Shocks and Exchange Rates in Small Open Economies*

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Abstract

We separately identify domestic and external shocks in small open economies, and find that they give rise to markedly different exchange rate dynamics. External shocks feature large and predictable deviations from uncovered interest parity, while domestic shocks do not. Moreover, external shocks are associated with fluctuations in global risk aversion and U.S. macroeconomic aggregates. A small open economy model with imperfect capital markets is consistent with these facts. In the model, global risk aversion shocks drive exchange rate dynamics, and a country's net foreign asset position governs their international transmission. We provide empirical evidence that a country's exposure to external shocks indeed depends on its net foreign asset position.

JEL classification: F31; F41; F44; G15
Keywords: Exchange rates; Identification; UIP deviations; Small open economy DSGE models; Global risk aversion.

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Exchange rates are arguably the most important price for small open economies (SOEs), yet the sources of their fluctuations are still far from understood. Partly because of scant disciplining evidence, the drivers of exchange rate dynamics largely differ across classes of open economy models. This paper studies the properties of domestic and external shocks on exchange rates in SOEs, presents a new set of exchange rate facts, and explores their implications for open economy models.

We begin by estimating a series of vector autoregressions (VARs) for a set of SOEs using monthly data including open economy variables. We show that it is possible to separately identify domestic and external shocks in SOEs using minimal assumptions that hold in any class of SOE models. In particular, we observe that domestic shocks originating from within a *small* economy should not influence world variables at any horizon, while external (or global) shocks should affect world variables at least at some horizon. In the context of our VARs, we show that this observation entails a set of parameter restrictions that allow to isolate domestic from external sources of fluctuations. We then extract the external shock that explains most of the fluctuations in the exchange rate of a SOE. Hence we study the properties of both domestic and external shocks, and interpret them by analyzing the dynamic comovement they lead to.

The first empirical finding is that domestic and external shocks give rise to substantially different exchange rate dynamics. While domestic and external shocks account for a comparable fraction of exchange rate variation, external shocks generate large and predictable deviations from uncovered interest parity (UIP), whereas domestic shocks result in exchange rate dynamics that are largely in line with UIP. In fact, external shocks explain more than 80% of all fluctuations in excess currency returns, and are primarily responsible for the emergence of the so-called forward premium puzzle – the evidence that interest rate differentials predict excess currency returns (Fama, 1984). Remarkably, the differences in conditional UIP deviations lead domestic and external shocks to display an opposite comovement between interest rate differentials and exchange rates. These facts indicate that country-specific UIP shocks are not a satisfactory representation of the data, and understanding exchange rates and UIP deviations requires inspecting the nature of external disturbances and their propagation channels.

The second empirical finding is that *one* external shock drives a large fraction of variation in exchange rates and excess currency returns, and it is linked to fluctuations in global risk aversion and U.S. macroeconomic aggregates. Our approach does not require that a single shock accounts for a large fraction of external variation or that any shocks have an intuitive interpretation. Nevertheless, when applying our decomposition, we find that one single external shock accounts for the bulk of the external variation in exchange rates and excess currency returns. Moreover, we find that this shock is strongly correlated with innovations in the VIX – a common proxy of global risk aversion – and it is associated with significant U.S. macroeconomic fluctuations; the identified external shock leads to a decline in global risk aversion and an increase U.S. output, inflation, and the Federal Funds rate. In the typical SOE, an expansionary external shock causes a temporary exchange rate appreciation along with a decline in its short-term interest rate, implying a significant decline in excess returns of the typical SOE's currency. While closely related to the evidence of the so-called global financial cycle (Rey, 2013, Miranda-Agrippino and Rey, 2020), the positive comovement among U.S. output, inflation and interest rates reveals that the bulk of external variation in exchange rates is not driven by U.S. monetary policy shocks. Relatedly, SOE models with only exogenous shocks to the external interest rate do not appear to be an adequate characterization of the data.

