

Revisiting the Exchange Rate Response to Monetary Policy Innovations: The Role of Spillovers of U.S. News Shocks*

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Abstract

Recursive vector autoregression (VAR) analysis suggests that the nominal exchange rate tends to depreciate after a contractionary monetary policy shock in most developing countries, a puzzle for virtually all open-economy macroeconomic models. Using a structural VAR approach, we document that when the U.S. economic outlook worsens developing countries' exchange rates significantly depreciate and their policy-controlled interest rates increase. We show that commonly used recursive VAR schemes inevitably confound these correlations for the monetary policy innovation. In our econometric framework, we identify the spillover effects of future U.S. business cycles as the innovations that best explain future movements in the Federal Funds rate over an horizon of two years. When the monetary policy shock is then cleansed of these variations, the exchange rate response puzzle disappears. We conclude by showing that a standard small open economy model with news about future fundamentals in a large economy is consistent with all the empirical findings of this paper.

JEL classification: E52; F31; F33; F41

Keywords: Exchange rates; Monetary Policy; Identification; Cyclical spillovers; Small-open economy DSGE models; U.S. business cycle news shocks

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1 Introduction

Does a policy-induced increase in the interest rate lead to an appreciation of the domestic currency? Examining data on a rich set of countries, Hnatkovska et al. (2016, hereinafter HLV) document that evidence on advanced countries suggests an affirmative answer to this question (see also earlier work by Eichenbaum and Evans, 1995, and Kim and Roubini, 2000), but a currency depreciation follows an interest rate increase in a large set of developing countries. This result, dubbed “the exchange rate response puzzle”, is primarily based on recursive schemes within the framework of vector-autoregressions (VARs) and it presents critical challenges for academic economists and policy makers alike. HLV interpret their finding as evidence of differential transmission mechanism of monetary policy. In this paper, we argue that the source of this puzzle is empirical rather than theoretical: we show that changes in the U.S. economic outlook – *U.S. business cycle news shocks* – are associated with sizable fluctuations in *both* exchange rates and interest rates in emerging economies. For instance, at the onset of a U.S. economic boom, emerging markets exchange rates tend to appreciate and their policy-controlled interest rates contemporaneously fall. Crucially, we show that recursive VAR identification strategies confound the effects of monetary policy innovations for those of U.S. business cycle news shocks, and thus predictably lead one to find an apparent depreciation after an increase in the interest rate even if such depreciation does not exist.

We propose a novel econometric strategy that allows to contemporaneously identify the country specific response to anticipated economic developments in the U.S. as well as the monetary policy shock cleansed of such response. In a trivariate VAR setting with, in the following order, the Federal Funds rate (FFR), the country’s interest rate, and the bilateral nominal exchange rate, we identify three shocks. First, a conventional surprise FFR shock is identified as the reduced form innovation in the FFR. Second, in the spirit of Barsky and Sims (2011), the U.S. business cycle news shock is identified as the shock orthogonal to the FFR innovation that best explains future movements in the FFR, thereby exploiting the information about the future path of the U.S. economy contained in the FFR. Last, the monetary policy shock is identified as the shock that has no effect on the FFR at any dates, a restriction consistent with all small open economy models. Thus, our identification strategy relies on the observations that the FFR is arguably endogenous to U.S. economic conditions

and plausibly exogenous to economic developments in small open economies. Within this framework, we demonstrate that the monetary policy shock based on recursive VAR scheme can be casted as a linear combination of the effect of the news shock and the monetary policy shock identified through our method. Thus, using a recursive VAR scheme to identify the exchange rate response to monetary policy innovations would be innocuous if either all U.S. shocks were fully unanticipated (i.e. there are no U.S. news shocks) or future U.S. economic conditions have no effect on small open economies. Our empirical findings indicate that neither of these conditions is met.

We implement our identification scheme on monthly data for a large set of countries, and uncover important differences relative to the existing literature. First and foremost, the exchange rate response puzzle disappears after accounting for the effect of U.S. business cycle news shocks on country-specific variables: in all countries, a monetary policy contraction is associated with a significant and persistent appreciation of the nominal exchange rate, with the quantitative effect being larger for developing countries (on average). Second, conditional on a U.S. business cycle news shock, all countries display similar dynamic correlations: an improvement in the U.S. economic outlook leads to an increasing FFR, higher U.S. industrial production and U.S. consumer price (CPI) inflation, *and* a nominal appreciation and interest rate decline in all the small-open economies in our sample.^{1, 2} Although qualitatively similar, the sensitivity of country-specific variables to U.S. news shocks differs considerably across groups of countries; in particular, for U.S. news shocks of similar size the exchange rate and interest rate responses are, on average, two to five times larger in developing economies relative to industrial ones. In fact, the response for most industrial countries becomes nearly insignificant in some specifications.³ Our evidence thus suggests that no empirical puzzle

¹A bad U.S. news shock is also associated with a decline in the Chicago Board Options Exchange (CBOE) Volatility Index (VIX), a forward-looking measure of uncertainty and risk aversion.

²In the existing literature, this correlation was mistakenly captured by the monetary policy shock.

³Note that our results would not necessarily be obtained by simply accounting for the contemporaneous response of the interest rate to the exchange rate. Recasting the VAR such that the exchange rate is ordered before the interest rate would imply that the exchange rate does not respond on impact to a monetary policy shock, a setting that would not allow to answer our main question. Alternatively, a structural VAR in the spirit of Blanchard and Quah (1989) by which the monetary policy shock is identified as the shock that has no long-run effect on the *real* exchange rate does not necessarily capture the right dynamics in the data. HLV show the exchange rate response puzzle is robust to such identification strategy; the model presented in Section 4 implies that neither U.S. news nor monetary policy shocks have permanent effects on the real exchange rate. Using simulated data, we confirm that in this context the Blanchard-Quah type identification strategy fails to recover the correct response to a monetary policy shock (results available upon request). It

emerges if the monetary policy shock is correctly identified. In general, our empirical results indicate that recursive identification schemes tend to underestimate the degree of exchange rate appreciation after a contractionary monetary policy shock. In particular, the extent to which recursive schemes underpredict a country’s exchange rate response to monetary policy innovations depends upon the quantitative importance of the effects induced by a U.S. news shock in the country. Thus, while our methodology implies larger exchange rates appreciations following monetary policy shocks for both industrial and developing countries, it is for the latter group that the correction is the largest. In fact, the reason behind the emergence of the puzzle is the large sensitivity of emerging countries’ variables to future economic developments in the U.S., consistent with the observations that capital flows to these countries are highly dependent on the state of the U.S. and the global economy, and that their monetary policy is acting to offset (the effects of) the resulting exchange rate fluctuations.⁴ In addition, evidence from a variance decomposition exercise indicates that U.S. news shocks explain a larger fraction of volatility in emerging economies’ interest rates (about 60% after two years) relative to advanced countries’ interest rates (about 20%), consistent with the observation that emerging countries’ monetary policy efforts are largely devoted to respond to external shocks.

A complementary objective of this paper is to provide a theoretical mechanism that rationalizes the transmission of a news shock from a large to a small economy. To this end, we build a two-country small open economy model based on Galí and Monacelli (2005) and De Paoli (2009) where economic developments in the large economy (the U.S. in our case) affect the small economy, but not vice versa. Besides monetary policy innovations in both countries, the large economy is subject to anticipated TFP innovations. In the model, when TFP in the large country is expected to be higher in the future – the onset of a boom – households in the large economy gradually raise current consumption because of their consumption-smoothing desire. The resulting inflationary pressures induce the monetary authority in the large economy to (gradually) raise their interest rate. In the model, the

is also important to notice that it is likely that during a period that precedes an important recession – a bad U.S. news in our jargon – interest rate increases anticipate a (expected) nominal depreciation. Under this circumstances, accounting for the *contemporaneous* response of the interest rate to the exchange rate would also fail to capture the correct effect of a monetary policy shock.

⁴For a detailed analysis of the dynamic and cross sectional patterns in capital inflows as a function of global push factors, see the recent paper by Avdjiev et al. (2017).

exchange rate is determined by the risk-sharing condition derived under complete asset markets: in this case, a lower marginal utility from consumption in the large economy brings about an exchange rate appreciation in the small economy. The ensuing deflationary pressures associated with exchange rate appreciation require the monetary authority in the small economy to lower the nominal interest rates. Overall, this parsimonious framework is thus capable of reproducing the conditional correlations that we document empirically. Besides, our estimated model implies impulse responses magnitudes that are generally in line with those obtained in our empirical analysis.⁵ To examine the performance of our empirical approach, we simulate data from our estimated model and perform a Monte Carlo estimation exercise. This highlights that our identification strategy succeeds in recovering the effect of both a news shock and a monetary policy shock fairly well: the identified monetary policy shock maps into the home monetary policy shock in the model, while the anticipated FFR shock maps to the foreign news shock, providing further support for our identification scheme. As a last exercise, we perform a recursive VAR analysis on model generated data and find that it predicts a counterfactual exchange rate response to a monetary policy innovation.⁶

The insights presented here are related to ideas in different strands of the literature. First, we aim to shed light on the empirical evidence on the effects of shocks to monetary policy on exchange rates. In their seminal article, Eichenbaum and Evans (1995) show that an orthogonalized contractionary shock to the FFR leads to a persistent and significant appreciation of the nominal exchange rate. Using a structural VAR approach along the lines of Sims and Zha (2006), Kim and Roubini (2000) find that contractionary monetary policy innovations induce nominal appreciations of the exchange rates in the non-U.S. G7 economies.⁷ Recently, using a recursive VAR analysis, HLV find that a striking cross-country difference emerges: while confirming that industrial economies' exchange rate appreciates, they show that it tends to depreciate in developing countries after a monetary policy contraction.^{8,9} We contribute this large literature by proposing a novel identification scheme for the effect

⁵The key parameters of the model are estimated via impulse response matching, while the remaining ones are calibrated to standard values.

⁶The standard Cholesky identification scheme obtains as a special case of our model.

⁷See also Faust and Rogers (2003).

⁸Results are robust to controlling for a large set of variables as well as using alternative identification strategies that aim at capturing the contemporaneous response of the interest rate to exchange rates.

