The Exchange Rate Response Puzzle[*]

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Abstract

We present a new data fact: in response to a monetary tightening, the nominal exchange tends to appreciate in developed countries but depreciate in developing countries. A model is formalized to rationalize this puzzling pattern. It has three key channels of monetary transmission: a liquidity demand channel, a fiscal channel and an output channel. These have offsetting effects on the exchange rate. The paper shows that a calibrated version of the model can explain the contrast between developed and developing countries. Using counterfactual experiments we identify differences in the liquidity demand effect as being key to the contrasting responses generated by the model. Finally, the paper provides independent evidence of systematic variation between appreciating and depreciating countries in the strength of the liquidity demand effect.

JEL Classification: F3, F4

Keywords: Monetary policy, interest rates, exchange rates

1 Introduction

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 tightenings.

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 practises, 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 interventions on the economy.

Somewhat paradoxically, the evidence on this to date has been sparse and somewhat limited. Probably, the most well 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.[1]

In this paper we will 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.[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

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[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.

[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.

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 75 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 is 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 in detail by considering sub-samples of countries and through various techniques. We show that even after controlling for expected inflation, output, and risk premium shocks, the divergence in the response of the exchange rate to identified interest rate shocks in developed and developing countries survives. While this is not an exhaustive list of shocks, 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.

Another explanation for the mixed results could be 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 show that the different responses of developed and developing countries are robust to allowing for contemporaneous movements of exchange rate and the interest rate. This raises doubts on the ability to precommit to monetary policy rules as being the reason for the contrasting responses. We should note that allowing for contemporaneous feedback between monetary policy and the exchange rate also addresses one of the key criticisms made by Faust and Rogers (2003) in their assessment of the identification schemes used by the literature in this area.[3]

We next turn to explaining the observed divergence between developed and developing countries by building a monetary model of a small open economy. The model we develop 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

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[3] We should note that a number of the studies that have used VARs to identify the effect of monetary policy shocks have attracted criticisms about their specific identification assumptions. An excellent summary of these criticisms can be found in Faust and Rogers (2003). Our strategy of using many different approaches including data correlations, country VARs, panel VARs, recursive identification schemes, non-recursive schemes through structural VARs etc., is a direct result of these criticisms. The multi-pronged approach is designed to alleviate concerns that can logically arise from any one approach.

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 captured by the money-to-GDP and the deposits-to-cash ratios. In the data both these ratios are systematically higher in the appreciating countries in our sample. A simple probit regression for the probability of the exchange rate appreciating in response to an interest rate increase reveals that including these two ratios as regressors has two effects: (a) they significantly increase the probability of the exchange rate appreciating in response to a rate hike; and (b) they make 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 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 as well as 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. Crucially, this relationship in the model does not rely on the UIP condition.[4]

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 3 presents the model while Section 4 discusses how the model is calibrated and solved. Section 5 presents our quantitative results using the calibrated model. The last section concludes.

2   Empirical facts

We start off by empirically documenting our motivating issue. 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 is from International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF). We use period average official exchange rates whenever available to measure exchange rates. If official rates are not available, we turn to period average market rates, otherwise we use the period average principal exchange rates. Exchange rates are in domestic currency units per U.S. dollar, so that an increase is a depreciation of local currency relative to the US dollar. Our focus is on policy-controlled interest rates, which we measured in the data as the period average T-bill rate. If the T-bill rate was not available, we used the discount rate, or the money market rate for that country. For the majority of countries in our sample we used the T-bill rate. This rate is the closest to the overnight interbank lending rates, which would be our preferred policy rate, but is not available for most of our countries.[5] 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.

We focus only on those countries and time periods that are characterized by a flexible exchange rate regime. To perform the selection, we rely on the Reinhart and Rogoff (2004) classification of historical exchange rate regimes. We classify a country as having a flexible exchange rate regime if, in a given year, its exchange rate was either (i) within a moving band that is narrower than or equal to +/-2% (i.e., allows for both appreciation and depreciation over time); or (ii) was classified as managed floating; or (iii) was classified as freely floating; or (iv) was classified as freely falling according to Reinhart and Rogoff (2004).[6] These correspond to their fine

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[4]In contrast, evidence of UIP failing in the data is problematic for models whose main result rely on the UIP condition. An example of this is the "exchange rate overshooting" result due to Dornbusch (1976).

[5]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.

[6]These categories are generally used in the literature to represent floating exchange rate regimes (see Reinhart and Rogoff

classification indices of 11, 12, 13, and 14, respectively.[7] We only focus on the post-Bretton Woods period for all countries. High income OECD countries are included in our sample, irrespective of their exchange rate classification. For the Eurozone countries, we used their national exchange rates before the introduction of the Euro as separate episodes. Since 1999:1 we included a separate episode for the Euro area, for which we used the Euro-dollar exchange rate and the ECB marginal lending facility rate as the policy rate.

According to the Reinhart and Rogoff (2004) classification, some countries had multiple episodes of flexible exchange rates. We considered each such episode separately. To be included in our sample we also require that an episode has at least 24 months of data in the flexible regime for each country. This selection gives us a sample of 25 industrial country-episode pairs and 55 developing country-episode pairs, for a total of 80 country-episode pairs. All country-episode pairs are listed in the Appendix A.1.[8]

2.1 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.[9] Column "full sample" reports the mean and median of all the time-series correlations obtained for the countries in our sample. Columns labelled "developed" and "developing" computes the corresponding correlations for the two groups of countries separately. The results show that the correlation between exchange rates and interest rates is low, on average. However, when the sample is broken into developed and developing countries, the correlation is consistently negative in developed countries and consistently positive in developing economies. Recall that 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 interest rate differential (or its first-difference) on a country-by-country basis. We then report the average of the slope coefficients from these regressions and its 95% confidence interval for the full sample and separately for developed and developing countries in the Panel B of Table 1. These regressions confirm our findings from the correlations: exchange rates and interest rates are

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(2004)). In what follows we also check for robustness of our results with respect to the regime classification (see Section 2.3).

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

[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), 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 can not reject the presence of a unit root in the levels of both interest rate and (log) exchange rate for 90 percent of all country-episode pairs in our sample. Unit root is rejected in *all* country-episode pairs at 10 percent significance level when both variables are in first-differences.

negatively correlated in industrial countries but positively correlated in developing countries. These results hold in both levels and first-differences and are highly statistically significant. Importantly, the confidence intervals for the slope coefficients in developed and developing countries do not overlap, indicating significant differences between them.

Table 1: Correlation between exchange rate and interest rate

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

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

2.2 Exogenous interest rate rules

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 exogenous interest rate rules, while in sub-section 2.4 we turn to endogenous interest rate rules. We estimate VARs on a country-by-country basis for our sample using log exchange rate and interest rate differential between home and the U.S..[10] Our VAR specification also includes a constant term.[11] We use the estimated VARs to calculate the impulse response of the exchange rate to an orthogonalized one standard deviation innovation in the interest rate differential for each country.[12] Following Eichenbaum and Evans (1995), we compute the impulse responses using the ordering: interest rate differential, exchange rate.[13]

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[10]The simple bi-variate specification allows us to use and draw inference from the largest possible sample of countries. In section 2.4 we extend our benchmark VAR specification to include a broader set of other macroeconomic variables, such as output, prices, inflation, risk-premium, etc. Due to data limitations, such an analysis can only be conducted for a much smaller sample of countries.

[11]We also tried a VAR specification with a trend and have found that the results remained largely unchanged.

[12]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.

[13]We conduct robustness checks with respect to the ordering of the variables in Section 2.5.

Figure 1: Country VARs: Impulse responses of exchange rate to interest rate shock
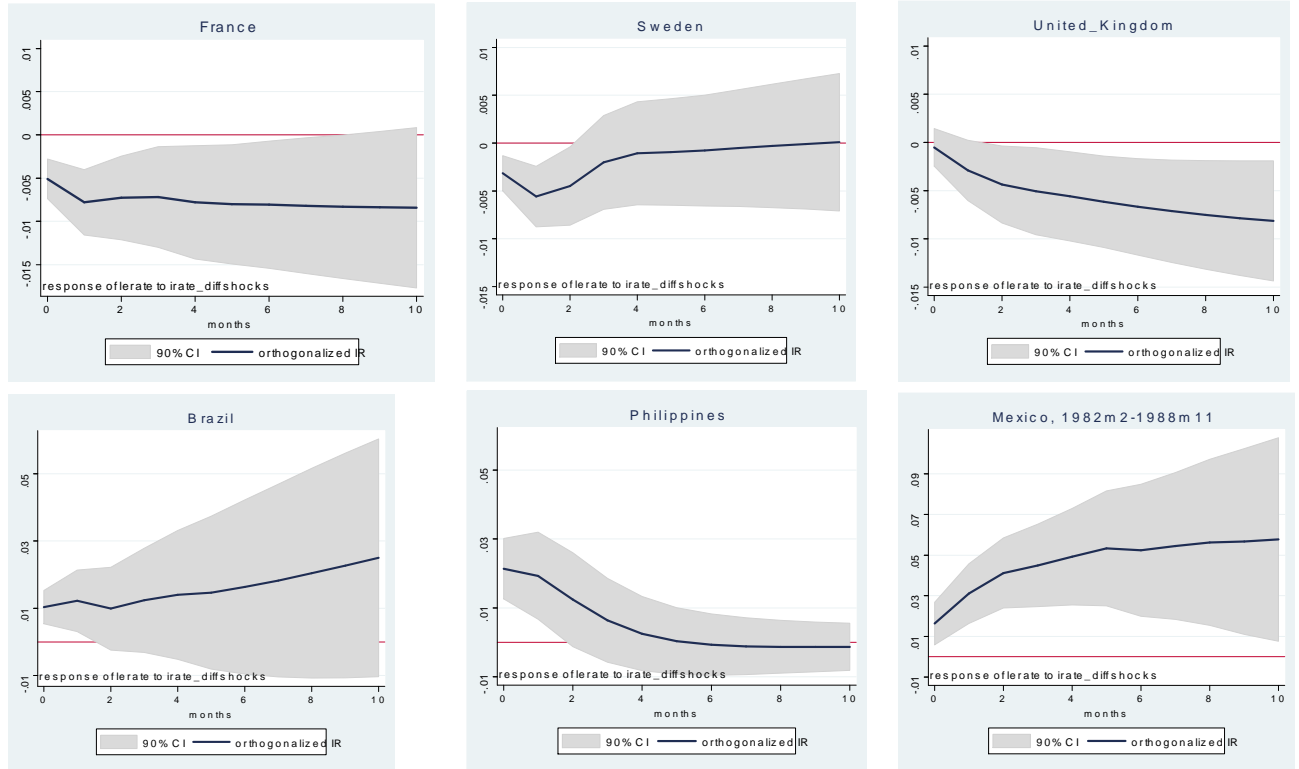
Note: These figures present impulse responses of exchange rate to a positive interest rate innovation from individual country VARs estimated on (log) exchange rate and interest rate differential between home and abroad. The following ordering is used: $i - i^{US}, E$.

We start by presenting the impulse responses of the nominal exchange rate to interest rate shocks in several selected countries in our sample to illustrate the more general data fact. Figure 1 presents the impulse responses in three developed and three developing countries. The picture reveals some systematic patterns. For the developed countries – France, Sweden and the UK – there is a significant appreciation of the currency in response to an increase in the interest rate differential. This is the well-known result of Eichenbaum and Evans (1995). For the developing group, the effect is the opposite. In Brazil, Mexico and Philippines, a positive innovation in the interest rate differential between home and the U.S. induces a significant depreciation of the currency.[14]

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.[15] We adopted several approaches to classifying a country as exhibiting appreciation: (i) if the response of its

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[14] 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), Eichenbaum and Evans (1995), among others). While there is ongoing debate as for the reasons for such "delayed overshooting" of exchange rates to monetary policy shocks (Faust and Rogers (2003), Bacchetta and van Wincoop (2010), Engel (2011)), our interest is in the immediate response of the exchange rate. Thus when presenting results, we focus on the immediate responses.