We show that an open economy model with segmented international asset markets and global risk aversion shocks reproduces all the above empirical regularities. Building on a standard two-country SOE framework with nominal rigidities (cf. Galí and Monacelli, 2005, and De Paoli, 2009), we assume that international financial markets are segmented, and financial traders – a subset of U.S. households – are averse to holding currency risk (cf. Gabaix and Maggiori, 2015).[1] Besides a standard set of structural shocks, we model a "global risk aversion shock" as an exogenous change in the level of risk aversion of U.S. households and financial traders.

In the proposed model, excess returns arise as compensation for financial traders to hold the currency risk of the SOE, and the pattern of excess returns fluctuations depends on the position that traders hold on the SOE bond. A SOE with net external debt requires traders to hold a long position on its currency, while traders are required to hold a short position on the currency of a net-lender SOE. In this context, a reduction in traders risk aversion induce traders to demand lower excess returns on net-borrower SOEs, while higher excess returns

[1] In this framework, economic developments in the large economy (the U.S.) affect the small economy, but not *vice versa*. The two-country SOE environment is thus consistent with our key empirical identification restrictions.

on net-lender SOEs. In our calibrated model, net-borrower (net-lender) SOE's currencies appreciate (depreciate) after a reduction in global risk aversion, and the net foreign asset to GDP (NFA/GDP) of the SOE is the relevant measure of its external imbalance, which determines the amount of currency risk held by international traders.

In the baseline model economy calibrated to the sample average NFA/GDP (-13.5%), global risk aversion shocks reproduce the observed comovement following an external shock. When global risk aversion declines, higher U.S. households' demand leads to an increase in U.S. output, inflation, and Federal Funds rate. Because U.S. financial traders are long in the SOE's currency, lower risk aversion induces them to demand lower excess returns on the SOE's currency, bringing about a large impact appreciation of the SOE's currency despite an equilibrium decline in the interest rate differential.[2]

Unlike global risk aversion shocks, other structural shocks (e.g. monetary policy shocks) generate negligible movements in excess currency returns. Global risk aversion shocks are in fact the main drivers of excess currency returns fluctuations and their predictability. Therefore, this parsimonious framework reproduces the empirical conditional properties of UIP deviations, provided that global risk aversion shocks are the main source of external fluctuations in SOEs' exchange rates.

We verify the model's central predictions on the role of NFA/GDP in the transmission of global risk aversion shocks. As outlined above, a reduction in traders risk aversion induces opposite interest rate (differentials) and exchange rate responses between net-borrower and net-lender SOEs. Thus, if global risk aversion shocks drive the external variation in SOEs' exchange rates, the identified external shock should generate different comovements between net-borrower and net-lender SOEs. We thus study the responses of SOEs separately for countries with positive and negative average NFA/GDP, and find support for our hypothesis. Following an expansionary external shock, countries with negative (positive) NFA/GDP experience a currency appreciation (depreciation) and lower (higher) interest rate differentials, and the differential patterns of excess currency returns drive these responses. We therefore argue that, overall, the empirical moments of interest rates and exchange rates do favor a representation of SOEs' exchange rates as being primarily driven by global risk aversion movements in segmented international asset markets.

[2] In response to this shock, domestic central banks cut their policy rate in the short run, in line with our empirical evidence, to avoid excessive fluctuations in consumer price inflation.

Related literature This paper presents a set of empirical moments that discipline the properties of the shocks underlying exchange rate fluctuations in SOEs. In particular, the main empirical findings are that (i) domestic shocks give rise to exchange rate fluctuations that are largely in line with UIP; (ii) one external shock explains a large variation in exchange rates and the bulk of fluctuations in excess currency returns; (iii) this external shock is associated with movements in global risk aversion and U.S. macroeconomic aggregates; (iv) the exchange rate response of SOEs to the external shock depends on its average NFA/GDP.