⁹Using a high frequency identification scheme, Kohlscheen (2014) finds similar puzzling responses for three developing countries.

of monetary policy on the exchange rate that accounts for spillover effects of business cycles of a large economy. This reveals that the exchange rate response puzzle is likely to be a figment of specification error rather than a data fact. Second, our paper is related to the rapidly growing literature on news and business cycles (see Beaudry and Portier, 2014, for a recent survey of the literature). In particular, our identification scheme is related to the work of Barsky and Sims (2011) on the VAR identification of the effect and importance of news shocks. We differ from this literature in few respects: unlike the existing literature, which focuses on the *closed* economy effects of news about future U.S. *TFP*, we are interested in empirically capturing the role of news about the *overall* U.S. economy on a large set of small *open* economies. To do so, we exploit the fact that the FFR is inherently endogenous to U.S. economic conditions and plausibly exogenous to economic conditions to the small open economies in our sample. Besides, our econometric framework is able to cleanse the monetary policy shock identified through recursive schemes by the effect of the U.S. news in a trivariate VAR, a method that likely has applicability that goes beyond the specific questions addressed in this paper. Third, the findings of this paper highlight the importance of the spillover effects of U.S. business cycles on several economies, especially developing ones. In doing so, we add to the literature on the spillover effects of U.S. economic shocks, recently exemplified by Bruno and Shin (2015) and Rey (2015).¹⁰ Unlike these papers, we emphasize the implications of these cyclical spillovers for the estimation of the effect of monetary policy innovations in small open economies.

The paper proceeds as follows: Section 2 describes the structural VAR model and discuss its relationship with a recursive VAR scheme. Section 3 presents all the estimation results and robustness checks. Section 4 outlines the dynamic general equilibrium model, displays its ability to match the empirical impulse responses as well as highlights the performance of relevant identification strategies on simulated data. Section 5 concludes.

2 Econometric strategy

Consider a trivariate VAR with Federal Funds rate (FFR_t), policy-controlled interest rate of country k ($i_{k,t}$), and logarithm of the bilateral nominal exchange rate between country

¹⁰Other papers that study the effect of various U.S. shocks on emerging economies include Canova (2005), Uribe and Yue (2006), Mackowiak (2007), Akinci (2013), Viccondoa (2016)

k 's currency and the U.S. dollar (s_t). Within this context, we propose an identification strategy that allows to disentangle the effect of U.S. business cycle news shocks from those of small open economy monetary innovations. Specifically, we assume that the FFR is properly characterized as following a stochastic process driven by surprise and anticipated shocks, and that the latter have no contemporaneous effect on the FFR.¹¹ Anticipated FFR shocks are interpreted as U.S. business cycle news shocks, and evidence in support of this interpretation is provided in Section 3.3.1. The small economy monetary policy shock is then identified as the linear combination of the VAR innovations that is orthogonal to surprise and anticipated FFR shocks.¹²

2.1 Identifying monetary policy shocks

Let $y_t \equiv [FFR_t \ i_{k,t} \ s_t]'$ be the 3×1 vector of observables that have length T . Thus, the FFR is ordered first, while the policy controlled interest rate of country k is ordered second, and the log of nominal exchange rate is ordered last. Denote by

$$y_t = B(L)u_t$$

the reduced form moving average representation in the levels of the observables, formed by estimating an unrestricted VAR in levels. The relationship between reduced-form innovations and structural shocks is given by:

$$u_t = A_0 \varepsilon_t \tag{1}$$

which implies the following structural moving average representation:

$$y_t = C(L)\varepsilon_t$$

where $C(L) = B(L)A_0$ and $\varepsilon_t = A_0^{-1}u_t$. The impact matrix A_0 must satisfy $A_0 A_0' = \Sigma$, where Σ is the variance-covariance matrix of innovations. Importantly, A_0 is unique up to any rotation D of the structural shocks. Specifically, for any 3×3 orthonormal matrix D , the entire space of permissible impact matrices can be written as $\tilde{A}_0 D$, where $\tilde{A}_0$ is an arbitrary orthogonalization (e.g. a Cholesky decomposition).

¹¹We relaxed this contemporaneous restriction and we found that results are robust to this modification

¹²We are going to use the terms anticipated FFR shock and US business cycle news shock interchangeably.

The h step ahead forecast error is:

$$y_{t+h} - E_{t-1}y_{t+h} = \sum_{\tau=0}^h B_{\tau} \tilde{A}_0 D \varepsilon_{t+h-\tau}$$

where B_{τ} is the matrix of moving average coefficients at horizon τ . The share of the forecast error variance of variable i attributable to the structural shock j at horizon h is then:

$$\Omega_{i,j}(h) = \frac{\sum_{\tau=0}^h B_{i,\tau} \tilde{A}_0 \gamma \gamma' \tilde{A}_0' B_{i,\tau}'}{\sum_{\tau=0}^h B_{i,\tau} \Sigma B_{i,\tau}'}$$

where γ is the j th column of D , while $B_{i,\tau}$ corresponds to the i th row of B_{τ} .

In order to identify the monetary policy shock of country k such that it is orthogonal to exogenous movements of the FFR, we adopt a procedure which extends the identification scheme proposed by Barsky and Sims (2011) and that can be divided into two steps. First, we recover the surprise and the anticipated shock of FFR. The former is identified as the orthogonal innovation in the FFR. The latter is identified as the shock that maximizes the contribution to the forecast error variance of the FFR up to a truncation horizon H , subject to the restriction that this shock has no contemporaneous effect on the FFR. Formally, the identification of the anticipated FFR shock boils down to solving the following maximization problem

$$\gamma^* = \arg \max \sum_{h=0}^H \Omega_{1,2}(h) = \frac{\sum_{\tau=0}^h B_{1,\tau} \tilde{A}_0 \gamma \gamma' \tilde{A}_0' B_{1,\tau}'}{\sum_{\tau=0}^h B_{1,\tau} \Sigma B_{1,\tau}'}$$

s.t.

$$\tilde{A}_0(1, j) = 0 \quad \forall j > 1 \tag{C.1}$$

$$\gamma(1, 1) = 0 \tag{C.2}$$

$$\gamma' \gamma = 1 \tag{C.3}$$

The first two constraints ensure that the anticipated shock has no contemporaneous effect on the FFR. The third restriction narrows the solutions space to the one of possible orthogonalizations of the reduced form by preserving the orthonormality of the rotation matrix D . By imposing that γ must be a unit vector, the second column γ of D matrix is identified.

In the second step, we recover the small open economy monetary policy shock of country k . This shock can be identified by making use of the condition that the matrix D must be orthonormal, i.e. $DD' = D'D = I$. More specifically, let $\gamma^* = [0 \ \gamma_1 \ \gamma_2]$ where $\gamma_2 = -\sqrt{1 - \gamma_1^2}$, then one can express D as:¹³

$$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \gamma_1 & \gamma_2 \\ 0 & -\gamma_2 & \gamma_1 \end{bmatrix} \quad (2)$$

where the first column ensures that the surprise shock of the FFR (ε_t^{FFR}) is the orthogonal innovation to the FFR. The second column results from the maximization problem above and therefore it captures the whole set of shocks that induce future movements of the FFR and that in the next section we show being US business cycle news (ε_t^n). The third column identifies the monetary policy shock of country k (ε_t^{mp}) that may affect both the nominal exchange rate and the policy controlled interest rate, while it has no contemporaneous and future impact on the FFR.¹⁴ Last, *for any* orthogonalization $\tilde{A}_0$ of residuals u_t which satisfies the first constraint (C.1), the structural shocks can be recovered from the relation

$$u_t = \tilde{A}_0 D \varepsilon_t. \quad (3)$$

where D is the rotation matrix previously identified, and $\varepsilon_t \equiv [\varepsilon_t^{FFR} \ \varepsilon_t^n \ \varepsilon_t^{mp}]'$.

2.2 Comparison with a recursive identification scheme

The common assumption in open economy models is that domestic monetary policy shocks have no effect on the world interest rate (FFR). Our identification strategy is based solely on this assumption.¹⁵ This entails a zero restriction on the contemporaneous relation matrix

¹³The negative sign in front of γ_2 is just a normalization. Specifically, to preserve the orthonormality of D , one needs the 2×2 lower right submatrix of D to have either opposite diagonal elements or opposite off-diagonal elements.

¹⁴By construction this condition is subjected to the maximization above, therefore results can still deliver that a monetary policy shock has some, but likely insignificant, future effects on the FFR.

¹⁵In the context of a small versus large open economy the common practice has consisted of estimating a VAR by assuming block exogeneity restrictions on the reduced form parameters. The block exogeneity restriction means that the shocks in the small open (domestic) economy do not affect the variables in the large economy either contemporaneously or with lags. However, restricting the FFR to be unaffected by variations in domestic variables is in sharp contradiction with the Granger causality relation implied by the news shock.

$\tilde{A}_0$, and the extraction of the news shock component from the otherwise spurious shock that would arise by adopting a recursive identification scheme. Specifically, recall equation (1) and suppose that A_0 is the Cholesky matrix that arises from decomposing Σ . What is the relation between the shocks identified and the ones identified through our identification scheme? By combining equations (1) and (3) one can derive the following result:

$$\varepsilon_t^c = \gamma_1 \varepsilon_t^n + \gamma_2 \varepsilon_t^{mp} \quad (4)$$

where ε_t^c is the shock identified through Cholesky decomposition, whereas ε_t^n and ε_t^{mp} are the news shock and the domestic monetary policy shock respectively, identified by using the methodology described in the previous section. Thus, under the existence of news shocks and if $\gamma_1 \neq 0$, that is U.S. business cycle news shocks affect the variables in the system, standard recursive identification schemes fail to correctly recover the true monetary policy shock. Therefore, the relation above shows that our identification scheme nests the Cholesky one. As we do not restrict the value of γ_1 to be zero we allow for the case in which the two identification procedures are equivalent.¹⁶

3 Estimation results

This section describe the dataset and reports the results of estimating the VAR model using the approach described above. It begins by showing the results for the effect of a country-specific monetary policy shock (Section 3.2), and then presents the impulse responses associated with a U.S. business cycle news shock (Section 3.3). We frame our main results in the form of impulse-response functions (IRFs). Bootstrapped 90% confidence intervals are based on 1000 replications.