[15] One may be concerned that the use of a linear VAR specification is not warranted in countries that experienced large jumps in the level of the exchange rate or crisis episodes. We check the robustness of our results with respect to crisis episodes and periods of high inflation in Section 2.3.

exchange rate after an interest rate shock is negative on impact; (ii) if the response of its exchange rate to an interest rate shock is negative at the end of the 1st month; and (iii) if the response of its exchange rate to an interest rate shock is negative at the end of the 1st quarter (3rd month). Depreciation is defined similarly. Table 2 summarizes the results. Panel (a) reports the share of developed countries that have experienced appreciations and the share of developing countries that experienced depreciations of their exchange rates following a positive shock to the interest rate differential, based on level VARs.

Table 2: Individual country VARs: Summary

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

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

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

The results from the individual VARs estimated on the first difference of the (log) exchange rate and the interest rate differential are summarized in panel (b) of Table 2. They confirm our earlier findings. Among industrial economies, 84 percent have experienced exchange rate appreciation after an interest rate shock on impact, 88 percent still saw their currency appreciate after the 1st month and 52 percent did so by the end of the first quarter. For the developing countries, the corresponding numbers were 70 percent, 62 percent and 60 percent, respectively.[16]

We further confirm our empirical findings by running unrestricted, bivariate *panel* VARs for industrial and developing countries separately. We start with a simple specification in which both the (log) exchange rate and interest rate variables are included in levels. In the panel VAR analysis country heterogeneity is likely to be important due to the presence of unobservable individual country fixed effects. We eliminate country-specific

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

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.[17] An alternative transformation that eliminates the fixed effects is the first-difference transformation. We present the results from the panel VARs on the first-differenced data below.

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

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

Figure 2: Panel VAR: Impulse responses of exchange rate to interest rate shock (levels)
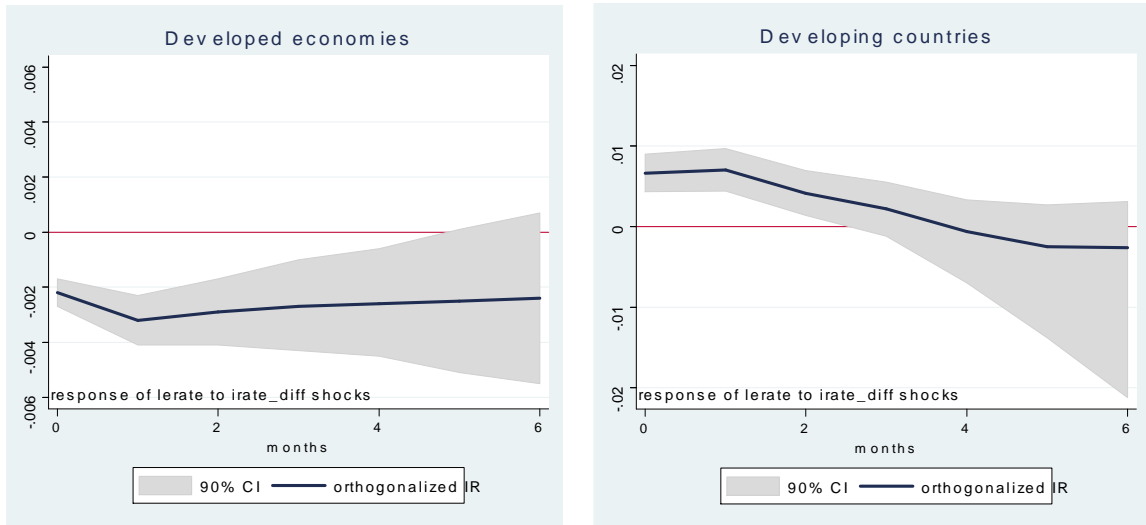
Note: Figures present the impulse responses of the exchange rate to a positive interest rate differential shock from panel VARs estimated for developed and developing countries. Estimation uses (log) exchange rates and interest rates in levels. Both series are de-meaned and linearly de-trended.

Figure 3 presents the resulting impulse responses from the model estimated in first-differences. As before,

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

the exchange rate appreciates in our sample of developed countries; and depreciates for developing countries, with the key difference being that these responses are more short-lived.

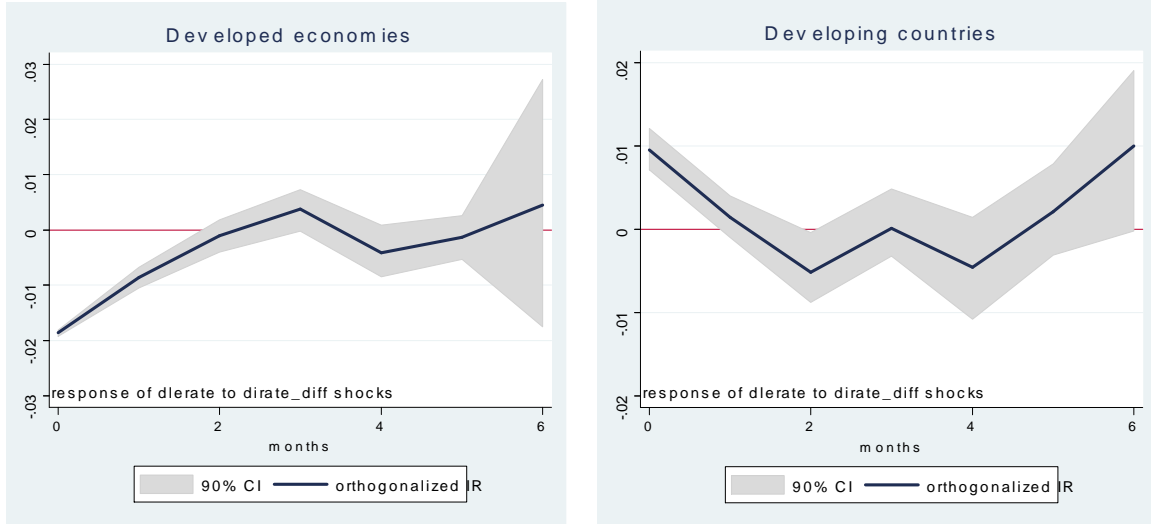Figure 3: Panel VAR: Impulse responses of exchange rate to interest rate shock (1st differences)

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

2.3 Exchange rate classification, crisis and high inflation episodes

How robust are our results with respect to the floating exchange rate classification we used? As we noted above, we used the definition of the floating exchange rate regime following Reinhart and Rogoff (2004) and the existing literature. This classification included, among others, the "freely falling" category consisting of (i) countries that have experienced inflation rates above 40 percent over the 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.[18] Table 3 reports correlation and regression results for this modified sample. As is easy to see, all results remain practically unchanged and highly significant.

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

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[18]Note that no industrial country is classified as "freely falling" in Reinhart and Rogoff (2004).

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

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

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

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.

2.4 Endogenous interest rate rules

One concern that may arise in the bivariate VAR specification we estimated above is related to endogeneity of interest rate and the exchange rate to various exogenous shocks, such as shocks to output, inflation, 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 here such rules are endogenous to economic conditions.

We begin by considering specifications in which monetary policy reacts to inflation. There are two specifications that are popular in the literature.

Specification (1): Price level shocks. First, following Eichenbaum and Evans (1995), for every country we estimate a three-variable VAR that includes its (log) consumer price index (CPI), its interest rate differential with the U.S., and its (log) exchange rate. To obtain orthogonalized impulse responses we use the same ordering as in Eichenbaum and Evans (1995): Price level, interest rate differential, exchange rate. The data on all three variables, however, is available only for a subsample of our countries. Thus, our subsample with CPI consists of 59 country-episode pairs, of which 17 are for developed economies and 42 are for developing countries. We find that our results remain robust under this extended model specification. As shown in panel (1) of Table 4, among developed countries, 82 percent exhibit a currency appreciation on impact after a positive interest rate innovation. In contrast, 76 percent of developing countries saw their currency depreciating on

impact after a positive interest rate shock. By the end of the first month, 82 percent of developed countries saw an appreciation of their currency, while 67 percent of developing countries experienced depreciations. By the end of the third month, the corresponding numbers were 82 percent and 74 percent. When estimated in growth rates, our VAR analysis suggests an impact exchange rate appreciation in 82 percent of developed countries and an exchange rate depreciation in 73 percent of all developing countries.

Specification (2): Inflation shocks. Second, we estimate another specification that is common in the literature using the inflation rate rather than the price level (see, for instance, Grilli and Roubini (1995, 1996)). Hence, we estimate a three-variable VAR that includes the domestic CPI *inflation rate* differential over the U.S. CPI inflation rate, the interest rate differential between home and the US, and the (log) exchange rate. We obtain orthogonalized impulse responses using the ordering: Inflation rate differential, interest rate differential, exchange rate. As can been seen in panel (2) of Table 4, under this specification, an orthogonalized interest rate shock leads to an impact appreciation of the exchange rate in 82 percent of all developed countries but a depreciation in 67 percent of developing countries. At the end of the first and third month, the corresponding numbers are 82 percent for developed countries and 69 percent for developing economies.[19]

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

Specification (4): Risk premium shocks. Another potential concern is 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. To account for such a possibility, we control for the risk-premium in the country VARs. 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.[20] We re-run our VARs and obtain orthogonalized impulse responses using the ordering: Risk-premium, interest rate differential, exchange rate. The proportions of appreciating developed countries and depreciating developing countries are reported in panel (4) of Table 4. An overwhelming majority of all industrial countries in our sample still see their exchange rate appreciating following shocks to the interest rate, even after controlling for changes in the risk-premium. In contrast, in the majority of developing countries in our sample, exchange

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[19]Note that we do not run this specification in first-differences since CPI inflation is already the first-difference of the log price level.

[20]Blanchard (2004) also uses Baa spread and shows that it is a good instrument for risk-premium in Brazil.

Table 4: Individual country VARs: Robustness

	(a). Levels			(b). First-differences		
	impact	1 month	3 months	impact	1 month	3 months
(1) With CPI level: $\ln P, i - i^{US}, \ln E$						
Industrial countries: appreciation	82%	82%	82%	82%	82%	52%
Developing countries: depreciation	76%	67%	74%	73%	65%	68%
(2) With inflation differential: $\pi - \pi^{US}, i - i^{US}, \ln E$						
Industrial countries: appreciation	82%	82%	82%	–	–
Developing countries: depreciation	67%	69%	69%	–	–
(3) With forward inflation differential: $\pi_{t+1} - \pi_{t+1}^{US}, i_t - i_t^{US}, \ln E_t$						
Industrial countries: appreciation	82%	82%	82%	–	–
Developing countries: depreciation	71%	69%	71%	–	–
(4) With risk-premium: $rp, i - i^{US}, \ln E$						
Industrial countries: appreciation	72%	84%	84%	–	–
Developing countries: depreciation	72%	72%	69%	–	–
(5) With output: $\ln y, i - i^{US}, \ln E$						
Industrial countries: appreciation	84%	89%	84%	–	–
Developing countries: depreciation	64%	73%	64%	–	–
(6) With output, inflation and risk-premium: $rp, \ln y, \pi_{t+1} - \pi_{t+1}^{US}, i - i^{US}, \ln E$						
Industrial countries: appreciation	91%	91%	91%	–	–
Developing countries: depreciation	70%	70%	80%	–	–

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

rates depreciate in response to interest rate shocks. We also use the Merryl Lynch High Yield Master II bond yield spreads to measure the risk-premium and find that the results remain robust.[21] Both series are available from the Board of Governors of the Federal Reserve System.

While using the Baa corporate bond spread allowed us to conduct the analysis on the largest possible sample of country-episode pairs, it is nevertheless just a proxy for country-specific risk-premium. We now examine how good a proxy the Baa spread is for country risk premium as well as the robustness of our results to alternative (country-specific) measures of risk-premium. For this we focus on a subset of countries in our sample for which we were able to obtain historical country credit default swap (CDS) spreads over their respective flexible exchange rate episodes.[22] This subsample includes Brazil, Mexico, South Africa, Thailand, Turkey, Indonesia, Iceland, Japan, Sweden, and United Kingdom. Our findings are supportive of using the Baa spread. First, CDS spreads are highly positively correlated with the Baa spread, with the average correlation

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

[22] CDS spreads are from Bloomberg.