We show that a SOE model with segmented international asset markets, global risk aversion shocks, and a non-zero steady-state NFA/GDP satisfies these properties. The workhorse New-Keynesian SOE models in the literature á la Galí and Monacelli (2005) instead assume UIP, abstract from characterizing the sources of external variation, and assume zero steady-state NFA/GDP.[3,4] Recently, Itskhoki and Mukhin (2017, 2019) show that introducing a time-varying wedge in the UIP condition resolves several exchange rate puzzles in international macroeconomics. In Itskhoki and Mukhin's model, UIP deviations are generated by noise trader shocks in segmented international asset markets.[5] Within the class of models with segmented international asset markets, we show that a distinct shock – global risk aversion shock – better characterizes the documented properties of UIP deviations. In fact, global risk aversion shocks naturally reproduce the overall comovement induced by external shocks, and, in line with our evidence, their international transmission depends on a country's NFA/GDP. To the contrary, noise trader shocks do not reproduce the empirical comovement in U.S. macroeconomic aggregates, and cannot explain the documented cross-country differences in exchange rate responses to external disturbances. Akinci and Queralto (2018) propose a New Keynesian model in which endogenous UIP deviations arise from limits to arbitrage in private intermediation. In Akinci and Queralto's (2018) model, large UIP deviations arise in response to both domestic and external shocks. To the contrary, our model can rationalize the evidence that the domestic

[3] See also Gopinath et al. (2020).

[4] While nearly all open economy models assume zero steady-state NFA/GDP, some exceptions are Benigno (2009), Cavallo and Ghironi (2002), Ghironi (2008) and Ghironi et al. (2008), but do not study their implications for the transmission of global risk aversion shocks in segmented international asset markets.

[5] Devereux and Engel (2002), Eichenbaum et al. (2020), Cavallino (2019), and Fanelli and Straub (2018) also develop models with shocks to the UIP condition. These shocks share the same properties of noise-trader shocks.

variation in SOEs' exchange rates is largely consistent with UIP.

By documenting new conditional properties of UIP deviations, our findings contribute to the literature on the so-called forward premium puzzle (see, e.g., Engel, 2014). While we characterize the conditional properties of UIP violations of *both* domestic and external shocks, some recent papers emphasize the importance of global shocks in driving excess currency returns. Using firm-level data from Turkey, di Giovanni et al. (2017) document the presence of significant UIP deviations at both firm and country level, and show that these are strongly correlated with movements in the VIX. Lustig et al. (2011, 2014) document that excess returns on different carry trade strategies are intimately related to world-wide risk factors.[6]

Our finding that external imbalances matter for the transmission of external shocks to SOEs' currencies extends the existing evidence on the relationship between external imbalances and exchange rate movements. Gourinchas and Rey (2007) document that movements in external imbalances predict future exchange rates changes. Della Corte et al. (2016) show that a global imbalance risk factor explains the cross-sectional variation in currency excess returns, while Hong and Yogo (2012) show that futures-market speculators' positions help predict currency returns.[7]

We contribute to the literature on the empirical effects of external/global shocks in SOEs, by characterizing the properties of the main external driver of exchange rate fluctuations. While most papers aim to identify the effects of *specific* external shocks, our approach is designed to extract the largest external variation in exchange rates without *a priori* structural assumptions on its structural nature.[8] The literature on the global financial cycle (cf. Bruno and Shin (2015), Rey (2013) and Miranda-Agrippino and Rey (2020)) documents large financial spillovers to global asset prices associated with movements in global risk aversion, typically proxied by the VIX, and study the effects of U.S. monetary policy. While we also find that the main external driver of SOEs' exchange rates is associated with changes in global risk aversion, we interpret it as resulting from global risk aversion shocks.

[6] See also Lustig and Verdelhan (2019) and Hassan and Mano (2019).

[7] See also Adrian et al. (2009), Adrian et al. (2011), and Liao and Zhang (2020).

[8] A list of papers that study the effect of specific U.S. or global shocks on SOEs include Canova (2005), Uribe and Yue (2006), Mackowiak (2007), Akinci (2013), Levchenko and Pandalai-Nayar (2020), Ben Zeev et al. (2017), Vicondoa (2019), Davis and Zlate (2019), Georgiadis and Mehl (2016), Iacoviello and Navarro (2018), Cesa-Bianchi et al. (2018), Bhattarai et al. (2019), Ilzetzki and Jin (2020) and Fernández et al. (2016).