¹⁶A limitation of our approach is that it cannot identify both the news shock and the monetary policy shock in a system with more than three shocks. This is because the orthonormal matrix D would be only partially identified. One may overcome this issue by identifying both shocks separately. The news shock would be identified using the procedure proposed by Barsky and Sims (2011), while the monetary policy shock would be identified as the shock that minimizes the forecast error variance of the FFR up to a certain truncation horizon. Clearly the success of such identification approach depends upon the information set spanned by the variables in the system and the dynamics implied by the associated structural shocks. Further advancements on this topic are part of our research agenda.

3.1 Dataset

Our data construction and sample selection exactly follows the approach of HLV. We use a large sample of countries over the period 1974:1–2010:12 for which monthly data on exchange rates and interest rates were available, focusing on countries and time periods that are characterized by a flexible exchange rate regime.

The main data source is the International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF). The preferred measure of exchange rates are official exchange rates. If these are not available, we use period average market rates, or period average principal exchange rates. Exchange rates are in domestic currency units per US dollar, so that an increase is a depreciation of local currency relative to the US dollar. Policy-controlled interest rates are measured in the data as the period average T-bill rates, the closest to the overnight interbank lending rates. If these are not available, discount rates, or money market rates are used. The Federal Funds rate (FFR) is the measure of U.S. policy-controlled interest rate. Exchange rate regimes are determined according to the historical exchange rate classification in Reinhart and Rogoff (2004).¹⁷ According to these criteria, our dataset features 25 industrial country-episode pairs and 55 developing country-episode pairs, for a total of 80 country-episode pairs.^{18, 19}

3.2 Effects of a monetary policy shock

Figure 1 reports the exchange rate responses to a 1% policy-induced increase in the interest rate obtained by applying our econometric framework to each of the countries in our sample. Panel (a) features the non-US G7 economies IRFs, and Panel (b) reports the IRFs for the largest developing economies in our sample.

As clearly shown in Figure 1, the exchange rate response puzzle does not emerge under our

¹⁷A country is deemed to have a flexible exchange rate regime if, in a given year, its exchange rate was either (i) within a moving band that is narrower than or equal to ± 2 percent; or (ii) was classified as managed floating; or (iii) was classified as freely floating; or (iv) was classified as freely falling in Reinhart and Rogoff (2004). For countries that had multiple episodes of flexible exchange rates during this period, we follow HLV in considering each episode separately subject to the restriction that there were at least 24 months of data in each episode.

¹⁸The present analysis focuses on the 6 largest industrial economies and 6 largest developing economies. These are United Kingdom (UK), Canada (CDN), Japan (JPN), Italy (ITA), Germany (GER), France (FRA), South Africa (SA), Philippines (PHI), Indonesia (IDN), Brazil (BRA), South Korea (KOR) and Mexico (MEX). In the next iteration of the paper, we plan to expand our estimation procedure to all countries in the sample.

¹⁹For a comprehensive list of all country-episode pairs in the sample we refer the reader to Appendix A in HLV.

proposed identification strategy. In fact, in nearly all countries, regardless of their development status, a policy-induced interest rate hike leads to a significant impact appreciation of the local currency, with the only exception being Brazil.²⁰ The quantitative impact response of the nominal exchange rate to a 1% policy-induced increase in the interest rate differs somewhat notably from country to country. Generally, the interest-rate sensitivity of the exchange rate is on average larger in developing countries relative to industrial ones, but there are also important differences within country groups. In fact, the impact appreciation of the exchange rate that we observe ranges from around 5% to around 20%. In Section 4 we show that these magnitudes are consistent with the predictions of a standard small-open economy model with sticky prices.

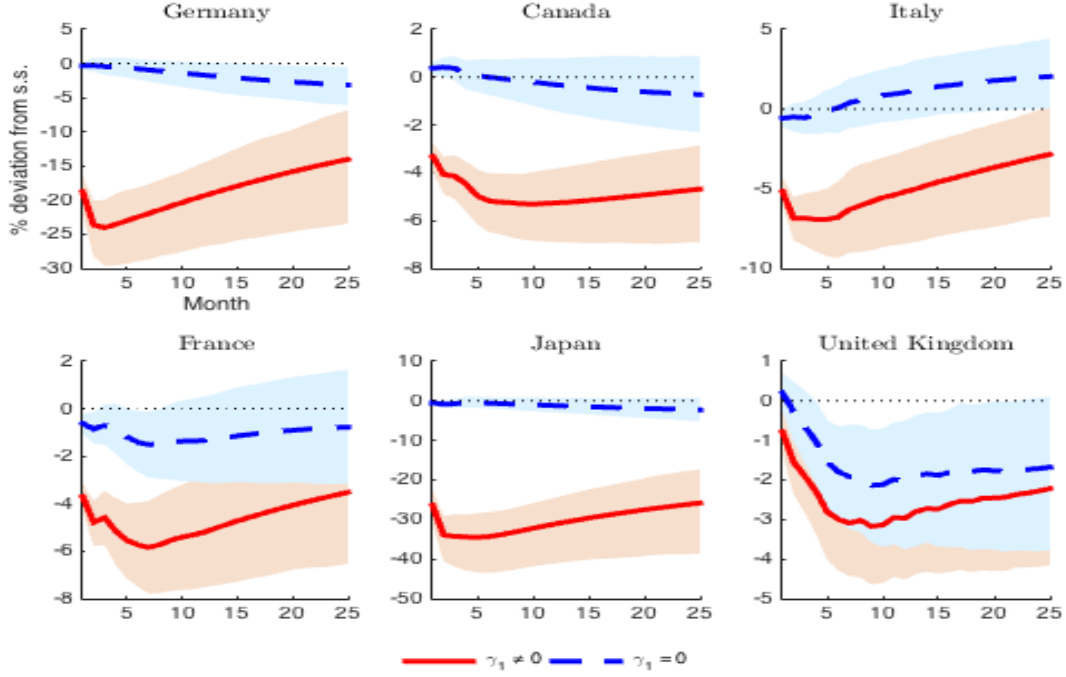
Figure 1 also reports the IRFs that result from a monetary policy shock identified through a recursive scheme. These obtain as a special case of our identification strategy when γ_1 is set equal to zero. In line with the existing literature, under a recursive identification scheme applied to our data the exchange rate response puzzle emerges: the impact response of most developing countries' exchange rate to a monetary contraction is positive (i.e., a nominal depreciation), unlike for most industrial countries whose impact response is either negative (i.e., a nominal appreciation) or statistically insignificant, with the only exception being Canada.²¹ The following sections aim at interpreting why a recursive VAR scheme tends to underpredict the appreciation of the exchange rate following a contractionary monetary policy impulse, and why this problem is more prevalent in developing countries.

3.3 Effects of a U.S. business cycle news shock

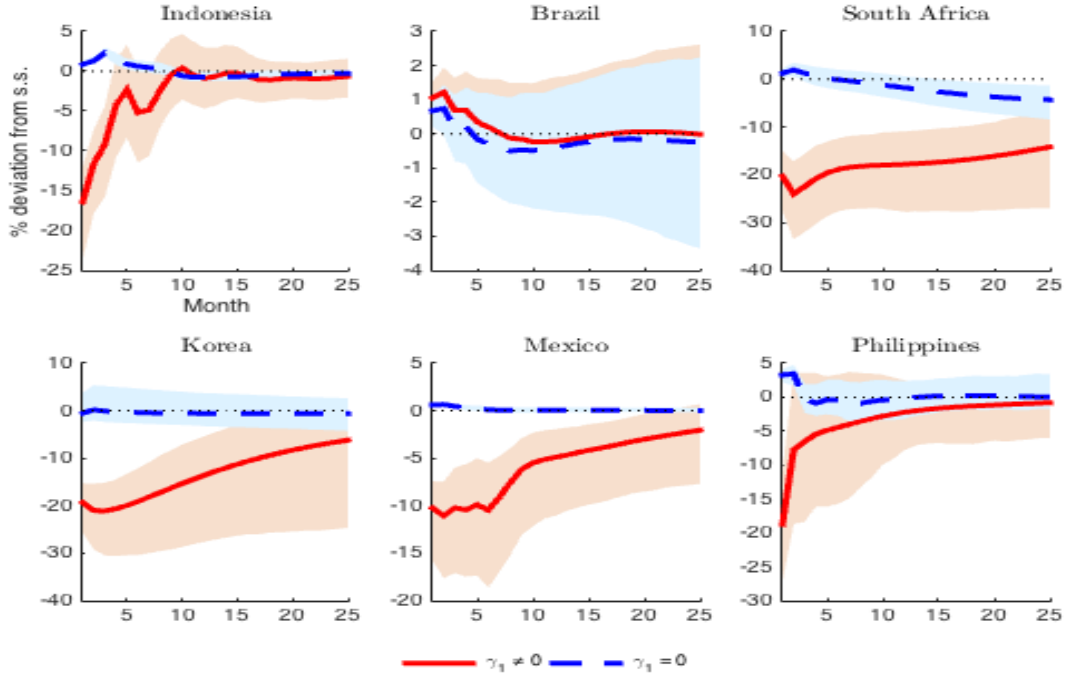
Why does the exchange rate response puzzle disappear once the monetary policy shock is cleansed of anticipated variations in the FFR? To answer this question, one has to look at the effect of anticipated FFR shocks on small open economies' exchange rates and interest rates, and investigate the nature of this shock. In this section we show that anticipated

²⁰As Blanchard (2004) discusses, an exchange rate depreciation may follow an interest rate increase if the increase in the interest rate also increases the probability of default on the government debt. He suggests that such outcome is more likely the higher the initial level of debt, the higher the proportion of foreign-currency-denominated debt, and the higher the price of risk (this perverse effects can worsen if the central bank follows a strict inflation targeting regime). Blanchard later argues that these conditions were present in the Brazilian economy during 2002 and 2003, a period of high financial turbulence. Our sample period for Brazil (1999:2 - 2007:12) includes these years.

²¹The impulse responses obtained under the Cholesky identification scheme (reported in Figure 1) are slightly different from those reported in HLV because they run a bivariate VAR with interest rate differential and bilateral exchange rate. Instead, we separate the two interest rates and run a trivariate VAR.