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. The only exceptions were two developed countries: Japan, where the exchange rate response switched to a depreciation, and the UK, where the response switched to an appreciation when the CDS spread was used.[23]

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

Specification (6): All shocks. Finally, we estimate an extended VAR specification, where we include CPI inflation differential with the U.S., industrial production and risk-premium into the benchmark specification. We assume the following ordering for the variables: risk-premium, industrial production, inflation differential, interest rate differential, exchange rate. This identification strategy implies that innovations to interest rates have effects on domestic real activity, the inflation rate 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 variables percolates only with a lag. The ordering of the first three variables assumes that risk-premium shocks are the most exogenous.[25] The assumption that output shocks affect prices immediately is standard in the literature (see, for instance, Bernanke and Blinder (1992)).

Due to limited data availability, this extended VAR can only be estimated for 21 country-pairs, of which 11 are industrial country-pairs and 10 are developing country-pairs. The results for this VAR specification are

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[23]We also used J. P. Morgan's EMBI+ country spreads as a measure of risk-premium. For five developing countries for which the data was available (Brazil, Mexico, Nigeria, South Africa and Turkey) we found that the VAR results remained largely unchanged relative to the VARs with Baa spread.

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

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

presented in Panel (6). A shock to interest rate that is orthogonal to domestic output, the price level, and risk-premium, leads to currency appreciation on impact in 91 percent of developed countries, with the share remaining at 91 percent one month and three months following the shock. The corresponding numbers for developing countries are 70 percent, on impact, 70 percent after 1 month and 80 percent after 3 months.[26]

This extended VAR also allows us to examine the responses of output, inflation and risk-premium to monetary policy shocks to verify that the shocks we identified are indeed monetary policy shocks. We find that the rest of the variables show symmetric responses in developed and developing countries. In particular, we find that output falls in the majority of developed (55 percent) and developing (90 percent) following an increase in the interest rate. Inflation rate, however, increases after monetary policy tightening in the majority of developed (73 percent) and developing (80 percent) countries. Thus, there is evidence of "price puzzle" in both groups of countries. Lastly, risk-premium rises after the shock in both groups of countries, although the increase affects a greater number of and is longer-lived in developing countries. We re-examine these responses through the lens of the structural model in Section 5.

2.5   Simultaneity between interest rate and the exchange rate

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

To address this question we estimate a structural VAR (SVAR) in which we allow for a contemporaneous correlation between 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. This is a standard neutrality assumption that holds in a number of theoretical monetary models (see Clarida and Gali (1994)) and has been recently used in several empirical studies (see Bjørnland (2009)).[27] Thus, we estimate a structural VAR containing interest rate differential, $i - i^{US}$, and the first difference of the log real exchange rate $\Delta_t lrer$, imposing the long-run neutrality restriction described above.[28] We find that our results remain largely unchanged. Based on structural impulse responses, we find that 73 percent of all developing countries in our sample experienced impact depreciations following an interest rate shock, 69 percent depreciated 1 month after the shock while 55

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[26] We also estimate this extended VAR with CPI level rather than inflation rate and find very similar results.

[27] This restriction is also satisfied by the model we develop in this paper.

[28] We estimate the SVAR on the first differenced (log) real exchange rate so that, in the spirit of Blanchard and Quah (1989), the effects of the interest rate shock on the level of the exchange rate add up to zero. See Appendix A.2 for econometric details.

percent experienced depreciations 3 months after the shock. We do not interpret these results as necessarily suggesting that the contemporaneous feedback between interest rates and exchange rate is not important. Rather, we think that the exchange rate classification scheme of Reinhart and Rogoff (2004) that we used to identify flexible exchange rate countries, by being based on the de-facto exchange rate regime, allowed us to focus on the countries and episodes for which "fear of floating" was less of a concern.

Overall, based on the variety of samples and the battery of approaches, the evidence suggests that interest rates and exchange rates are negatively related in industrial countries. However, the relationship between the two variables is reversed for developing countries. We will refer to these contrasting findings in industrial versus developing countries as the "exchange rate response puzzle". This study, to the best of our knowledge, is the first to document the contrasting response of exchange rates to monetary shocks as a general feature of the data by using a large number of flexible exchange rate episodes in both developed and developing countries, and by using a variety of econometric approaches.

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 focus on 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 four developed 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) refines 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 the monetary policy shocks rather than appreciating as in the developed country sample of Zettelmeyer (2004). This evidence provides confirmation of the presence of the "exchange rate response puzzle" in higher frequency data as well.

3   The Model

The empirical results described above present a puzzle: why do developing countries respond differently to interest rate increases relative to developed countries? We develop a small-open economy model below to provide an explanation for the contrasting data patterns along these lines. The question that we examine below is whether differences in the specifics of the monetary transmission mechanism can account for the different responses of the exchange rate to monetary policy shocks in developed and developing countries.

Consider a small open economy that is perfectly integrated with the rest of the world in both goods and capital markets. It is populated by four types of agents: households, firms, banks and the government. The

infinitely-lived representative household receives utility from consuming a (non-storable) good and disutility from supplying labor. The world price of the good in terms of foreign currency is fixed and normalized to unity. Free goods mobility across borders implies that the law of one price applies. The representative firm combines capital and labor to produce final goods, and is subject to a working capital requirement. As a result, it must borrow from the banks. The representative bank acts as an intermediary between households and firms, but also lends to the government. The latter is comprised of a fiscal and monetary authority. We describe the problem of each agent next.

3.1 Households

Household's lifetime welfare is given by

$$V = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t, x_t\right), \tag{3.1}$$

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

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

Here σ is the intertemporal elasticity of substitution, $\nu - 1$ is the inverse of the elasticity of labor supply with respect to the real wage. These preferences are well-known from the work of Greenwood, Hercowitz, and Huffman (1988), which we will refer to as GHH.[29]

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

$$s_t = v\left(\frac{H_t}{P_t}\right) + \psi\left(\frac{D_t}{P_t}\right), \tag{3.2}$$

where P is the nominal price of goods in the economy, and s denotes the non-negative transactions costs incurred by the consumer. Let $h\ (= H/P)$ denote cash and let $d\ (= D/P)$ denote interest-bearing demand deposits in real terms. We assume that the transactions technology is strictly convex. In particular, the functions $v(h)$ and $\psi(d)$, defined for $h \in [0, \bar{h}]$, $\bar{h} > 0$, and $d \in [0, \bar{d}]$, $\bar{d} > 0$, respectively, satisfy the following properties:

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

---

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

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

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

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

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

$$\kappa_t = \kappa \left(I_t, k_{t-1} \right), \quad \kappa_I > 0, \kappa_{II} > 0, \tag{3.3}$$

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

$$I_t = k_t - (1 - \delta) k_{t-1}. \tag{3.4}$$

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

$$b_{t+1} + h_t + d_t + c_t + I_t + s_t + \kappa_t \tag{3.5}$$
$$= R b_t + w_t x_t + \rho_t k_{t-1} + \frac{h_{t-1}}{1 + \pi_t} + \left(\frac{1 + i_t^d}{1 + \pi_t} \right) d_{t-1} + \tau_t + \Omega_t^f + \Omega_t^b.$$

$1 + \pi_t = \frac{P_t}{P_{t-1}}$ denotes the gross rate of inflation between periods $t - 1$ and t. We define the nominal interest rate as

$$1 + i_{t+1} = R \mathbb{E}_t \left(1 + \pi_{t+1} \right). \tag{3.6}$$

Households maximize their lifetime welfare given by equation (3.1) subject to equations (3.2), (3.3), (3.4) and (3.5).

3.2 Firms

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

$$y_t = F \left(k_{t-1}, A_t l_t \right) = A_t k_{t-1}^\alpha l_t^{1-\alpha}, \tag{3.7}$$

with $\alpha > 0$, and A_t denoting the current state of productivity which is stochastic. l is labor demand. At the beginning of the period, firms observe shocks for the period and then make production plans. They rent

capital and labor. However, a fraction ϕ of the total wage bill needs to be paid upfront to workers. Since output is only realized at the end of the period, firms finance this payment through loans from banks. The loan amount along with the interest is paid back to banks next period.[30] Formally, this constraint is given by

$$N_t = \phi P_t w_t l_t, \quad \phi > 0, \tag{3.8}$$

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

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

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

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

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

Define

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

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

$$a_{t+1}^f + \Omega_t^f = R a_t^f + y_t - \rho_t k_{t-1} - w_t l_t \left[1 + \phi \left\{ \frac{1 + i_{t+1}^l - R \left(1 + \pi_{t+1} \right)}{R \left(1 + \pi_{t+1} \right)} \right\} \right]. \tag{3.9}$$

Note that $\phi \left\{ \frac{1 + i_{t+1}^l - R(1 + \pi_{t+1})}{R(1 + \pi_{t+1})} \right\} w_t l_t = \left\{ \frac{1 + i_{t+1}^l - R(1 + \pi_{t+1})}{R(1 + \pi_{t+1})} \right\} n_t$ is the additional resource cost that is incurred by firms due to the credit-in-advance constraint.[31]

The firm chooses a path of l and k to maximize the present discounted value of dividends subject to equations (3.7), (3.8) and (3.9). Given that households own the firms, this formulation is equivalent to the firm using the household's stochastic discount factor to optimize. The first order conditions for this problem are given by two static conditions and an Euler equation which is identical to the household's Euler equation. The two static conditions are standard – the firm equates the marginal product of the factor to its marginal cost. In the case of labor the marginal cost includes the cost of credit. This is proportional to the difference between the nominal lending rate and the nominal interest rate.

---

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

[31] We should note that the credit-in-advance constraint given by equation (3.8) holds as an equality only along paths where the lending spread $1 + i^l - R(1 + \pi)$ is strictly positive. We will assume that if the lending spread is zero, this constraint also holds with equality.

3.3 Banks

The banking sector is assumed to be perfectly competitive. The representative bank holds foreign real debt, d^b, accepts deposits from consumers and lends to both firms, N, and the government in the form of domestic government bonds, Z.[32] It also holds required cash reserves, θD, where $\theta > 0$ is the reserve-requirement ratio imposed on the representative bank by the central bank. Banks face a cost q (in real terms) of managing their portfolio of foreign assets. Moreover, we assume that banks also face a constant proportional cost ϕ^n per unit of loans to firms. This is intended to capture the fact that domestic loans to private firms are potentially special as banks need to spend additional resources in monitoring loans to private firms.[33] The nominal flow constraint for the bank is

$$
\begin{aligned}
N_t + Z_t - (1-\theta)\,D_t + P_t q_t - P_t d^b_{t+1} &= \left(1 + i^l_t - \phi^n\right) N_{t-1} + (1 + i^g_t)\,Z_{t-1} \\
&\quad - \left(1 + i^d_t\right) D_{t-1} + \theta D_{t-1} - P_t R d^b_t - P_t \Omega^b_t,
\end{aligned}
\tag{3.10}
$$

where i^g is the interest rate on government bonds. We assume that banking costs are a convex function of the foreign debt held by the bank: $q_t = q\left(d^b_{t+1}\right)$, and $q' > 0$, $q'' > 0$. The costly banking assumption is needed to break the interest parity condition between domestic and foreign bonds.[34]

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

$$
\Omega^b_t = \left[\frac{R(1+\pi_t)-1}{1+\pi_t}\right] \left[(1-\theta)\,d_{t-1} - n_{t-1} - z_{t-1}\right] + \frac{i^l_t - \phi^n}{1+\pi_t} n_{t-1} + \frac{i^g_t}{1+\pi_t} z_{t-1} - \frac{i^d_t}{1+\pi_t} d_{t-1} - q_t,
\tag{3.11}
$$

where we have used the bank's balance sheet identity: $P_t d^b_{t+1} = N_t + Z_t - (1-\theta)\,D_t$. Note that this is equivalent to setting the bank's net worth to zero at all times.

