5</td>
</tr>
<tr>
<td>14</td>
<td>1980m10</td>
<td>1983m10</td>
<td>54</td>
<td>1990m1</td>
<td>1993m10</td>
</tr>
<tr>
<td>15</td>
<td>1997m6</td>
<td>2001m12</td>
<td>55</td>
<td>1997m7</td>
<td>1999m11</td>
</tr>
<tr>
<td>16</td>
<td>1981m5</td>
<td>1988m12</td>
<td>56</td>
<td>1982m4</td>
<td>1998m5</td>
</tr>
<tr>
<td>17</td>
<td>2003m11</td>
<td>2007m12</td>
<td>57</td>
<td>1994m3</td>
<td>2001m3</td>
</tr>
<tr>
<td>18</td>
<td>1999m1</td>
<td>2010m11</td>
<td>58</td>
<td>2003m4</td>
<td>2007m12</td>
</tr>
<tr>
<td>19</td>
<td>1974m1</td>
<td>1998m12</td>
<td>59</td>
<td>2002m1</td>
<td>2005m6</td>
</tr>
<tr>
<td>20</td>
<td>1974m1</td>
<td>1998m12</td>
<td>60</td>
<td>1974m1</td>
<td>2007m12</td>
</tr>
<tr>
<td>21</td>
<td>1986m1</td>
<td>1991m9</td>
<td>61</td>
<td>1974m1</td>
<td>1985m8</td>
</tr>
<tr>
<td>22</td>
<td>1975m7</td>
<td>1998m12</td>
<td>62</td>
<td>1995m3</td>
<td>2007m12</td>
</tr>
<tr>
<td>23</td>
<td>1985m4</td>
<td>2001m3</td>
<td>63</td>
<td>1979m1</td>
<td>1998m12</td>
</tr>
<tr>
<td>24</td>
<td>1983m1</td>
<td>2000m12</td>
<td>64</td>
<td>1974m1</td>
<td>2010m11</td>
</tr>
<tr>
<td>25</td>
<td>2000m5</td>
<td>2002m6</td>
<td>65</td>
<td>1980m1</td>
<td>2010m11</td>
</tr>
<tr>
<td>26</td>
<td>1988m1</td>
<td>1991m12</td>
<td>66</td>
<td>1982m6</td>
<td>1987m12</td>
</tr>
<tr>
<td>27</td>
<td>1994m10</td>
<td>2007m12</td>
<td>67</td>
<td>1998m10</td>
<td>2002m10</td>
</tr>
<tr>
<td>28</td>
<td>1987m6</td>
<td>2010m11</td>
<td>68</td>
<td>2001m2</td>
<td>2007m12</td>
</tr>
<tr>
<td>29</td>
<td>1997m8</td>
<td>2007m12</td>
<td>69</td>
<td>1991m12</td>
<td>1996m5</td>
</tr>
<tr>
<td>30</td>
<td>1977m1</td>
<td>1979m10</td>
<td>70</td>
<td>2001m2</td>
<td>2007m12</td>
</tr>
<tr>
<td>31</td>
<td>1974m1</td>
<td>1998m12</td>
<td>71</td>
<td>1980m1</td>
<td>1988m8</td>
</tr>
<tr>
<td>32</td>
<td>1977m3</td>
<td>1998m12</td>
<td>72</td>
<td>1989m10</td>
<td>1992m12</td>
</tr>
<tr>
<td>33</td>
<td>1990m10</td>
<td>1992m12</td>
<td>73</td>
<td>1992m12</td>
<td>1996m9</td>
</tr>
<tr>
<td>34</td>
<td>1974m1</td>
<td>2010m11</td>
<td>74</td>
<td>1974m1</td>
<td>2010m10</td>
</tr>
<tr>
<td>35</td>
<td>1994m4</td>
<td>1996m5</td>
<td>75</td>
<td>1991m12</td>
<td>1995m9</td>
</tr>
<tr>
<td>36</td>
<td>1987m1</td>
<td>1995m12</td>
<td>76</td>
<td>2002m5</td>
<td>2005m5</td>
</tr>
<tr>
<td>37</td>
<td>1997m12</td>
<td>2007m12</td>
<td>77</td>
<td>1984m3</td>
<td>1996m6</td>
</tr>
<tr>
<td>38</td>
<td>1994m1</td>
<td>1999m11</td>
<td>78</td>
<td>1978m1</td>
<td>1983m7</td>
</tr>
<tr>
<td>39</td>
<td>1997m9</td>
<td>2000m3</td>
<td>79</td>
<td>1985m11</td>
<td>2007m12</td>
</tr>
<tr>
<td>40</td>
<td>1984m3</td>
<td>1991m7</td>
<td>80</td>
<td>1991m10</td>
<td>1999m3</td>
</tr>
</tbody>
</table>