We believe that this provides a better characterization of the source of external variation in exchange rates, as it leads to positive comovement among U.S. output, inflation, and interest rates.[9]

1 Decomposing the exchange rate variation in SOEs

In this section, we illustrate the approach we take in separately identifying the domestic and external sources of exchange rate variation in SOEs. After briefly describing the dataset, we outline the identifying assumptions underlying the proposed approach, and explain how to implement it in a VAR framework.

Dataset We focus on a group of advanced and emerging SOEs: Australia, Austria, Belgium, Brazil, Canada, France, Germany, Indonesia, Italy, Japan, Mexico, New Zealand, Norway, Philippines, South Africa, South Korea, Switzerland, and United Kingdom. We analyze time periods that are characterized by a flexible exchange rate regime, following Ilzetzki et al.'s (2017) classification. The longest sample period covers 1974:1-2010:12. For Eurozone countries, we used their national exchange rates before the introduction of the Euro as separate episodes. Further details on data sources and selection criteria are reported in Appendix A.

Identifying assumptions At this stage, our objective is to separately identify the domestic and external sources of exchange rate variation in SOEs, while being agnostic about their structural interpretation. Our main identifying assumption is that any domestic shocks of the SOE do not affect external variables *at any horizon*, while external shocks affect external variables at least at some horizon. This restriction holds in any class of SOE models – in fact it is the very definition of a SOE – regardless of the underlying set of structural disturbances and transmission mechanisms. More specifically, we note that (i) in an *open* economy, domestic variables respond to external shocks, and (ii) in a *small* economy, domestic (i.e. SOE-specific) shocks do not affect external variables (such as U.S. output, prices, and interest rates).

After having identified the domestic shock(s), we further identify the most important source of external variation is SOEs' exchange rates by selecting the external shock that

[9] See also Habib and Venditti (2019)

explains the majority exchange rate fluctuations of a SOE, while being orthogonal to the identified domestic shock(s). Next, we show that these identifying restrictions allow one to achieve the outlined objectives in any VARs that includes SOEs' exchange rates and at least one external variable.

Baseline SOE VAR. For each SOE in the dataset, the baseline is a three-variable VAR that features the U.S. short-term interest rate, the SOE short-term interest rate, and the bilateral nominal exchange rate. The three-variable VAR allows us to compare our results to those obtained in standard UIP regressions, as we do in Section 2. In addition, we verify that our three-variable VARs are informationally sufficient, by applying the test proposed by Forni and Gambetti (2014). In Section 3, we extend our VARs to feature additional macroeconomic and financial variables in order to trace out the effects of identified shocks on other macroeconomic variables.

VAR implementation Consider a three-variable VAR with the Federal Funds rate ($r^{\star}$), the short-term interest rate of SOE k (r_k), and the logarithm of the bilateral nominal exchange rate between country k's currency and the U.S. dollar (s). 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. The model is specified in levels and the number of lags is chosen according to the Akaike information criterion.[10]

Let $Y_t \equiv [r^{\star}_t \;\; r_{k,t} \;\; s_t]'$ be the 3×1 vector of observable variables of length T. Denote by $Y_t = B(L)u_t$ the reduced-form moving average representation in the levels of the observable variables, formed by estimating an unrestricted VAR. 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:

$$Y_t = B(L) A_0 \varepsilon_t. \tag{2}$$

[10] Unlike the case of a vector error correction model, the estimators of the impulse responses of a VAR in levels are consistent in the presence of nonstationary but cointegrated variables where the form of cointegration is unknown. Furthermore, estimators are consistent even in the absence of cointegrating relations among the variables, provided that enough lags are included in the VAR (see Hamilton, 1994).