The representative bank chooses sequences of N, Z, and D to maximize the present discounted value of profits subject to equations (3.10) taking as given the paths for interest rates i^l, i^d, i^g, i, and the value of θ and ϕ^n. We assume that the bank uses the household's stochastic discount factor to value its profits. Note that i^g_{t+1}, i^l_{t+1} and i^d_{t+1} are all part of the information set of the household at time t.

The bank optimality conditions imply that we must have

$$
i^l_{t+1} = i^g_{t+1} + \phi^n,
\tag{3.12}
$$

$$
i^d_{t+1} = (1-\theta)\,i^g_{t+1}.
\tag{3.13}
$$

---

[32] Commercial bank lending to governments is particularly common in developing countries. Government debt is held not only as compulsory (and remunerated) reserve requirements but also voluntarily due to the lack of profitable investment opportunities in crisis-prone countries. This phenomenon was so pervasive in some Latin American countries during the 1980's that Rodriguez (1991) aptly refers to such governments as "borrowers of first resort". For evidence, see Rodriguez (1991) and Druck and Garibaldi (2000).

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

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

These conditions are intuitive. Loans to firms and loans to the government are perfect substitutes from the perspective of commercial banks up to the constant extra marginal cost ϕ^n of monitoring loans to private firms. Hence, equation (3.12) says that the interest rate charged by banks on private loans should equal the rate on loans to the government plus ϕ^n. For every unit of deposits held the representative bank has to pay i^d as interest. The bank can earn i^g by lending out the deposit. However, it has to retain a fraction θ of deposits as required reserves. Hence, equation (3.13) shows that at an optimum the deposit rate must equal the interest on government bonds net of the resource cost of holding required reserves.

3.4 Government

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

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

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

$$\bar{\tau} + \frac{1 + i^g_t}{1 + \pi_t} z_{t-1} = m_t + z_t - \frac{1}{1 + \pi_t} m_{t-1}. \tag{3.14}$$

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

$$\frac{M_{t+1}}{M_t} = 1 + \mu_{t+1}, \qquad M_0 \text{ given.} \tag{3.15}$$

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

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

The consolidated government (both the fiscal and monetary authorities) has three policy instruments: (a) monetary policy which entails setting the rate of growth of nominal money supply; (b) interest rate policy which involves setting i^g (or alternatively, setting the composition of m and z and letting i^g be market determined); and (c) the level of lump sum transfers to the private sector τ. Given that lump-sum transfers are exogenously-given, only one of the other two instruments can be chosen freely while the second gets determined through the government's flow constraint (equation (3.14)). Since the focus of this paper is on the effects of interest rate policy, we shall assume throughout that i^g is an actively chosen policy instrument. This implies that the

rate of money growth μ adjusts endogenously so that equation (3.14) is satisfied.

3.5   Resource constraint

By combining the flow constraints for the consumer, the firm, the bank, and the government (equations (3.5), (3.9), (3.11) and (3.14)) and using equations (3.7) and (3.8), we get the economy's flow resource constraint:

$$a_{t+1} = Ra_t + y_t - c_t - I_t - \kappa_t - s_t - q_t, \tag{3.16}$$

where $a = b + b^f - d^b$. Note that the right hand side of equation (3.16) is simply the current account.

3.6   Equilibrium relations

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

Given a sequence of realizations $A\left(s^t\right)$, $i^g\left(s^t\right)$, r and $\bar{\tau}$, an equilibrium is a sequence of state contingent allocations $\left\{c\left(s^t\right), x\left(s^t\right), l\left(s^t\right), h\left(s^t\right), d\left(s^t\right), k\left(s^t\right), b\left(s^t\right), b^f\left(s^t\right), d^b\left(s^t\right), n\left(s^t\right), z\left(s^t\right)\right\}$ and prices $\left\{P\left(s^t\right), \pi\left(s^t\right), i\left(s^t\right), i^d\left(s^t\right), i^l\left(s^t\right), w\left(s^t\right), \rho\left(s^t\right)\right\}$ such that (a) at the prices the allocations solve the problems faced by households, firms and banks; (b) factor markets clear; and (c) the government budget constraint (equation (3.14)) is satisfied.

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

$$\bar{\tau} = h_t - \left(\frac{1}{1 + \pi_t}\right) h_{t-1} + \theta \left(d_t - \frac{d_{t-1}}{1 + \pi_t}\right) + z_t - \left(\frac{1 + i_t^g}{1 + \pi_t}\right) z_{t-1}. \tag{3.17}$$

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

$$E_t = \frac{M_t}{L\left(i_{t+1}, i_{t+1}^g\right)}, \tag{3.18}$$

where we used $P_t = E_t$.[35] Using $1 + \pi_t = \frac{P_t}{P_{t-1}}$ one can substitute equation (3.18) into (3.17) to solve out for

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[35] The model's implications for the exchange rate and the price level are identical since the law of one price holds and there is only one traded good in the model. Hence, the predictions for the exchange rate also apply to the price level. This tight link though is easily broken under very small modifications of the basic structure of the model. As an example, introducing a non-traded good into the model while continuing to retain the flexible exchange rate assumption would immediately break the tight link between the exchange rate and the price level even though the predictions for the exchange rate in such an augmented

$1 + \pi_t$ in terms of nominal money supply and real money demand at date t. For any given policy rate i^g_{t+1}, the nominal interest rate i_{t+1} (and hence the expected inflation rate between t and $t + 1$) is then determined from the government budget constraint (3.17). From equation (3.18), knowledge of i^g_{t+1} and i_{t+1} are sufficient to determine the nominal exchange rate E_t at that date for a given M_t. Note that the rate of nominal money growth μ between dates t and $t + 1$ also gets determined at date from equation (3.14). Hence, M_{t+1} gets determined at date t.[36]

At this stage it is informative to clarify that our model does *not* embody the "*fiscal theory of the price level.*" As is well-known, the fiscal theory of the price level is a specification in which the monetary authority sets (targets) the nominal interest rate on a pure bond (i.e., a bond with no liquidity properties) and the price level is determined through an intertemporal equilibrium condition in such a way as to make the real value of government debt consistent with intertemporal equilibrium. We do *not* have such a specification. Instead our's is more an "*unpleasant monetarist arithmetic*" argument wherein an exogenous government spending path renders the money growth path endogenous. This makes the rate of inflation endogenous which ties down the nominal interest rate. The price level (which is also the exchange rate in this model) is then tied down from the money market equilibrium condition since money demand is determined once the nominal interest rate is known.

From equations (3.17) and (3.18) 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.[37]

4 Calibration

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

Our basic approach is to keep the majority of the parameters of the model common to both sets of countries. The parameters that we calibrate separately for developed and developing countries are those that control the

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model would remain exactly the same as here. Clearly, the model's predictions for the exchange rate would not be the same as those for the price level under even small perturbations in the environment.

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

[37] In this paper we focus on the time series behavior of this model. Elsewhere, in Hnatkovska, Lahiri, and Vegh (2013) we examine the cross-sectional steady state properties of a simplified, deterministic version of this model without capital.

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 to focus on here.[38]

We calibrate the model to match the properties of the two groups of countries. The benchmark parameterization for the developed countries group utilizes data for 6 industrial economies – Australia, Canada, Netherlands, New Zealand, Sweden and UK – during the period 1974-2010. For developing countries we use the data for Argentina, Brazil, Korea, Mexico, Philippines, and Thailand for the same 1974-2010 period. When focusing on nominal variables, i.e. nominal interest rates, we restrict the sample to the 1998-2010 period to eliminate the periods of high interest rate volatility and high inflation in developing countries before and during the East Asian crisis. Detailed data description and data sources are discussed in the Appendix A.3. The model calibration is such that one period in the model corresponds to one quarter.

4.1 Functional forms and parameters

We assume that the capital adjustment cost technology is given by

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

with ξ being the level parameter.

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

$$s_\varkappa \left(\varkappa^2 - \lambda_\varkappa \varkappa + \left(\frac{\lambda_\varkappa}{2} \right)^2 \right), \tag{4.19}$$

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

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

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

where $d_{t+1}^b = \frac{N_t + Z_t - (1-\theta)D_t}{P_t}$. Here γ is a constant and $\bar{d}^b$ is a steady state level of banks' debt to GDP ratio. It is instructive to note that as the marginal banking cost becomes larger the bank will choose to keep its

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[38] 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 price considerations and instead stick to 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.

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

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 Perri (2005) and Mendoza (1991).[39] In particular, we set the coefficient of relative risk aversion, σ, to 5, while the curvature of the labor, υ, is set to 1.6. This value is within the range of values used in the literature.[40] This implies the elasticity of labor demand with respect to real wage, $\frac{1}{\upsilon-1}$, equal to 1.67, consistent with the estimates for the U.S. Labor weight parameter ζ in the utility function is chosen to match the average working time of 1/5 of total time and is set to 2.48. Subjective discount factor, β, is set to 0.97, as in Uribe and Yue (2006). Capital income share, α, is chosen to be equal to 0.38, while a depreciation rate for capital, δ, of 4.4% per quarter. Capital adjustment costs parameter ξ is calibrated to replicate the volatility of investment relative to the volatility of output in our sample. Table 5 summarizes calibration for parameters that are common across the two groups of countries.

Table 5: Benchmark parameter values: Common across countries

	PARAMETER	VALUE
PREFERENCES		
discount factor	β	0.97
risk-aversion	σ	5
labor curvature	υ	1.6
labor weight	ζ	2.48
TECHNOLOGY		
capital income share	α	0.38
depreciation rate	δ	0.044
share of wage-in-advance	ϕ	0.15
capital adjustment costs	ξ	4.5
banks cost technology	γ	100

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 θ determines the reserve requirement ratio in the model and is calibrated to match the observed reserve requirements in each group of countries. We measure reserve requirements in the data following Brock (1989), who computes reserve requirements as the ratio of monetary base less currency outside banks to M2 less currency outside banks. This gives us θ equal to 0.03 in developed countries and 0.10 in developing economies over our sample period. The reserve requirement ratio θ, together with $s_\varkappa$ and $\lambda_\varkappa, \varkappa = \{h, d\}$, jointly determine the level of money demand in the model. We calibrate them to match several targets.

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[39]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.

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

Table 6: Benchmark targets and parameter values: Country-specific

	DEVELOPED	DEVELOPING
DATA TARGETS		
reserve requirement ratio	0.03	0.10
M1/GDP	0.20	0.10
Deposits/Cash	4	1
Cash interest elasticity	-0.04	-0.04
Bank reserves interest elasticity	-0.04	-0.04
Net lending/borrowing by the general government/GDP	-0.013	-0.021
Spread of nominal lending rate over money market rate	0.05	0.09
Net foreign assets/GDP	-0.26	-0.33
MODEL PARAMETERS		
θ : reserve requirement	0.03	0.10
$s_\varkappa, \varkappa = \{h, d\}$: transaction cost	$s_h = 24.55, s_d = 0.097$	$s_h = 100, s_d = 4.8$
$\lambda_\varkappa, \varkappa = \{h, d\}$: transaction cost	$\lambda_h = 0.244, \lambda_d = 1.303$	$\lambda_h = 0.125, \lambda_d = 0.138$
τ : lump-sum transfers	1.3% of GDP	2.1% of GDP
ϕ^n : per unit loans costs	0.05	0.09
$\bar{d}^b$: debt to GDP ratio	-0.26	-0.33

First, we match the average ratios of M1 to GDP in the data equal to 20% in developed countries and 10% in developing economies. Second, we match the relative size of deposits to currency in circulation in the data equal to 1 in developing countries and 4 in industrial economies. 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).[41] 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).[42]

The lump-sum transfers paid by the government to the private sector, τ, are measured as the net lending/borrowing by the general government as a share of GDP. Over our sample period, this ratio is equal to -1.3% in developed economies, and -2.1% in developing countries.