(a) Industrial countries



(b) Developing countries

Figure 1: Empirical exchange rate response to a 1% contractionary monetary policy shock

Note: The red solid lines are the estimated IRFs to our identified 1% interest rate increase from the baseline three-variable VAR ($\gamma_1 \neq 0$). The blue dashed lines are the estimated IRFs to 1% interest rate increase from the baseline three-variable VAR identified using a recursive scheme ($\gamma_1 = 0$). The shaded areas are the 90% confidence intervals from 2000 bias-corrected bootstrap replications of the reduced-form VAR. Panel (a) reports the IRFs for industrial countries, while Panel (b) reports the IRFs for developing countries.

FFR variations bring about a opposite correlation between exchange rates and interest rates relative to monetary policy innovations, and we provide evidence that anticipated FFR movements carry information about the future state of the U.S. economy, rather than being orthogonal to U.S. business cycles. Figure 2 shows the IRFs to a shock that leads to a future increase in the FFR, what we call a positive *U.S. business cycle news shock*.²² A future increase in the FFR induces a nominal appreciation and interest rate cuts in all countries (see Panel (a)). Further inspection reveals that the effect on developing countries is much larger relative to the one on industrial countries; in fact, both median exchange rates and interest rates are considerably more sensitive to similar future increases in the FFR in developing economies relative to industrial ones (see Panel (b)). More specifically, a shock that leads the FFR to increase by about 10 basis points in the following ten months leads to a 0.5% and 2% median impact exchange rate appreciations in advanced and developing countries, respectively, as well as 15 basis points impact interest rate decline in industrial countries, while a 60 basis points impact interest rate decline in developing countries. At this point, it is important to recall that a recursive identification scheme would confound these correlations for the monetary policy innovation (see Section 2.2). We have shown that the two impulses – U.S. news and local monetary policy innovation – induce opposite correlations between exchange rate and interest rate: positive for the former, negative for the latter. A recursive identification scheme would thus suggest that a depreciation follows a monetary contraction if the news-induced positive correlation prevails on the negative one typical of a monetary policy innovation, i.e. if the effect of U.S. business cycle news shocks are strong enough. This outcome is more likely to obtain for countries with greater sensitivity to U.S. business cycles news, and our data indicates that this is the case for developing economies. This empirical result is consistent with the observations that capital flows to these countries are highly dependent on the state of the U.S. and the global economy, and that their monetary policy is acting to offset (the effects of) the resulting exchange rate fluctuations.²³ In the next section, we provide empirical support for the interpretation of anticipated FFR shocks as U.S. business cycle news shocks.

²²Since we estimate country-specific VARs, we could have plotted each country’s IRFs in separate figures. In the interest of space, we report the IRFs to a U.S. business cycle news shock all in the same graph. It should be noted that these IRFs are qualitatively similar and statistically significant in all countries. Individual countries’ VAR results are available upon request.

²³While we offer empirical results that aim to point at the main mechanisms at play, a detailed analysis of the channels behind the U.S.-news-shock effects in developing countries is beyond the scope of this paper.

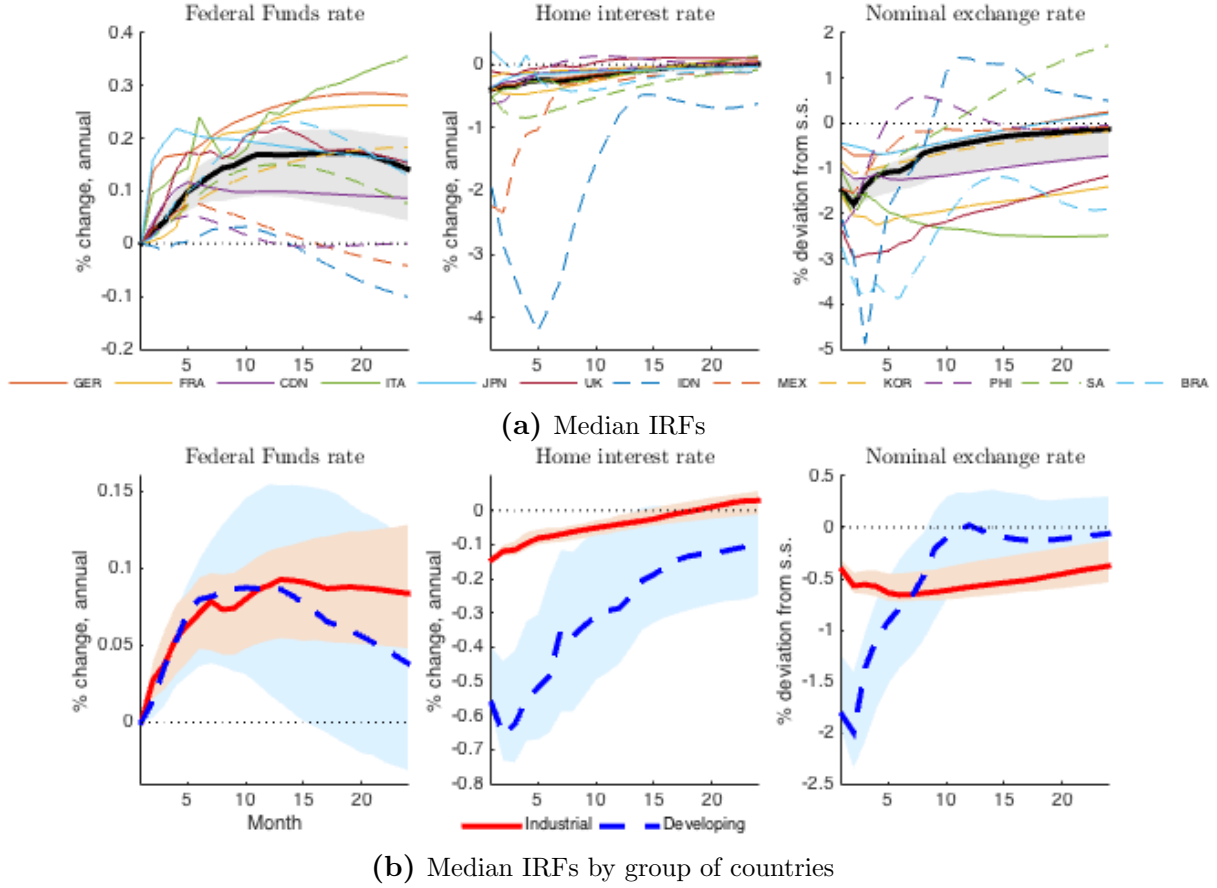


Figure 2: Empirical IRFs to an anticipated increase in the Federal Funds rate

Note: The lines are the estimated IRFs to the anticipated shock to the FFR from our baseline three-variable VAR. Panel (a): the solid lines are the IRFs for industrial countries; the dashed lines are the IRFs for developing countries. The thick black line is the median IRF for all countries and the shaded gray areas are the corresponding 90% confidence intervals from 2000 bias-corrected bootstrap replications of the reduced-form VAR. Panel (b): the solid lines denote median IRFs by group of countries with corresponding 90% confidence intervals. The reader is referred to Footnote 18 for the list of countries.

3.3.1 Are anticipated FFR movements carrying information about expected U.S. business cycle fluctuations?

So far we have operated under the hypothesis that future movements in the FFR contain information about future business cycles conditions in the United States. In other words, we conjectured that a future increase in the FFR captures the endogenous response of the FFR to an improving state of the U.S. economy, and vice versa. To bring evidence in support of this view, we present the empirical IRFs to a U.S. news shock in two four-variable versions of our VAR. One includes U.S. industrial production and the other inflation in the U.S. Consumer Price Index (CPI), besides our three baseline variables. The results, reported in Figure 3, conform to expectations: a good U.S. business cycle news induces an (hump-shaped)

increase in industrial production (see Panel (a)) and an (impact) increase in CPI inflation (see Panel (b)). These statistically significant movements are characteristic of business-cycle-like fluctuations.

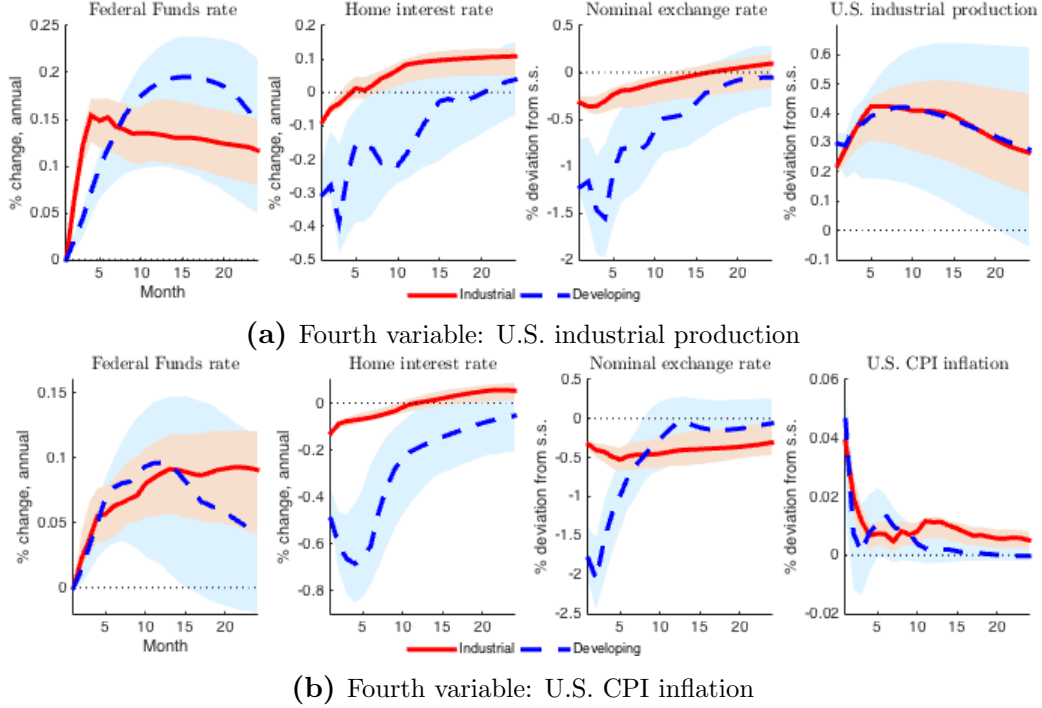


Figure 3: Empirical IRFs to an anticipated increase in the Federal Funds rate: four-variable VAR

Note: This figure features the estimated IRFs to the anticipated shock to the FFR from a four-variable

VAR with our three baseline variables and either U.S. industrial production (Panel (a)) or U.S. CPI inflation (Panel (b)) ordered fourth. The solid line and the dashed lines denote median IRFs of industrial and developing countries respectively. The shaded areas are the corresponding 90% confidence intervals from 2000 bias-corrected bootstrap replications of the reduced-form VAR.