We assume that the structural shocks are orthogonal with unitary variance. Therefore, the impact matrix A_0 has to satisfy the condition $A_0 A_0' = \Sigma$, where Σ is the variance-covariance matrix of innovations. This restriction is not sufficient to identify the matrix A_0. In fact, for any matrix A_0 there exists an alternative matrix $\tilde{A_0}$ such that $\tilde{A_0} D = A_0$, where D is an orthonormal matrix, that also satisfies $\tilde{A_0}\tilde{A_0}' = \Sigma$. Therefore, for some arbitrary matrix $\tilde{A}_0$ satisfying $\tilde{A_0}\tilde{A_0}' = \Sigma$ (e.g., the Cholesky decomposition of Σ), identification boils down to choosing an orthonormal matrix D.

Our first set of identifying restrictions consists in finding the column of D that isolates domestic from external sources of fluctuations. Formally, denote the k-step ahead forecast error of the i-th variable $y_{i,t}$ in Y_t by

$$y_{i,t+k} - E_{t-1} y_{i,t+k} = e_i' \left[\sum_{\tau=0}^{k-1} B_\tau \tilde{A}_0 D \varepsilon_{t+k-\tau} \right]$$

where e_i is a column vector with 1 in the i-th position and zeros elsewhere, and B_τ is the matrix of moving average coefficients at horizon τ.

We choose d_1, the first column of D, in order to minimize the contribution of the domestic shock on the forecast error variance of the Federal Funds rate up to a sufficiently long forecast horizon H. Formally, we solve

$$d_1^* = \underset{d_1}{\operatorname{argmin}} \;\; e_1' \left[\sum_{k=0}^{H} \sum_{\tau=0}^{k-1} B_\tau \tilde{A}_0 d_1 d_1' \tilde{A}_0' B_\tau' \right] e_1$$

subject to $d_1' d_1 = 1$.[11]

The above restrictions allow us to identify the shock that has the minimal contemporaneous and expected effect on the Federal Funds rate, i.e. the domestic shock.

Next, we are interested in identifying the most important external shock within the (residual) external variation. To do so, we draw from the maxshare identification method proposed by Uhlig (2003) and impose further restrictions that consist in finding the column of D that isolates the external shock that explains most of the forecast error variance of the exchange rate up to the horizon H, while being orthogonal to the domestic shock. Formally, we solve

[11] The problem is analogous to find the eigenvector associated with the smallest eigenvalue of the appropriately rearranged objective function.

$$d_2^* = \underset{d_2}{\text{argmax}} \; e_2' \left[\sum_{k=0}^{H} \sum_{\tau=0}^{k-1} B_\tau \tilde{A}_0 d_2 d_2' \tilde{A}_0' B_\tau' \right] e_2$$

subject to $d_2' d_2 = 1$ and $d_1' d_2 = 0$, where the last condition ensures the orthogonality between the domestic and the external shock.[12]

Finally, in the three-variate baseline, the last column of D can be recovered from observing that D must be an orthonormal matrix. However, the proposed identification method only requires to partially identify the matrix D, and therefore can be applied to VARs of any size.[13]

2 Conditional properties of exchange rates in SOEs

We examine whether the properties of exchange rates differ depending on their sources of fluctuations. The empirical evidence reported below is the result of estimating a set of individual-country VARs using the approach described in Section 1.

Along with the properties of exchange rates, we also study those of excess currency returns.[14] We define ex ante excess return on the foreign bond held from period t to period $t+m$, inclusive of the expected currency return, as:

$$\mathrm{E}_t\, \hat{x}_{t+m} \equiv \mathrm{E}_t\, \Delta \hat{s}_{t+m} - (\hat{r}_{t|m} - \hat{r}^\star_{t|m}) \tag{3}$$

where hatted variables denote series generated by the estimated VAR, E_t is the expectation operator conditional on time-t information, and $\hat{r}_{t|m}$ ($\hat{r}^\star_{t|m}$) are m-month domestic (foreign) interest rates.[15] Expected excess currency returns are constructed using the expectations implied by the VAR. Non-zero ex ante excess returns point to violation of UIP. In fact, under UIP the exchange rate is expected to depreciate at a rate that equals the interest rate differential.