It is important to note that the differences in the moments between developed and developing countries that we relied on so far to calibrate our key parameters are systematic. For instance, all developing countries in our calibration sample have higher reserve requirement ratios, lower ratios of M1 to GDP, lower ratios of deposits to cash, and larger negative fiscal imbalances.[43] 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

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[41] Mulligan 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.

[42] Total total 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.

[43] The only exception is Korea, whose fiscal balance to GDP ratio is positive, on average.

countries.

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

Lastly, we calibrate parameters γ 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.[44] The proportional cost parameter ϕ^n 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.[45]

4.2 Calibration of the shock processes

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

We assume that productivity, $\hat{A}_t$, in both developed and developing countries is an independent AR(1) process with autoregressive coefficient, ρ_A, equal to 0.95. The innovations, ε^A, to this process are assumed to

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[44] In fact, we restrict γ to be the same in the two groups of countries to reduce the number of the free parameters. The resulting banking costs, q, in the steady state are very small, equal to less than 0.00086% of GDP.

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

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

$$i^g_{t+1} = \rho_g i^g_t + \varepsilon^g_{t+1}, \tag{4.20}$$

with ε^g_{t+1} – i.i.d. normal innovations.[46] While this rule is not very realistic, it allows us to flesh out the mechanism of the model.

(ii) Taylor rule: The second rules 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:

$$i^g_{t+1} = \rho_g i^g_t + \alpha_1 \left(\pi_t - \pi^* \right) + \alpha_2 y^{gap}_t + \varepsilon^g_{t+1}, \tag{4.21}$$

with ε^g_{t+1} – i.i.d. normal innovations, as before. y^{gap} is output gap, measured as the deviation of industrial production in a given country from its Hodrick-Prescott trend.[47] π_t is inflation measured as the (annualized) CPI growth rate, while π^* 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:

$$i^g_{t+1} = \rho_g i^g_t + \alpha_1 \mathbb{E}_t \left(\pi_{t+1} - \pi^* \right) + \alpha_2 y^{gap}_t + \varepsilon^g_{t+1}. \tag{4.22}$$

$\mathbb{E}_t \left(\pi_{t+1} - \pi^* \right)$ is measured as the one period ahead forecast of inflation from the VAR estimated on (log)

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[46] 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.

[47] If industrial production at quarterly frequency was not available, we used GDP volume instead.

output, inflation and policy interest rate for each country in our calibration sample.

We conduct the estimation of the equations above separately for a panel of developed and developing countries. 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.[48]

Table 7: Estimated interest rate rules

| | Developed countries | | | Developing countries | | |
| | Exogenous | Generalized Taylor | IFB | Exogenous | Generalized Taylor | IFB |
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
i_t^g	0.982***	0.918***	0.897***	0.959***	0.684***	0.876***
	(0.007)	(0.018)	(0.024)	(0.023)	(0.086)	(0.059)
y_t^{gap}		0.054***	0.069***		0.116***	0.063***
		(0.012)	(0.013)		(0.031)	(0.019)
$\pi_t - \pi^*$		0.076***			0.382***	
		(0.026)			(0.138)	
$\mathbb{E}_t(\pi_{t+1} - \pi^*)$			0.107***			0.128***
			(0.030)			(0.075)
$\sigma(i^g)$	1.416			5.209		
$\sigma(\varepsilon_{t+1}^g)$	0.479	0.407	0.405	2.150	1.470	0.754

Note: Column (i) and (iv) present estimation results for equation (4.20); columns (ii) and (v) are for equation (4.21), while columns (iii) and (vi) are for equation (4.22). We obtain y^{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 $\sigma(i^g)$ and $\sigma(\varepsilon_{t+1}^g)$ report standard deviations of interest rate and innovations to interest rates, repectively. Robust standard errors are in parentheses. *,**, and *** indicate significance at 10%, 5%, and 1%, respectively.

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 loading on inflation, either contemporaneous or expected future, tends to be somewhat higher in developing countries, while the loadings on output are comparable in the two groups of countries. These results are comparable 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. Laxton and Pesenti (2003) confirm their results for emerging market economies. Our estimates are also in line with Clarida, Galí, and Gertler (2000).

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 labelled $\sigma(i^g)$ in Table 7).[49] The same differences extend to the volatility of innovations to interest rates in the two countries (row labelled $\sigma(\varepsilon_{t+1}^g)$). For instance, we get $\sigma(\varepsilon_{t+1}^g) = 0.48\%$ in developed countries and $\sigma(\varepsilon_{t+1}^g) = 2.15\%$ in developing countries in the simple exogenous rule, on average.[50]

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[48] 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.

[49] 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.

[50] We also estimated country-specific processes for i^g, and found them to be along the lines of the aggregate estimates.

Once the shock processes and other parameter values are set, we solve the model by linearizing the equations characterizing equilibrium around the steady state and solving the resulting system of linear difference equations.[51]

5 Results

We simulate the two versions of the model calibrated for developed and developing countries for a sequence of random productivity and interest rate shocks and compute the key business cycles moments. We find that the model replicates the higher volatility of output, interest rates and net exports in developing countries. It also predicts procyclical consumption, investment, and employment; and countercyclical net exports (more so in developing countries), all of which are consistent with the data for the two groups of countries. The model also produces a negative correlation between policy rates and output in developing countries, but close to zero correlation in developed economies, which is again consistent with the data patterns. The contrast of data moments in developed and developing countries can be found in Neumeyer and Perri (2005).

We next turn to the relationship between interest rate and the exchange rate. We compute the level of nominal exchange rate in the model as follows. First, from the money market equilibrium condition in conjunction with PPP, $M_0/E_0 = m^d(i_1^g, i_1)$, 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, π_t, predicted by the model. Clearly, the exchange rate is non-stationary in our model. We transform E_t into stationary terms by dividing it by the model-implied M_t. This is a standard transformation used in the literature to normalize nominal non-stationary variables in monetary models. 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 4 presents impulse responses of the exchange rate to a temporary positive one standard deviation shock to the policy-controlled interest rate i^g in the model under the three interest rate rules: exog (the exogenous rule in equation (4.20)); GT (the Generalized Taylor rule in equation (4.21)); and IFB (the Inflation-Forecast-Based rule in equation (4.22)). Panel (a) is based on the model parameterized for a developed country, while panel (b) is for the model calibrated to a developing country. We also report the impulse responses of the market interest rate, i, to the same i^g shock in developed and developing countries on Figure 4. Note that the response of i also illustrates the response of expected inflation through equation (3.6).

For developed countries, the model predicts an impact appreciation of the exchange rate under all three policy rules.[52] For instance, a one standard deviation increase in i^g is associated with a 0.02% appreciation of the exchange rate on impact in developed countries and a 0.06% depreciation of exchange rate on impact

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

[52]The fact that exogenous and endogenous policy rules produce the same qualitative exchange rate responses is not surprising, since the impact response of exchange rate should be the same under the two types of rules.

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

Panel (a). Developed countries

Panel (b). Developing countries
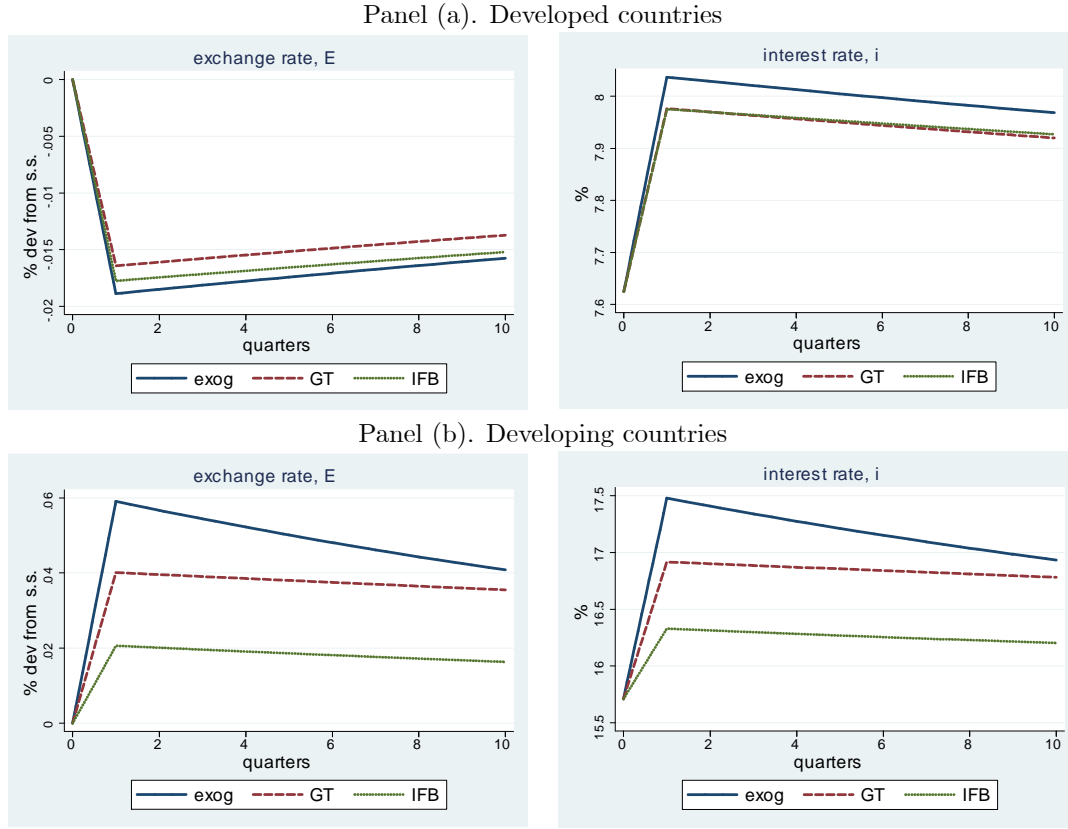
Note: The left panels present the responses of nominal exchange rate to a 1 std. dev. positive shock to policy-controlled interest rate, i^g, under three interest rate rules: exog–exogenous rule given in equation (4.20); GT–Generalized Taylor rule given in equation (4.21); and IFB–Inflation-Forecast-Based rule given in equation (4.22). The right panels show the response of the market interest rate, i, to the same shock. Panel (a) presents impulse responses from the model calibrated to developed countries, while panel (b) does the same for developing countries.

in emerging market economies under an exogenous interest rate rule. When endogenous interest rate rules are considered, the model predicts smaller appreciation in developed countries and smaller depreciation in developing countries. These differences in the quantitative responses of the exchange rate are primarily due to differences in the estimated persistence and size of shocks in the three interest rate rules. Note that these responses not only match the signs of the empirical impulse responses, but are also in line with the quantitative estimates of those responses in Figures 1 and 2.

The impulse responses in Panels (a) and (b) of Figure 4 highlight the inherent non-monotonicities in the relationship between interest rates and the exchange rate present in our model. They show that both the policy-controlled interest rate i^g and the market interest rate i show opposing correlations with the nominal exchange rate in developed and developing countries. Note that the impulse responses show a positive comovement between i and E in developing countries but a negative comovement in developed countries.[53]

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[53]Following the shock, the market interest rate remains above it's steady state value for a prolonged period of time in both

It is important to note from Figure 4 that the market interest rate, i, increases after the shock to i^g in both countries. This reflects the fact that under our calibration, the expected inflation rate responds similarly to i^g shocks in both groups. Hence, the different impact responses of the level of the exchange rate are not due to differences in the response of expected inflation. This is consistent with the empirical results we presented in Section 2.4 where the opposing responses of the exchange rate to interest rate shocks arose even after controlling for shocks to the expected inflation rate.

5.1 Under the hood

So what is behind the contrasting response of the exchange rate in developed and developing countries? Since our empirical results are similar for both endogenous and exogenous interest rate rules, in what follows we flesh out the effects of policy interest rate shocks in the model by focusing on the exogenous interest rate rule case.