3.3.2 Additional evidence on the effect of U.S. news shocks

In Appendix A (Figure 7, Panel (a)), we show that a positive U.S. news shock is associated with a significant impact decline in the Chicago Board Options Exchange (CBOE) Volatility Index (VIX), a forward-looking measure of uncertainty and risk aversion. This result indicates that the periods in which there is a change in the U.S. economic outlook are associated with fluctuation in the degree of uncertainty and risk aversion, an important determinant of the direction of capital flows (as recently argued, for example, by Rey (2015)).

In Appendix A (Figure 7, Panel (b)), we also show that after a U.S. news shock developing countries CPI inflation tends to fall after one or two months, in line with the observation these feature a large share of dollar denominated imported goods and therefore a signifi-

cant exchange rate pass-through into consumer prices (see, for example, Goldberg and Tille (2009) and Gopinath (2015)).

To further investigate the quantitative importance of U.S. business cycle spillovers on small open economies, in Appendix A, we present the fraction of forecast error variance of each variable from the shocks we identify. This variance decomposition exercise, (Figure 8, using the baseline trivariate VAR specification) shows that the news shocks explains around 15% of the variation of the FFR at a two-year horizon, around 35% of the variation of the median nominal exchange rates of all countries, and more than 60% of the variation in developing countries' interest rates, while only around 20% in industrial countries' ones. Thus, the U.S. business cycle news shock we identify explains a large part of the interest rate fluctuations in developing countries, but not in industrial ones. We believe that this result brings suggestive evidence in support of Rey's (2015) argument that, under free capital mobility, floating-exchange-rate countries that experience large capital flows (and ensuing exchange rate volatility) inevitably use their monetary policy tools to shield the economy from (these types of) external shocks and, in this sense, they lose monetary independence.

4 Model

This section introduces a two-country small open economy dynamic general equilibrium model, a basic framework to study the transmission of economic developments occurring in a large economy to a small open economy. We present a summary of the equilibrium conditions in log-linear form and highlight the key mechanisms (Section 4.1), while Appendix B contains the full derivation of the model. Then, we show that this simple model is capable of replicating the empirical IRFs fairly well, both qualitatively and quantitatively. We conclude this section by analyzing the performance of our structural VAR on data simulated from this model (Section 4.2).

4.1 Environment and equilibrium equations

The baseline framework belongs to the international macroeconomic tradition initiated by Obstfeld and Rogoff (1995). It consists of a two-country dynamic general equilibrium model with complete asset markets, monopolistically competitive producers and sticky prices, introduced along the lines of Calvo (1983). As prices are set in the producer's currency, the

model features complete exchange rate pass-through.²⁴ We follow De Paoli (2009) in characterizing the small open economy by taking the limit of the home economy size to zero. The limit is taken after having derived the equilibrium conditions for the two-country model. Thus, the two countries, Home and Foreign, represent the small open economy and the large closed economy (the United States in our case), respectively.

Large (Foreign) economy

$$c_t^* = \mathbb{E}_t c_{t+1}^* - (i_t^* - \mathbb{E}_t \pi_{t+1}^*) \quad (5a)$$

$$\pi_t^* = \beta \mathbb{E}_t \pi_{t+1}^* + \kappa(1 + \eta)(c_t^* - a_t^*) \quad (5b)$$

$$i_t^* = \rho i_{t-1}^* + (1 - \rho)\phi \pi_t^* + \varepsilon_{i^*,t} \quad (5c)$$

$$a_t^* = a_{t-1}^* + \varepsilon_{a^*,t-12} \quad (5d)$$

Small (Home) economy

$$c_t = \mathbb{E}_t c_{t+1} - (i_t - \mathbb{E}_t \pi_{t+1}) \quad (6a)$$

$$\pi_{H,t} = \beta \mathbb{E}_t \pi_{H,t+1} + \kappa(c_t + \eta y_t - (1 + \eta)a_t + \lambda(1 - \lambda)^{-1}q_t) \quad (6b)$$

$$i_t = \rho i_{t-1} + (1 - \rho)\phi \pi_t + \varepsilon_{i,t} \quad (6c)$$

$$\pi_t = (1 - \lambda)\pi_{H,t} + \lambda(\Delta s_t + \pi_t^*) \quad (6d)$$

$$y_t = (1 - \lambda)c_t + \lambda c_t^* + \lambda(2 - \lambda)(1 - \lambda)^{-1}\theta q_t \quad (6e)$$

$$a_t = a_{t-1} + \psi(a_{t-1}^* - a_{t-1}) \quad (6f)$$

$$q_t = c_t - c_t^* \quad (6g)$$

$$\Delta s_t = \Delta q_t - \pi_t^* + \pi_t \quad (6h)$$

Table 1: Log-linearized equilibrium conditions

The log-linear equilibrium conditions are reported in Table 1, while all parameters are defined in Table 2. For a given TFP process, the economic dynamics in the large economy are fully described by the consumption Euler equation (Eq. (5a)), the New Keynesian

²⁴Alternatively assuming that all prices are set in dollars (dollar pricing), the currency of the large economy, would not change the main observations made here. To the contrary, adopting the assumption that all prices are set in the currency of the consumer (local currency pricing) would change the model's qualitative implications. As made clear in the text, the currency denomination of imports is what matters to determine the response of the home interest rate to exchange rate fluctuations. The assumption that imported goods are invoiced in dollars seems to us an empirically relevant one for developing countries (see, for example, Gopinath, 2015).

Phillips curve (Eq. (5b)) and the monetary policy rule (Eq. (5c)).²⁵ The monetary authority follows a CPI-inflation targeting Taylor (1993)-type rule with some degree of interest-rate smoothing. As illustrated in Equation (5d), TFP in the large economy follows a random walk process where TFP innovations are known one year in advance.²⁶

As in the large economy, small (domestic) economy's consumption dynamics, c_t , are governed by the Euler equation (Eq. (6a)), inflation in domestically produced goods (PPI), π_t^H , is determined by a Phillips curve (Eq. (6b)), and the monetary authority targets CPI inflation, π_t , which is defined in Equation (6c). Unlike the large economy, however, the small economy is effectively open to trade in final consumption goods. For this reason, marginal costs in Eq. (6b) and aggregate demand for domestically produced goods (Eq. (6e)) depend upon the terms of trade (which can be expressed as a function of the real exchange rate, q_t). Also, aggregate demand for the Home good depends on Foreign consumption, in proportion to the degree of trade openness, λ . Importantly, complete exchange rate pass-through implies that nominal exchange rate fluctuations directly translate into changes in Home CPI (Eq. (6d)), exactly because imports are denominated in the (Foreign) producer's currency. Consistent with the data counterpart, the nominal exchange rate, s_t is defined in Home currency units per Foreign currency, so that an increase is a depreciation of local currency relative to the Foreign one. Finally, TFP in the small economy gradually adjusts to the TFP level in the large economy, where the adjustment speed is determined by the parameter ψ .

The risk-sharing condition, Eq. (6g), pins down the value of the real exchange rate, determined by the consumption differential. In this environment, there are three structural shocks. Besides the news shocks about future TFP innovations in the large economy, $\varepsilon_{a^*,t-12}$, both countries are buffeted by monetary policy innovations, modeled as Taylor rule shocks as it is common in the New Keynesian literature, and represented by $\varepsilon_{i^*,t}$ and $\varepsilon_{i,t}$. It is important to stress that Foreign shocks affect the Home economy but the reverse is not true.

4.1.1 Parameter estimation and calibration

We follow Christiano et al. (2005) in calibrating some model parameters and estimating others to minimize the distance between the model and empirical IRFs. More specifically, we minimize the distance between the IRFs that arise from VAR estimation on model generated

²⁵Foreign country variables are denoted by a star superscript.

²⁶Reducing or extending the anticipation horizon by one semester does not change the qualitative results presented below.

data and the median IRFs for developing countries. We limit the parameters that we estimate to those that govern the convergence in the TFP shock processes, the monetary policy rule and the shocks size. The remaining parameters are calibrated to values commonly used in the literature. In the model, each period is a month. We thus set $\beta = 0.9967$ which implies a steady state annual interest rate of about 4%, and $\eta = 1$ which implies a unit Frisch elasticity. Our calibration of the Calvo parameter ($\alpha = 0.9167$) implies an average duration of price contracts of one year. We set the GDP share of imports $\lambda = 0.4$, the elasticity of substitution across differentiated goods $\sigma = 11$, and the trade elasticity $\theta = 1$. Using an impulse response matching approach, we estimate the remaining parameters. Parameter estimates are reported in Table 2, while details of the IRF matching approach can be found in Appendix C. Parameter estimates imply a persistent process for interest rates setting, and relatively small monetary policy shocks. In fact, the estimated standard deviations for monetary policy shocks are two orders of magnitude smaller than the estimated standard deviation of the anticipated foreign TFP shocks.