[12] The ordering of the vectors in D is without loss of generality.
[13] Note that one could use the so-called block exogeneity assumption to improve econometric efficiency of the estimators for the reduced form parameters. This assumption is often used in SOE VARs (see e.g. Uribe and Yue, 2006). However, in Appendix B we show that the assumption of block exogeneity is violated in most of the countries in our dataset. Therefore, we choose not to impose block exogeneity so to preserve consistency of the estimators for the reduced form parameters.
[14] In the analyses that follow we omit the subscript k when referring to country k's variable.
[15] Below, we report the returns from an investment of one year maturity on the foreign bond. That is, $m = 12$ months, which is the typical maturity of the domestic interest rates in our sample.

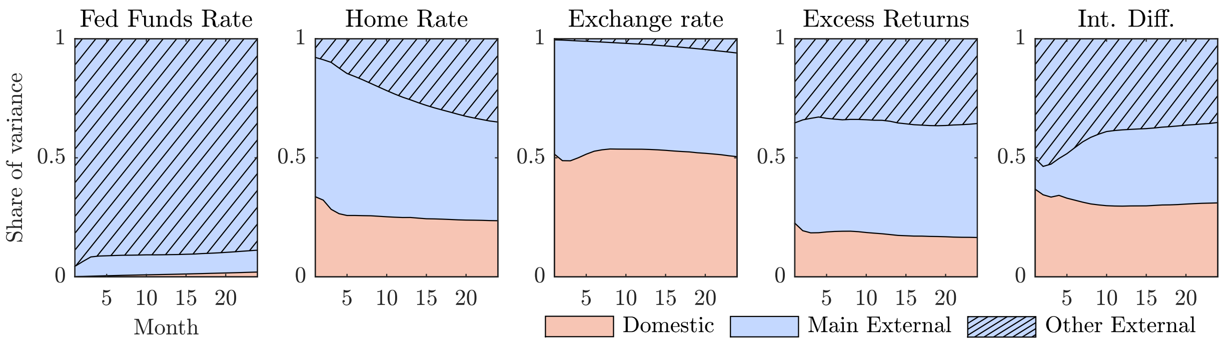


Figure 1: Relative contribution of domestic and external shocks

Note: The horizontal axes refer to forecast horizons, while the vertical axes denote the fraction of forecast error variance explained by domestic and external shocks. Excess returns are one-year ahead expected excess returns on the foreign currency.

Relative importance of domestic and external shocks We first assess the relative importance of domestic and external shocks in driving exchange rates and excess currency returns. To this end, Figure 1 reports the variance decomposition of the variables in the VAR, along with excess currency returns and interest rate differentials. The Federal Funds rate appears to be exclusively explained by external disturbances, indicating that the external shocks capture all the variation in the Federal Funds rate. The domestic interest rate is also predominantly driven by external shocks, suggesting that SOE monetary policy is largely devoted to respond to external sources of fluctuations. Crucially, we find that domestic and external shocks explain a comparable fraction of exchange rate variation, while excess currency returns are to a large extent explained by external disturbances.

Furthermore, we find that a single external shock drives virtually all of the external variation in exchange rates, as well as at least two-thirds of the external variation in excess currency returns. Because the external variation in SOEs' exchange rates can be largely summarized by this single external shock, below we solely focus on this source of external fluctuations.

The forward premium puzzle The Fama regression (see Fama, 1984) is the basis for the forward premium puzzle, that is the empirical observation that high interest rate differentials $(r_t - r_t^\star)$ tend to predict high expected currency returns. A familiar version of the