To build intuition for the results, consider a perfect foresight version of the model. In addition, assume that $\gamma \approx \infty$ so that banking costs are infinitely large. In this case the banking sector will hold a constant amount of foreign assets, i.e., $d^b = \bar{d}^b$. From expression (3.18), the exchange rate at any date t is determined by $E_t = \frac{M_t}{h_t + \theta d_t}$, which is just a rewritten version of the money market equilibrium condition. Clearly, for a given M_t, the effect of changes in i^g on E depends on the effect that changes in i^g have on h and d.

The optimality conditions for cash and deposits holdings along with the definition for the nominal interest rate under perfect foresight, $1 + i_{t+1} = R\left(1 + \pi_{t+1}\right)$, yield the equilibrium cash and deposit demands in the model as

$$h_t = \tilde{h}\left(\frac{i_{t+1}}{1 + i_{t+1}}\right) \qquad \text{and} \qquad d_t = \tilde{d}\left(\frac{i_{t+1} - (1 - \theta)\, i_{t+1}^g}{1 + i_{t+1}}\right), \qquad (5.23)$$

where both functions are decreasing in their arguments.[54] Clearly, a rise in i^g positively affects E by increasing the demand for deposits d. This is the *direct* effect of i^g on E. However, i^g also affects E *indirectly* through its effect on the market interest rate, i, since i affects the demand for both cash and deposits. The effect of i^g on i in turn is determined from the government flow budget constraint

$$\bar{\tau} + \frac{1 + i_t^g}{1 + \pi_t} z_{t-1} = h_t - \frac{h_{t-1}}{1 + \pi_t} + \theta d_t - \frac{\theta d_{t-1}}{1 + \pi_t} + z_t, \qquad (5.24)$$

where $z = (1 - \theta)\, d - n + \bar{d}^b$ (assuming $\gamma \approx \infty$). The left hand side of equation (5.24) gives total expenditures while the right hand side gives net revenues.[55]

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

[54]Derivations are provided in Appendix A.4.

[55]Note equation (5.24) can be rewritten as a first order difference equation in i_{t+1} and i_t. The standard condition for a unique flexible price monetary equilibrium is that the difference equation in i be unstable. We impose it through out. It can be verified that this stability condition also implies government revenues are increasing in the nominal interest rate i.

There are three indirect channels through which changes in i^g affect i. The first operates through the government budget constraint (5.24). Specifically, an increase in i^g directly increases the cost of servicing government bonds z tomorrow, which increases the future fiscal burden and hence the required inflation rate. This is due to the "fiscal" effect. Second, a rise in i^g raises the lending spread $i^l - i$. A higher lending spread $i^l - i$ lowers the amount of private loans, n, for a given level of demand deposits, and thereby raises commercial bank loans to the public sector, i.e., z rises. This reduces the reliance on inflationary finance today but raises the future fiscal burden through a higher base level of debt. This effect arises as a consequence of the "output" effect. Third, a higher i^g lowers the deposit spread $i - i^d$ which raises demand deposits with commercial banks. For a given level of private loans, this reduces the reliance on inflationary finance today to finance government spending. This effect arises due to the "liquidity demand" effect. These effects impact the inflation rate that is required to finance the government budget and thereby affect the market nominal interest rate i. The changes in i, in turn, feedback to the demand for cash as well as deposits and loans through their effect on the deposits and lending spreads (see equations (5.23), (3.13) and (3.12)). These indirect effects determine the end impact of i^g on money demand, and therefore, on the level of the exchange rate.

We illustrate these effects by plotting the impulse responses of various variables to a positive shock to i^g. To facilitate the comparison across developed and developing countries calibrations we use the same size of the shock (equal to developed country standard deviation of i^g) in both calibrations. Also, since the steady states are different in the two calibrations, we present all impulse responses as deviations from the steady state (multiplied by 100). We choose to present results in terms of the absolute changes in h and d since the effect on the nominal exchange rate depends on whether the $m = h + \theta d$ rises or falls in absolute terms. Results are in Figure 5.

Panel (a) of Figure 5 shows that deposits rise in both groups in response to an increase in i^g. Crucially though, deposits respond much more in developed countries. This is due to a larger steady state value of d in that group of countries.[56] We return to this issue below. Panel (b) shows that output falls symmetrically on impact in both groups. This is to be expected since we set the wage-in-advance parameter ϕ to be the same in both the developed and developing groups.[57] The response is more long-lived in developed countries due to a higher persistence of the process for i^g in that group of countries.

Panel (c) of Figure 5 shows that government bond holdings of commercial banks rise in both groups of countries but much more sharply in developed economies. This is due to the fact that deposit demand increases more in developed than in developing countries, while the fall in loan demand is symmetric across the two countries. Hence, banks' demand for government bonds rises by more in industrial economies, as they seek to rebalance their portfolios. Panel (d) shows that the response of inflation, π, is practically symmetric in

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[56] With matching interest rate elasticities of bank reserves in the developed and developing countries in our calibration, a given interest rate change is associated with a larger change in deposit demand in developed economies where the steady state level of deposits is higher.

[57] Note that the loan to output ratio is $\frac{\phi wl}{y}$. Under the Cobb-Douglas specification for technology, $\frac{wl}{y} = 1 - \alpha$ is the same for both groups. Hence, under our maintained parameterization of a common ϕ, the loan-output ratio is the same across countries. This is the reason for the symmetric output effect on impact for developed and developing countries in Figure 5. We investigate the robustness of our results with respect to this parameter in Section 5.2 below.

the two groups of countries. This is due to the offsetting effects to the government budget of the higher cost of servicing existing government bonds and the additional infusion of funds to the budget through higher d_t and new government bond issuances z_t. Notice that the magnitude of these effects are larger for developed countries but enter in offsetting ways in the government budget constraint. Hence, the net effect is very similar for the two sets of countries. The symmetric inflation effect implies that the increase in i is also symmetric in developed and developing countries.

The rise in the market interest rate i reduces the demand for cash in both groups of countries, since a rise in i unambiguously increases the opportunity cost of holding cash. This effect is larger for developed countries due to a larger steady state value of h in that group (see panel (e) of Figure 5).[58] An increase in i also raises the opportunity cost of holding deposits which partially offsets the increase in deposits arising from the direct effect of higher i^g. Finally, aggregate money demand shows opposing responses in the two countries: the indirect effect of lower cash and deposits demand from higher i swamps the direct effect on deposits from higher i^d in developing countries, but it is not strong enough to overturn the direct effect in developed countries. As a result, the nominal exchange rate appreciates in developed countries while depreciating in developing countries. This is illustrated in panel (f) of Figure 5.

From the perspective of understanding the difference between developing and developed economies in their exchange rate responses to interest rate shocks, the preceding discussion illustrates that the key lies in uncovering the reason for the differing responses of real money demand m. It is instructive then to differentiate $m = h + \theta d$ with respect to i^g to get

$$\frac{dm}{di^g} = \left[\tilde{h}' \frac{\partial I}{\partial i} + \theta \tilde{d}' \frac{\partial I^d}{\partial i} \right] \frac{\partial i}{\partial i^g} + \theta \left(1 - \theta\right) \tilde{d}' \frac{\partial I^d}{\partial i^d}.$$

Here we denote $\frac{i}{1+i} = I$ and $\frac{i-i^d}{1+i} = I^d$.

Noting that $\frac{\partial I}{\partial i} = \frac{1}{(1+i)^2}$ and $\frac{\partial I^d}{\partial i} = \frac{1+i^d}{(1+i)^2}$, the expression above can be rewritten as

$$\eta_m = \eta_i \left[-\eta_h \frac{h}{m} \left(\frac{1}{1+i} \right) - \eta_d \frac{d}{m} \left(\frac{1+i^d}{i-i^d} \right) \left(\frac{i}{1+i} \right) \right] + \eta_d \frac{d}{m} \left(\frac{i^d}{i-i^d} \right) \tag{5.25}$$

where $\eta_h = -\tilde{h}' \frac{I}{h} > 0$, $\eta_d = -\theta \tilde{d}' \frac{I^d}{d} > 0$, $\eta_i = \frac{\partial i}{\partial i^g} \frac{i^g}{i}$, $\eta_m = \frac{dm}{di^g} \frac{i^g}{m}$. Notice that from panel (d) of Figure 5, our calibration yields $\eta_i > 0$ since inflation always responds positively to an increase in i^g in both groups of countries. Hence, if the RHS is positive, i.e., the last term dominates, then $\eta_m > 0$ and m rises with i^g leading to E appreciation, else there is a depreciation.

Our steady state calibration sets $\eta_h = \eta_d$ and $\eta_h(emerging) = \eta_h(developed) = \eta_h^{ss}$, i.e., these elasticities

Figure 5: Impulse responses following 1 std dev shock to i^g
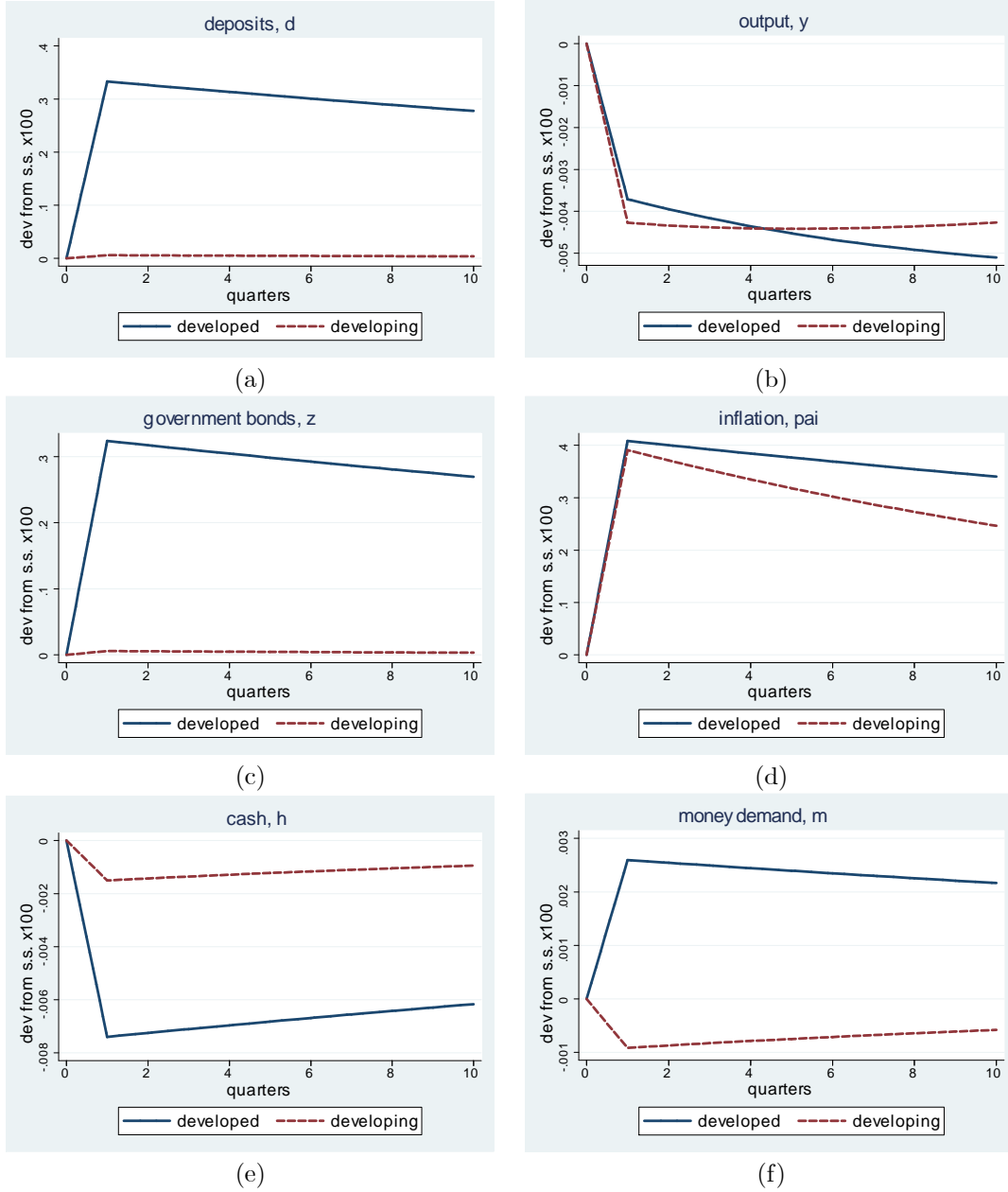
Note: The figures present the responses of various variables to a 1 std. dev. positive shock to policy-controlled interest rate, i^g, in the versions of the model calibrated to developed and developing countries. The shock is set to be the same in the two groups of countries equal to the std. dev. of i^g in developed economies. All responses are presented in deviation from the steady state multiplied by 100.

are the same across countries.[59] Hence, around the steady state we can write η_m as

$$\eta_m^{ss} = \frac{\eta_h^{ss}}{1+i}\left[\frac{d}{m}\frac{i^d}{I^d}\left\{1 - \left(\frac{1+i^d}{i^d}\right)\left(\frac{i}{1+i}\right)\eta_i^{ss}\right\} - \eta_i^{ss}\frac{h}{m}\right]$$

[59]This assumption both helps and hurts the prospects of the exchange rate appreciating in response to an increase in i^g. The higher deposit base in developed countries along with identical deposit elasticities implies a bigger positive effect on d in developed countries. However, the higher cash base in developed countries along with the same cash elasticity of demand also implies a larger fall in h in developed countries in response to the higher i that is induced by a rise in i^g. This makes the negative effect also stronger. Hence, the effect of this assumption on m and therefore on E is ambiguous.