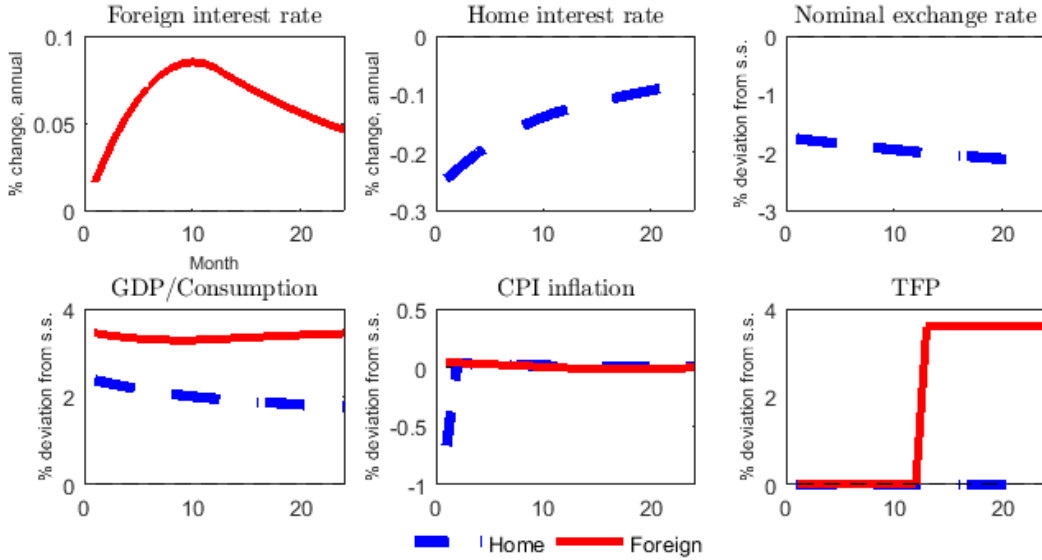


Figure 4: Theoretical IRFs to a Foreign TFP news shock

Note: The impulse is an anticipated one-standard-deviation increase in the foreign country's TFP. The period of anticipation is one year.

4.1.2 Equilibrium dynamics following a news shock to foreign TFP

Figure 4 reports the IRFs to a news shock in the large economy implied by the estimated model. Suppose that TFP is expected to increase in one year and then permanently remain at this higher level. Consider first its effect in the Foreign (closed) economy. By the

consumption-smoothing logic implied by the Euler equation, households desire to increase current consumption. Consumption thus starts increasing in the periods before the TFP innovation actually occurs, provided that the current nominal interest rate is not responsive enough.²⁷ As current consumption has increased without a corresponding increase in current fundamentals, the resulting higher marginal costs will raise Foreign inflation. Depending on the (estimated) degree of inflation responsiveness and interest rate smoothing, the central bank responds to these inflationary pressures by gradually raising the nominal interest rate. A positive news shock will therefore be associated with rising consumption (output), inflation, and a rising nominal interest rate in the economy that will experience the future TFP innovation, i.e. the large economy.²⁸

Consider now the transmission of the large-economy news shock to the small open economy. *Ceteris paribus*, by the risk-sharing equation, the lower Foreign marginal utility from consumption induces an instantaneous appreciation of the Home real exchange rate (i.e. q_t declines, see Eq. (6g)), and, if nominal prices are rigid enough, also an instantaneous appreciation of the nominal exchange rate, s_t . This brings about a contemporaneous fall in import prices (in local currency) which puts downward pressure on domestic CPI inflation (see Eq. (6d)), and a worsening of the terms of trade, which leads to a reduction in domestic PPI inflation.²⁹ Figure 4 illustrates that these deflationary forces (especially the former) outweigh the inflationary forces due to higher Foreign demand (for domestic goods). In response, the Home central bank reduces the nominal interest rates.

Therefore, this simple model is overall capable of reproducing the dynamic patterns observed empirically after a Foreign news shock. However, there is a stark difference between Monte Carlo and empirical exchange rate response to news (Figure 5b): the Monte Carlo (and model) response of the exchange rate implies that this appreciates on impact and over time. To the contrary, the (median) empirical response suggests that, while the exchange rate appreciates on impact it returns to its original value about after one year. Thus the data responses imply a violation of the Uncovered Interest Parity (UIP) condition, conditional on

²⁷In fact, if the inflation coefficient in the Taylor rule, ϕ , goes to infinity, the equilibrium converges to the equilibrium of a flexible-price economy, where real variables are unchanged in the periods before the actual TFP innovation.

²⁸See Lorenzoni (2011) for an analytical description of the (demand-shock-like) effects of a news shock in a closed economy.

²⁹This contractionary impact is due to the so-called expenditure-switching channel.

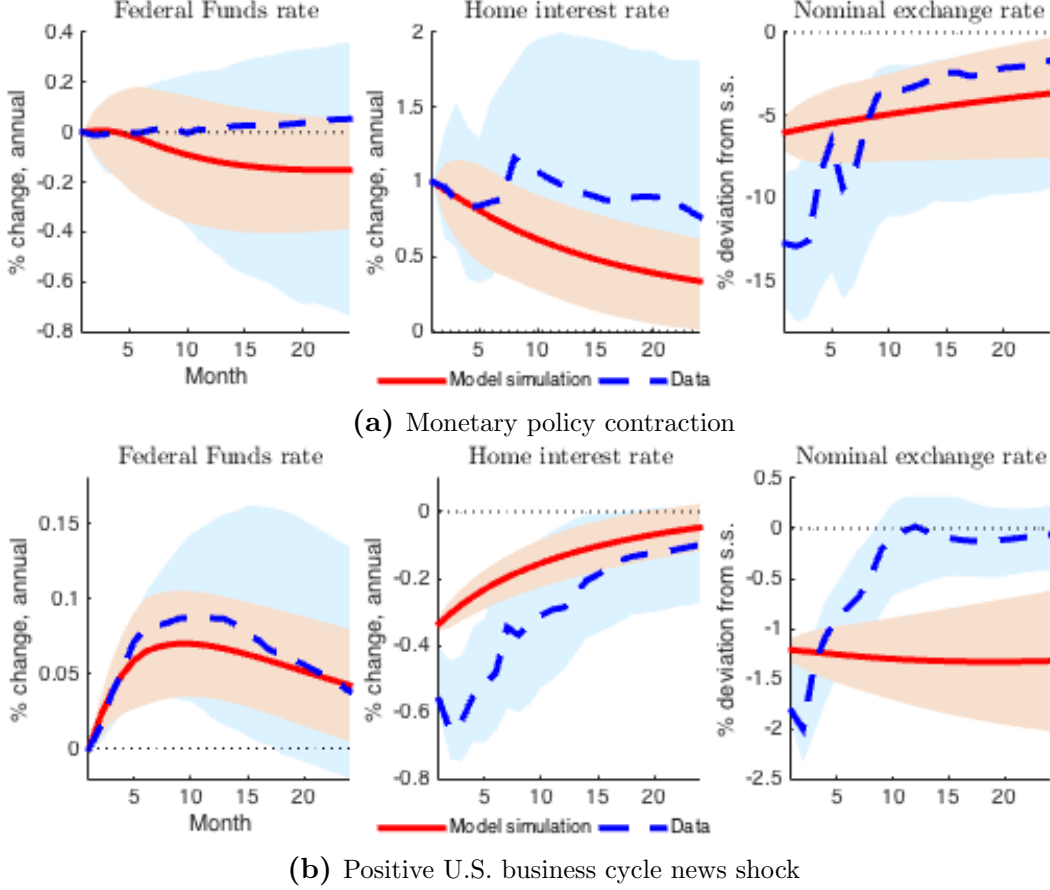


Figure 5: Data and Monte Carlo estimated VAR IRFs

Note: The red solid line shows the average estimated IRF from a Monte Carlo simulation with 2000 repetitions and 442 observations per repetition. The blue dashed line is the estimated median empirical IRF for developing countries. The shaded areas are the 90% confidence intervals.

U.S. news shocks – a condition that is always satisfied in the model. We believe that this observation is important, but we leave further analysis of it to future research.

Last, Figure 5a reports the data and Monte Carlo estimated VAR IRFs to a monetary policy shock. These are clearly in line with each other.

4.2 Monte Carlo results

In this section, data are simulated from the DSGE model presented above to examine the performance of our empirical approach. A three-variable system identical to the baseline empirical specification in Section 2 is estimated on model generated data, and it is shown that our empirical approach performs quite well, whereas a recursive VAR scheme would suggest that a monetary policy contraction leads to a counterfactual depreciation of the nominal exchange rate.

Parameter	Description	Value
Calibrated parameters		
β	Discount factor	0.9967
η	Inverse of Frisch elasticity	1
σ	Elasticity of substitution	15
θ	Trade elasticity	1
λ	Import share of H GDP	0.4
α	Price rigidity	0.9167
Estimated parameters		
ρ	Interest-rate smoothing	0.988
ϕ	Inflation response coefficient	2.586
σ_i	Home MP shock std. dev.	0.0003
σ_{i^*}	Foreign MP shock std. dev.	0.0001
σ_{a^*}	News shock std. dev.	0.0361
ψ	TFP convergence parameter	$8(10)^{-7}$

Table 2: Model parameters

Note: Each period in the model coincides with one month

Figure 6 indicates that the IRFs stemming from our VAR-based identification scheme are generally in line with the theoretical ones. In fact, the identified domestic monetary policy shock maps closely into the home monetary policy shock in the model, while the anticipated FFR shock maps into the foreign news shock, providing support for our identification scheme. In Figure 6a, the estimation performance of a recursive VAR scheme ($\gamma_1 = 0$) is tested and presented alongside the one of our identified monetary policy shock. Unlike our structural VAR, the recursive VAR fails to correctly capture the exchange rate response to a monetary policy innovation. In contrast to the theoretical response, the recursive VAR suggests that a nominal depreciation follows a policy-induced interest rate hike. As explained in Section 2.2 above, the monetary policy innovation identified by a recursive VAR combines the effects of both the true monetary policy shock and the U.S. business cycle news shock. The Monte Carlo estimated FFR response to a domestic monetary policy shock confirms that this is the case. Moreover, the significant hump-shaped decline of the FFR following a Cholesky monetary policy shock is a feature that one observes also in the data (results available upon request).