Let $\left(\frac{d}{h}\right)_{developed} = \gamma^d$ and $\left(\frac{d}{h}\right)_{emerging} = \gamma^e$. Hence, depreciation in developing countries must be due to the fact that

$$\gamma^e \frac{i^d}{I^d} \left\{ 1 - \left(\frac{1+i^d}{i^d}\right) \left(\frac{i}{1+i}\right) \eta_i^{ss} \right\} < \eta_i^{ss}, \tag{5.26}$$

while the appreciation in developed economies is because

$$\gamma^d \frac{i^d}{I^d} \left\{ 1 - \left(\frac{1+i^d}{i^d}\right) \left(\frac{i}{1+i}\right) \eta_i^{ss} \right\} > \eta_i^{ss}. \tag{5.27}$$

Equations (5.26) and (5.27) highlight the key features of domestic money demand that are *directly* at play in determining the effect of an increase in i^g on the nominal exchange rate.[60] The first is the deposits-to-cash ratio in emerging and developed economies as measured by γ^e and γ^d, respectively. Notice that in our calibration $\left\{ 1 - \left(\frac{1+i^d}{i^d}\right) \left(\frac{i}{1+i}\right) \eta_i^{ss} \right\} > 0$ in both developed and developing countries. Therefore, the higher the $\frac{d}{h}$ ratio the more likely that the country will exhibit an appreciation in response to the same interest rate increase. Intuitively, a higher $\frac{d}{h}$ ratio implies that the same increase in i^g will lead to a larger rise in d. Effectively, a higher $\frac{d}{h}$ ratio makes the "liquidity demand" effect stronger.

The second factor is the magnitude of the nominal interest rate i. The lower the level of i the greater are the left hand sides of equations (5.26) and (5.27) and hence, the more likely that the currency will appreciate in response to an interest rate increase. The steady state level of the nominal interest rate i depends on the steady state level of inflation which, in turn, depends on the government's financing needs. This depends on three factors: the money base m, the fiscal spending τ and the amount of outstanding government bonds z. To see this note that the government budget constraint (equation (3.14)) in steady state reduces to $\frac{\bar{\tau}}{y} + \left(\frac{i^g - \pi}{1+\pi}\right) \frac{z}{y} = \left(\frac{\pi}{1+\pi}\right) \frac{m}{y}$ 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 π to finance a given amount of government spending. Similarly, the lower is the fiscal spending to GDP ratio $\frac{\tau}{y}$, the lower is the required π to finance the budget. Lastly, note that the impact of the "output" effect on π comes through z since government bonds are linked to loans to the private sector n through the commercial bank balance sheets. A higher ϕ raises private sector loans which reduces z. Since $i^g < \pi$ under our baseline calibration, this necessitates a higher π in order to finance government spending.

The preceding discussion makes clear that all else equal, the likelihood of a currency depreciation increases with higher government spending τ (the *fiscal effect*), with a higher credit constraint parameter ϕ (the *output effect*), and with either a lower $\frac{d}{h}$ ratio or a lower $\frac{m}{y}$ ratio (the *liquidity demand effect*). In our baseline calibration (based on data numbers), $\frac{\tau}{y}$ is set at 0.013 for emerging economies and 0.021 for developed countries thereby making a depreciation more likely for emerging countries. Similarly, our quantitative model also implies a stronger liquidity demand effect for developed countries since we have $\gamma^e = 1$ and $\frac{m}{y} = 0.10$ for emerging economies and $\gamma^d = 4$ and $\frac{m}{y} = 0.20$ for developed countries. This too makes it more likely for the

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[60]The steady state elasticity term η_i^{ss} too is clearly important. However, it is second order since it is an indirect effect that works off the response of inflation to a change in the policy rate in the new steady state. In fact our quantitative results imply that η_i^{ss} is similar for the two groups since the inflation effect is quite symetric (see panel (d) of Figure 5).

model to generate depreciations for emerging economies. Lastly, recall that we have kept the wage-in-advance parameter ϕ the same across the groups. Hence, the output effect is not directly impacting the results in either direction. To the extent that the output effect may be stronger in developing countries, potentially through higher reliance of private firms on bank's finance in those countries, there will be an even more pronounced tendency for their exchange rate to depreciate following rises in i^g.

5.2 Counterfactual experiments

So how important are these three channels individually for the quantitative results? More specifically, would changing the relative strengths of any one of these margins change the result on whether the currency appreciates or depreciates? To examine this, we now carry out a sequence of counterfactual experiments. Specifically, we sequentially vary one out of the four factors $\tau, \phi, \frac{d}{h}, \frac{m}{y}$ while keeping the other three factors unchanged and examine the effect on the impulse response of the exchange rate to shocks to i^g.

Figure 6 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 $\bar{\tau}$. For developed countries, a higher i^g induces an impact currency appreciation, i.e. a fall in E, for the entire range of $\bar{\tau}$'s plotted. For developing economies however, a higher i^g induces a depreciation of the currency on impact, i.e., a rise in E, for the entire range of $\bar{\tau}$. Therefore, the difference between developed and emerging economies that we found in Figure 4 is robust to changes in the level of $\bar{\tau}$ since changes in τ do not appear to qualitatively change the impact effect of i^g on the exchange rate.

Figure 6: Comparative statics for parameter τ
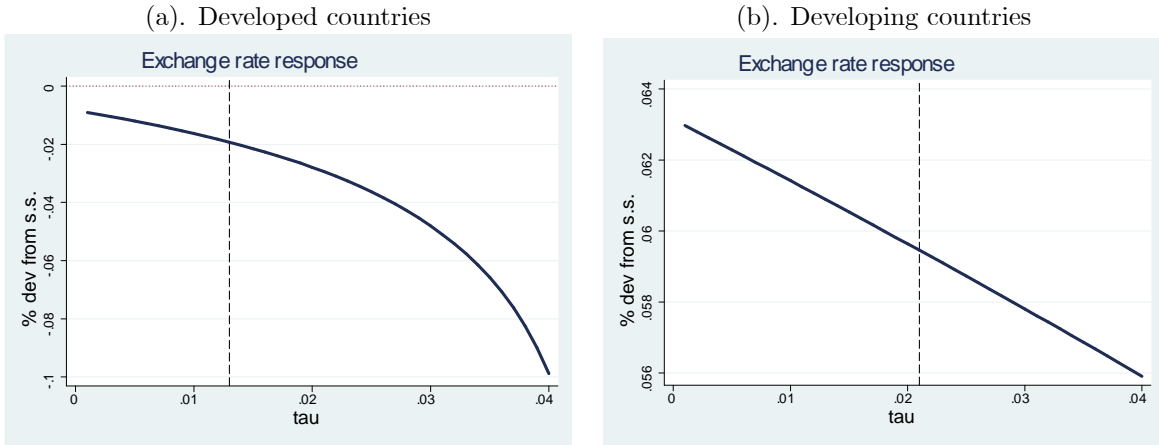
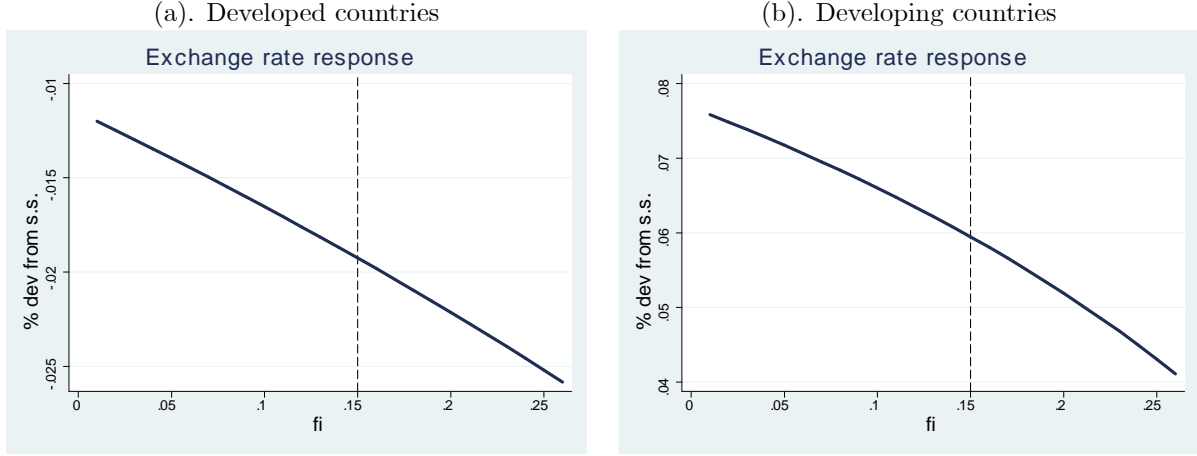(a). Developed countries   (b). Developing countries

Note: The figure presents the responses of nominal exchange rate to a positive shock to i^g for various levels of τ. 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 τ under our benchmark calibration in each country group.

The size and importance of the "output" effect is captured by the wage-in-advance parameter ϕ. As we noted earlier, there are complications in calibrating this parameter with precision. However, this makes it all

the more important to examine the sensitivity of the results to variations in ϕ. Figure 7 shows the effects of varying ϕ in our model. The figure 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 ϕ. Therefore, we conclude that the differences in the impulse responses for the two groups to interest rate shocks highlighted in Figure 4 are robust to variations in the wage-in-advance parameter ϕ.
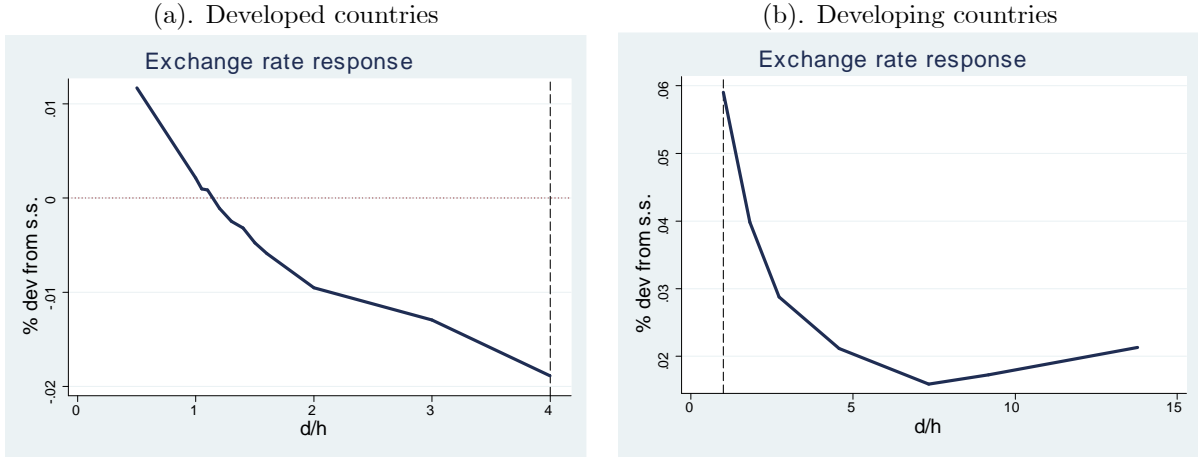
Figure 7: Comparative statics for parameter ϕ

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

Note: The top panel presents the responses of nominal exchange rate to a positive shock to i^g for various levels of ϕ. 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 ϕ under our benchmark calibration in each country group.