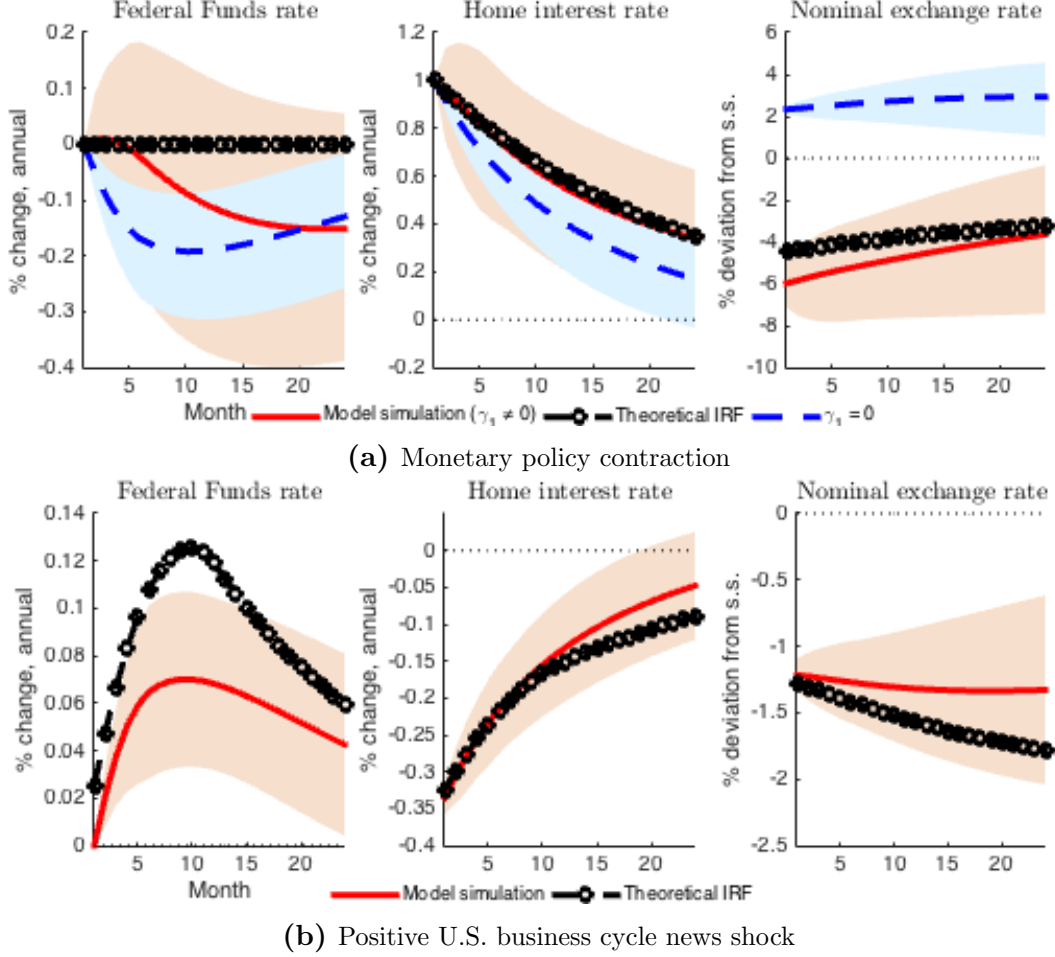


Figure 6: Model and Monte Carlo estimated IRFs: three-variable VAR

Note: The black circled line shows the theoretical IRF from the model presented in Section 4. The red solid line is the average estimated IRF from a Monte Carlo simulation with 2000 repetitions and 442 observations per repetition. The shaded areas are the 90% confidence intervals from the 2000 Monte Carlo repetitions. In Panel (a) two types of VARs are estimated on model generated data: our identification strategy ($\gamma_1 \neq 0$) and a monetary shock identified through Cholesky ($\gamma_1 = 0$)

4.2.1 Discussion

Although the simple model presented here is generally able to rationalize our empirical results, it should not be interpreted as a comprehensive descriptor of the economics at play. In other words, our analysis by no means excludes that there may be other complementary channels determining the spillover effects and/or the response of monetary policy to these. For instance, while we choose to model the U.S. business cycle news shock as a news about future TFP, other types of disturbances likely lie behind our estimated news shocks. In fact, demand-type shocks such as uncertainty or pure sentiment shocks can induce qualitatively similar correlations (as discussed in Lorenzoni, 2011). Our empirical analysis does not re-

quire to distinguish between these, and the question of which of these (or other) shocks is more prevalent in U.S. business cycles is beyond the scope of the present paper.³⁰ Model tractability and comparability with news-driven business cycles literature determined our modeling choice. Also, financial and non-financial institutions in emerging economies borrow in foreign currency (dollars in most cases); in an economy with liability denominated in foreign currency, a nominal depreciation raises their debt burden, thus tightening financial frictions. In this context, raising the domestic nominal rate in response to a nominal depreciation can be the optimal policy because it avoids depreciation and the associated adverse balance sheet effect.³¹ Nevertheless, the model presented here is deliberately simple in order to show that workhorse sticky price models are per se able to explain the empirical response of exchange rates to monetary policy changes, and to capture qualitative and quantitative aspects of the spillover effects stemming from anticipated changes in the performance of leading economy.

5 Conclusions

It is well known that emerging countries are largely exposed to economic shocks that originate abroad. In this context, the exchange rate is perhaps the most sensitive variable to external shocks, and exchange rate volatility has often been associated with significant disruptive effects. Stabilization policy in the wake of external shocks is thus a first-order concern for monetary authorities in these countries. In this paper, we documented that when the U.S. economic outlook worsens, developing countries' exchange rates significantly depreciate and their policy-controlled interest rates increase. This evidence reinforces the observations that capital flows to these countries largely depend on the state of the U.S. and the global economy, and that their monetary policy acts to offset (the effects of) the resulting exchange rate fluctuations. We have argued that accounting for these patterns is important to obtain sensible estimates of the exchange rate response to monetary policy innovations. Our main finding is that previous estimates, based on recursive VAR schemes, confound the correlations induced by U.S. economic shocks for the monetary policy innovations. Therefore, cleansing

³⁰Generally, candidate shocks must generate positive comovement between output and inflation and their realization should be anticipated.

³¹See for instance Choi and Cook (2004) and Aoki et al. (2015) for models in which financial institutions face a mismatch in the currency denominations of their liabilities.

the monetary policy shock of these variations leads to qualitative and quantitative different predictions for the exchange rate response, as well as implications for stabilization policy.

The simple model presented in the paper provided an economic environment in which the aforesaid empirical correlations can be interpreted as the equilibrium of a two-country small-open economy subject to (anticipated) shocks to total factor productivity (TFP) in the large economy and shocks to policy interest rates in both countries. Besides, it points to one potential limitation of dynamic stochastic models of emerging markets driven by shocks to the external interest rate. While the present paper suggests that external shocks indeed play an important role in emerging markets, it also suggests that changes in the external interest rate can have different effects depending on whether they reflect U.S. monetary policy shocks or the systematic response of the Federal Funds rate to other types of shocks.

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A Additional empirical results

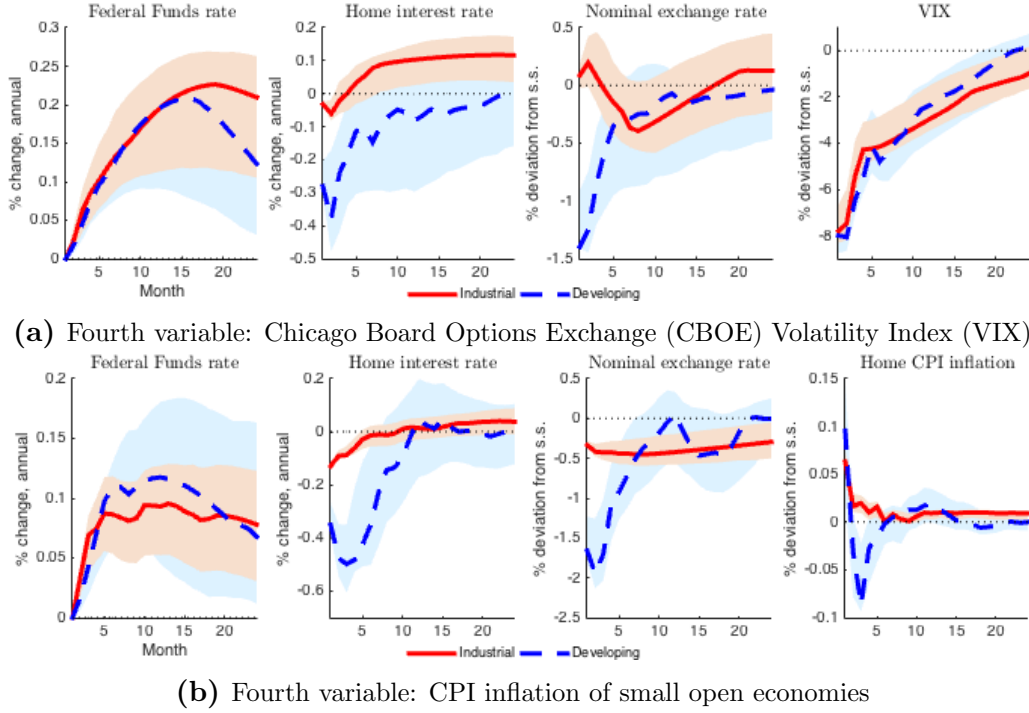


Figure 7: Empirical IRFs to an anticipated increase in the Federal Funds rate: four-variable VAR

Note: This figure features the estimated IRFs to the anticipated shock to the FFR from a four-variable VAR with our three baseline variables and either the Chicago Board Options Exchange (CBOE) Volatility Index (VIX) (Panel (a)) or the small open economies CPI inflation (Panel (b)) ordered fourth. The solid lines denote median IRFs by group of countries. The shaded areas are the corresponding 90% confidence intervals from 2000 bias-corrected bootstrap replications of the reduced-form VAR.