To examine the sensitivity of the exchange rate response to the strength of the "liquidity demand" channel, we vary the target $\frac{d}{h}$ and the $\frac{m}{y}$ ratios individually and examine the effect of these changes on the impact response of the exchange rate to a positive i^g shock. Panel (a) of Figure 8 shows the effect of *reducing* the $\frac{d}{h}$ ratio for developed countries while keeping all other developed country targets unchanged. A lower $\frac{d}{h}$ ratio makes the impact appreciation of the exchange rate smaller in developed countries. In fact, for all $\frac{d}{h}$ less than 1.15, the exchange rate response to a rise in i^g switches from appreciation to depreciation. Figure 8 (b) shows the corresponding effect of *raising* the $\frac{d}{h}$ ratio for emerging economies keeping all their other parameters unchanged. The picture here is different. While raising the $\frac{d}{h}$ ratio does tend to reduce the impact depreciation initially, the response never switches to an appreciation. In fact, for $\frac{d}{h}$ ratios greater than 7.2 the size of the exchange rate depreciation begins to rise again. In terms of equation (5.26), beyond this point the indirect effect on η_i^{ss} (which rises with $\frac{d}{h}$) swamps the direct effects. This exercise suggests that the relatively high $\frac{d}{h}$ ratio in developed countries is important for their currency appreciations in response to increases in i^g. The low $\frac{d}{h}$ ratio in emerging economies however was not, by itself, the reason for their currency depreciation.

Next, we examine the importance of the $\frac{m}{y}$ ratio in a similar way. Starting from the baseline target of $\frac{m}{y} = 0.20$ for developed countries, we lower the target while keeping all other developed country targets unchanged. For emerging economies, we raise the $\frac{m}{y}$ ratio from their baseline value of 0.10. Figure 9 shows the results. Panel (a) of Figure 9 shows that reducing the $\frac{m}{y}$ ratio in developed countries makes their impact
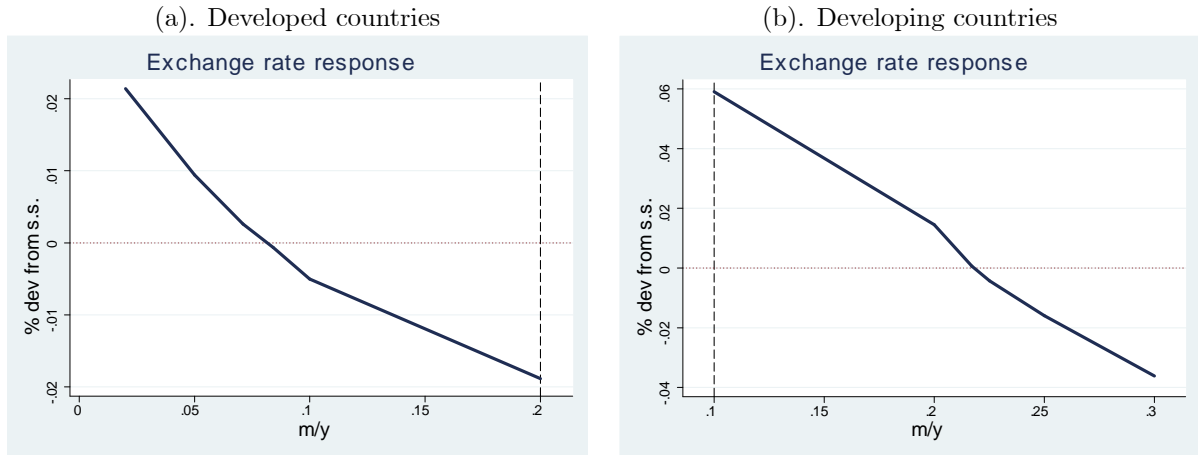
Figure 8: Comparative statics for deposits-to-cash ratio

(a). Developed countries

(b). Developing countries

Note: The figure presents the responses of nominal exchange rate to a positive shock to i^g 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.

appreciation smaller. For all values of $\frac{m}{y}$ 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 $\frac{m}{y}$ 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 $\frac{m}{y}$ ratio.

Figure 9: Comparative statics for money-to-GDP ratio

(a). Developed countries

(b). Developing countries

Note: The figure presents the responses of nominal exchange rate to a positive shock to i^g for various levels of the $\frac{m}{y}$ 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 $\frac{m}{y}$ under our benchmark calibration in each country group.

Our broad conclusion from these results is that the differential responses of exchange rates to monetary policy shocks in developed and developing countries are quite robust to varying the fiscal and output parameters

in our model, τ and ϕ, respectively. On the other hand, the liquidity demand effect appears to be a key aspect of understanding the differences between developing and developed economies since varying the target variables $\frac{d}{h}$ and $\frac{m}{y}$ tend to switch the exchange rate responses predicted by the model. Note that the composition of money demand is controlled by the $\frac{d}{h}$ ratio while the overall level of money demand is determined by the $\frac{m}{y}$ ratio. This last result suggests that both the composition and the level of liquidity demand is important. *Ceteris paribus*, the greater the tilt of liquidity demand toward demand deposits, the greater the chances of higher interest rates appreciating the currency. Similarly, all else equal, the higher the level of money demand the greater the prospects of an exchange rate appreciation in response to an increase in the interest rate.

5.3 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 use 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 2. 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 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.[61] 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 to be indicative of support for one of the liquidity demand channel, which is one of the main mechanisms of the model.

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 ratio 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 as well as the level of financial

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[61]See Appendix A.3 for data sources. To have the broadest country coverage possible, we also supplemented these data sources with individual country Central Banks websites. This way we were able to put together data on deposits to cash ratio for 36 countries in our dataset. m/y ratio is available for 73 country-episode pairs in our sample, however, to retain comparability across specifications we restricted the sample to only countries for which both m/y and d/h ratios are available. When we consider a broader sample of countries in estimating specification (iii), we find that the results remain qualitatively unchanged.

Table 8: Probit regression for exchange rate responses

	(i)	(ii)	(iii)	(iv)
1-developing, 0-developed	-0.4073***	-0.1835	0.0362	0.2452
	(0.1658)	(0.2763)	(0.2577)	(0.3467)
d/h		0.0440		0.0460
		(0.0336)		(0.0498)
m/y			0.0545***	0.0551***
			(0.0164)	(0.0169)
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.

development. More generally, our results suggest that the transmission of monetary policy to the economy is likely 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.

6 Conclusions

The effect of monetary policy on the exchange rate has long been one of the fundamental concerns of academics and practitioners alike. A 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 of 72 countries between 1974 and 2010 to show that while most developed countries indeed exhibit exchange rate appreciations in response to interest rate increases, in developing countries the effect is the opposite: most of them exhibit depreciating currencies in response to interest rate increases. Importantly, the differing responses in developing and developed countries is not due to simply 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. We call this puzzling new data fact the "exchange rate response puzzle".

We have provided an explanation for this puzzle using a simple open economy monetary model. Our explanation rests on the contrasts in the interplay 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 puzzle 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 puzzle.

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A Appendix

A.1 Empirical evidence

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

Data description and sources are summarized in Table A1.

Table A1: Data description and sources

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

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.

Table A2: Sample used in the empirical work

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

A.2 Structural VAR: Details

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

$$y_t = (I - A_1 L - ... - A_p L^p)^{-1} u_t,$$

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

$$y_t = (I - A_1 L - ... - A_p L^p)^{-1} B \varepsilon_t. \tag{A1}$$

Parameters in $A_1, ... A_p$ and Σ can be estimated from the data. Thus, to obtain structural interpretation from the reduced form VAR we need to identify matrix B. Matrix B satisfies $\Sigma = BB'$. To obtain identification in our structural VAR we impose a long-run neutrality restriction as discussed in the text. Specifically, we assume that interest rate shocks cannot have long-run effects on the real exchange rate. This is achieved by

setting the values of the relevant lag coefficients in equation (A1) to zero. For instance, if we redefine

$$(I - A_1 L - ... - A_p L^p)^{-1} B = C(L)$$

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

A.3 Calibration: Data sources

In this Appendix we describe data and sources used in model calibration. We focused on a sample of 6 industrial economies – Australia, Canada, Netherlands, New Zealand, Sweden and UK and 6 developing countries – Argentina, Brazil, Korea, Mexico, Philippines, and Thailand – during 1974-2010 period. When focusing on nominal variables, i.e. nominal interest rates, we restrict the sample to 1998-2010 period to eliminate the periods of high interest rate volatility and high inflation in developing countries before and during the East Asian crisis.

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

Fiscal variables: We used general government net lending/borrowing as a share of GDP to calibrate parameter τ. This data is from the World Economic Outlook (WEO) dataset of the IMF.

Other: We obtained average net foreign asset position (NFA) from Lane and Milesi-Ferretti (2007) dataset. To proxy the policy-controlled interest rates in the data we use the period average T-bill rate. For Netherlands we used a 3-month interbank rate in the Euro area. For Argentina, Australia, Brazil, Korea, Philippines and Thailand the T-bill rate was either not available or had large gaps in coverage, so we used the money market rate for these countries. This data is from the IFS database.

A.4 Deriving money demand

Household's first order conditions are

$$U_c(c_t, x_t) = \beta R \mathbb{E}_t U_c(c_{t+1}, x_{t+1}), \tag{A2}$$

$$\nu \zeta x_t^{\nu-1} = w_t, \tag{A3}$$

$$U_c\left(c_t, x_t\right)\left(1 + v'(h_t)\right) \quad = \quad \beta\mathbb{E}_t\left[U_c\left(c_{t+1}, x_{t+1}\right)\frac{P_t}{P_{t+1}}\right], \tag{A4}$$

$$U_c\left(c_t, x_t\right)\left(1 + \psi'(d_t)\right) \quad = \quad \beta\mathbb{E}_t\left[U_c\left(c_{t+1}, x_{t+1}\right)\left(1 + i_{t+1}^d\right)\frac{P_t}{P_{t+1}}\right], \tag{A5}$$

$$U_c\left(c_t, x_t\right) = \beta\mathbb{E}_t\left[\left\{\frac{\rho_{t+1} + (1-\delta)\left(1 + \kappa_I\left(t+1\right)\right) - \kappa_k\left(t+1\right)}{1 + \kappa_I\left(t\right)}\right\}U_c\left(c_{t+1}, x_{t+1}\right)\right] \tag{A6}$$

Equation (A2) 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 (A3) 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 (A6) dictates the optimal capital accumulation decision by households. Note that by combining equations (A2) and (A6) one can derive a modified no-arbitrage condition which determines the optimal portfolio composition between bonds and physical capital.

Equations (A4) and (A5) 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 (4.19) and substitute in the definition of the nominal interest rate in (3.6) to the first order conditions for cash and deposit demand to obtain their implicit demand functions:

$$h_t \quad = \quad \tilde{h}\left(\frac{i_{t+1}}{1 + i_{t+1}}\right), \qquad \tilde{h}' < 0. \tag{A7}$$

$$d_t \quad = \quad \tilde{d}\left(\frac{i_{t+1} - i_{t+1}^d}{1 + i_{t+1}}\right), \qquad \tilde{d}' < 0. \tag{A8}$$

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