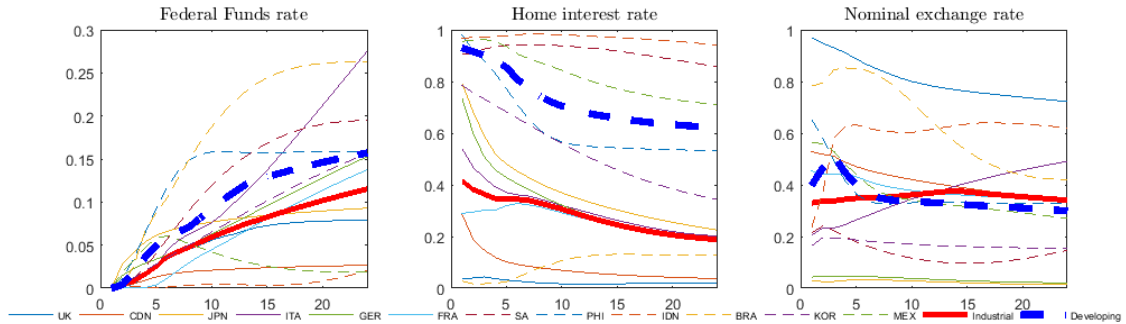


Figure 8: Fraction of forecast error variance of each variable from our identified U.S. news shock

Note: The variance decomposition is done with our baseline three-variable specification. The horizontal axes refer to forecast horizons, while the vertical axes denote the fraction of forecast error variance from our identified U.S. news shock. The reader is referred to Footnote 18 for the list of countries.

B Model details

B.1 Households

There are two countries, Home (H) and Foreign (F), and a continuum of agents of unit mass, where the population in the segment $[0, n)$ belongs to country H and the population in the segment $(0, n]$ belongs to country F . The utility function of the representative consumer in country H is given by:

$$U_t = \mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\log(C_s) - \frac{N^{1+\eta}}{1+\eta} \right] \quad (7)$$

where C is a Dixit-Stiglitz aggregator of home and foreign goods, defined by:

$$C = \left[\nu^{\frac{1}{\theta}} C_H^{\frac{\theta-1}{\theta}} + (1-\nu)^{\frac{1}{\theta}} C_F^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \quad (8)$$

where $\theta > 0$ is the intratemporal elasticity of substitution and C_H and C_F are consumption sub-indexes that refer to the consumption of home-produced and foreign-produced goods, respectively. The parameter determining home consumers' preferences for foreign goods, $(1-\nu)$, is a function of the relative size of the foreign economy, $1-n$, and of the degree of openness, λ ; more specifically, $(1-\nu) = (1-n)\lambda$.

Similar preferences are specified for the rest of the world,

$$C = \left[\nu^{\star \frac{1}{\theta}} C_H^{\star \frac{\theta-1}{\theta}} + (1-\nu^{\star})^{\frac{1}{\theta}} C_F^{\star \frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \quad (9)$$

with $\nu^{\star} = n\lambda$.

The sub-indexes C_H ($C_H^{\star}$) and C_F ($C_F^{\star}$) are Home (Foreign) consumption of the differentiated products produced in countries H and F. These are defined as follows:

$$C_H = \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma}} \int_0^n c(z)^{\frac{\sigma-1}{\sigma}} dz \right]^{\frac{\sigma}{\sigma-1}} \quad (10)$$

$$C_F = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma}} \int_n^1 c(z)^{\frac{\sigma-1}{\sigma}} dz \right]^{\frac{\sigma}{\sigma-1}} \quad (11)$$

$$C_H^{\star} = \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma}} \int_0^n c^{\star}(z)^{\frac{\sigma-1}{\sigma}} dz \right]^{\frac{\sigma}{\sigma-1}} \quad (12)$$

$$C_F^* = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma}} \int_n^1 c^*(z)^{\frac{\sigma-1}{\sigma}} dz \right]^{\frac{\sigma}{\sigma-1}} \quad (13)$$

where $\sigma > 1$ is the elasticity of substitution across the differentiated products. The utility-based Consumer Price Indexes (CPIs) that correspond to the above specifications of preferences are given by:

$$P = [\nu P_H^{1-\theta} + (1-\nu) P_F^{1-\theta}]^{\frac{1}{1-\theta}} \quad (14)$$

and

$$P^* = [\nu^* (P_H^*)^{1-\theta} + (1-\nu^*) (P_F^*)^{1-\theta}]^{\frac{1}{1-\theta}} \quad (15)$$

where P_H (P_H^*) is the price sub-index for home-produced goods expressed in the domestic (foreign) currency and P_F (P_F^*) is the price sub-index for foreign produced goods expressed in the domestic (foreign) currency:

$$P_H = \left[\left(\frac{1}{n} \right) \int_0^n p(z)^{1-\sigma} dz \right]^{\frac{1}{1-\sigma}} \quad (16)$$

$$P_F = \left[\left(\frac{1}{1-n} \right) \int_n^1 p(z)^{1-\sigma} dz \right]^{\frac{1}{1-\sigma}} \quad (17)$$

$$P_H^* = \left[\left(\frac{1}{n} \right) \int_0^n p^*(z)^{1-\sigma} dz \right]^{\frac{1}{1-\sigma}} \quad (18)$$

$$P_F^* = \left[\left(\frac{1}{1-n} \right) \int_n^1 p^*(z)^{1-\sigma} dz \right]^{\frac{1}{1-\sigma}} \quad (19)$$

Total demand for a generic good h , produced in country H , and the demand for a good f , produced in country F :

$$y_t^d(h) = \left[\frac{p_t(h)}{P_{H,t}} \right]^{-\sigma} \left[\frac{P_{H,t}}{P_t} \right]^{-\theta} \nu C_t + \left[\frac{p_t^*(h)}{P_{H,t}^*} \right]^{-\sigma} \left[\frac{P_{H,t}^*}{P_t^*} \right]^{-\theta} \frac{\nu^*(1-n)}{n} C_t^* \quad (20)$$

$$y_t^d(f) = \left[\frac{p_t(f)}{P_{F,t}} \right]^{-\sigma} \left[\frac{P_{F,t}}{P_t} \right]^{-\theta} \frac{(1-\nu)n}{1-n} C_t + \left[\frac{p_t^*(f)}{P_{F,t}^*} \right]^{-\sigma} \left[\frac{P_{F,t}^*}{P_t^*} \right]^{-\theta} (1-\nu^*) C_t^* \quad (21)$$

We follow ? in taking the limit for $n \rightarrow 0$ to represent the small open economy. As a result, Equations (20) and (21) become:

$$y_t^d(h) = \left[\frac{p_t(h)}{P_{H,t}} \right]^{-\sigma} \left[\frac{P_{H,t}}{P_t} \right]^{-\theta} (1 - \lambda) C_t + \left[\frac{p_t^*(h)}{P_{H,t}^*} \right]^{-\sigma} \left[\frac{P_{H,t}^*}{P_t^*} \right]^{-\theta} \lambda C_t^* \quad (22)$$

$$y_t^d(f) = \left[\frac{p_t^*(f)}{P_{F,t}^*} \right]^{-\sigma} \left[\frac{P_{F,t}^*}{P_t^*} \right]^{-\theta} C_t^* \quad (23)$$

B.2 Asset market structure

We assume that asset markets are complete both domestically and internationally. In this setting, agents have access to a complete set of state-contingent securities, and the intertemporal marginal rate of substitution is equalized across countries:

$$\mathbb{E}_t \left[\frac{C_t^*}{C_{t+1}^*} \frac{S_t P_t^*}{S_{t+1} P_{t+1}^*} \right] = \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \right] \quad (24)$$

Under symmetric initial conditions:

$$Q_t = \frac{C_t}{C_t^*} \quad (25)$$

where the real exchange rate, Q_t is defined as $Q_t = \frac{S_t P_t^*}{P_t}$, and the nominal exchange rate, S_t , denotes the price of foreign currency in terms of domestic currency.

B.3 Firms

Each country features a continuum of firms that produce output under a constant-returns-to-scale production function. The economy-wide production function are thus:

$$Y_{H,t} = A_t N_t \quad (26)$$

and

$$Y_{F,t} = A_t^* N_t^* \quad (27)$$

Each country's TFPs, A_t and A_t^* , evolve according to:

$$a_t^* = a_{t-1}^* + \varepsilon_{a^*,t-k} \quad (28)$$

$$a_t = a_{t-1} + \psi(a_{t-1}^* - a_{t-1}) \quad (29)$$

where $a_t^* \equiv \log(A_t^*)$ and $a_t \equiv \log(A_t)$. TFP disturbances, $\varepsilon_{a^*,t}$, are i.i.d. drawn from a Normal distribution with mean zero and standard deviation σ_{a^*} .

We assume that each producer sets her price in her own currency. In this case the law of one price holds, so:

$$p_t(h) = S_t p^*(h) \quad (30)$$

and

$$p_t(f) = S_t p^*(f) \quad (31)$$

The last two equations together with Equations (16)-(19) imply that $P_{H,t} = S_t P_{H,t}^*$ and $P_{F,t} = S_t P_{F,t}^*$ for each t . However, the home bias specification leads to deviations from purchasing power parity; that is, $P_t \neq S_t P_t^*$.

B.4 Monetary policy

In each country, the monetary authority is assumed to follow a Taylor (1993)-type rule with interest-rate smoothing:

$$i_t^* = \rho i_{t-1}^* + (1 - \rho) \phi \pi_t^* + \varepsilon_{i^*,t}$$

$$i_t = \rho i_{t-1} + (1 - \rho) \phi \pi_t + \varepsilon_{i,t}$$

where $\varepsilon_{i^*,t}$ and $\varepsilon_{i,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviations σ_{i^*} , and σ_i , respectively.

C Impulse response matching procedure

We follow Christiano et al. (2005) in calibrating some model parameters and estimating others to minimize the distance between the model and empirical impulse response functions. The vector of estimated parameters, θ is chosen to minimize the loss function:

$$L(\theta) = \left(\hat{\psi} - \psi^T(\theta) \right)' V^{-1} \left(\hat{\psi} - \psi^T(\theta) \right)$$

where $\hat{\psi}$ collects the empirical IRFs, $\psi^T(\theta)$ collects the IRFs that arise from the VAR estimation of model-simulated data, and the diagonal weighting matrix V is composed of the diagonal entries corresponding the bootstrapped variances of the elements of $\hat{\psi}$. The

empirical response functions in $\hat{\psi}$ include the first 5 periods of the developing-country median response of FFR, domestic interest rate and exchange rate to a domestic monetary policy shock and to a U.S. business cycle news shock. The standard deviation of the surprise FFR shock, σ_{i^*} , is estimated so that the model matches the impact response of the FFR to a FFR surprise shock.