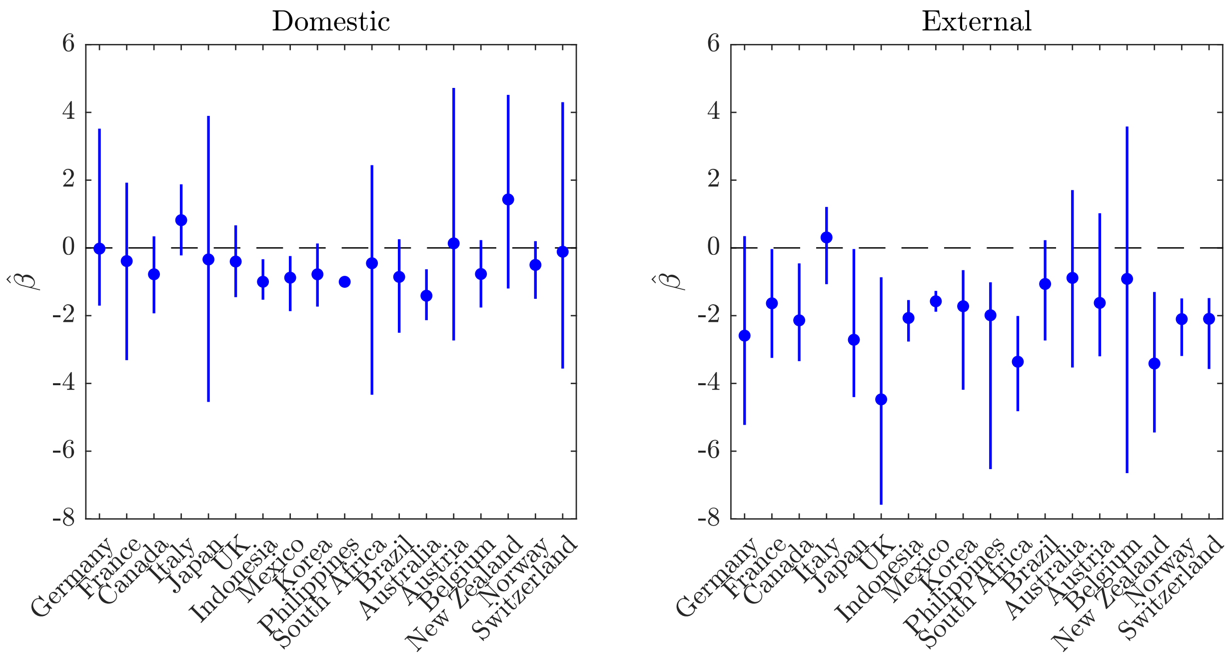


Figure 2: Forward premium puzzle

Note: The figure reports the UIP regression coefficients, $\hat{\beta}$, in conditional versions of the Fama's (1984) regression: $\mathrm{E}_t \hat{x}_{t+m} = \alpha + \beta(\hat{r}_{t|m} - \hat{r}^{\star}_{t|m}) + \varepsilon_t$. Excess returns on the foreign currency $\mathrm{E}_t \hat{x}_{t+m}$, defined in Equation (3), are constructed using the conditional expectations implied by the VAR, where $m = 12$ months. For each country, we report the median value of the coefficient along with 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

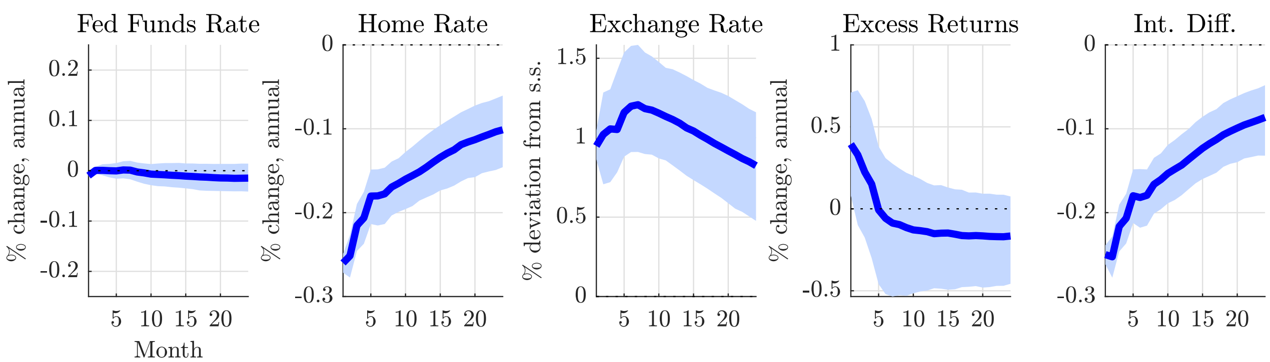
original regression specification of Fama (1984) reads:

$$x_{t+1} = \alpha + \beta(r_t - r^{\star}_t). \tag{4}$$

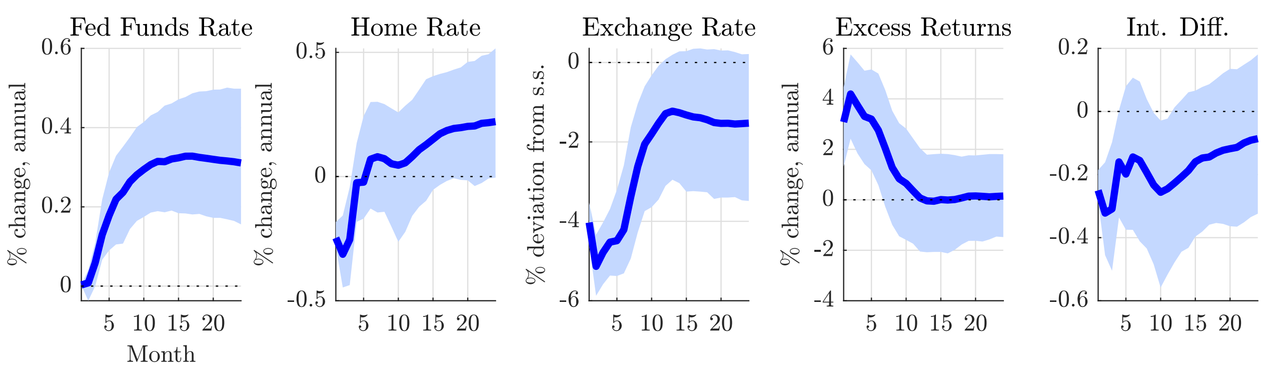
Under the null of UIP, $\beta = 0$ implying that average excess returns are not predictable by the current interest rate differential. To the contrary, typical estimates reveal that $\beta < 0$, meaning that higher interest rate differentials are associated with higher excess returns on the home currency.

We inquire whether our decomposition can shed light on the sources of the forward premium puzzle. To do so, we estimate two sets of β coefficients of Eq. (4). In particular, we first run the Fama regression on data generated only under domestic shocks, and then we do the same for external shocks. Figure 2 reports the estimated conditional β coefficients. A difference in the estimated βs emerges. The Fama coefficients computed under domestic shocks are by and large not statistically different from zero. In contrast, the data generated by external shocks only reproduces the forward premium puzzle: the β coefficients are, in fact, for the most part negative and significant.

In light of the results in figures 1 and 2 we conclude that the external variation in the exchange rates is associated with significant and predictable UIP violations, and it is, in fact, responsible for the forward premium puzzle. Conversely, the domestic variation in exchange rates does not significantly contribute to the variance or the predictability of UIP violations. Since the dynamics of UIP violations influence the dynamics of the level of the exchange rate (cf. Engel, 2016), this finding suggests that domestic and external shocks may imply different exchange rate dynamics. We explore this question next.



(a) Domestic



(b) External

Figure 3: Empirical impulse responses

Note: The lines denote median IRFs by countries with corresponding 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR. The external shock is normalized to have the same one-year response on the Federal Funds rate across all countries. Both shocks are rescaled to deliver a 0.25% impact decline in the interest rate differential. Excess returns are one-year ahead expected excess returns on the foreign currency.

Conditional interest rate and exchange rate dynamics We investigate the comovement among interest rates, exchange rates, and excess currency returns implied by domestic and external shocks. To do so, we study the impulse response functions (IRFs) generated by each of these shocks. We frame our results in the form of median IRFs across countries. Bias-corrected bootstrapped 90% confidence intervals are based on 1000 replications (see Kilian, 1998).

Figure 3 collects our findings. Following a domestic shock that leads to a 0.25% decline in the interest rate differential, the exchange rate depreciates on impact and then experiences an appreciation towards its steady state. These exchange rate dynamics are qualitatively in line with the prediction of UIP: following a decline in the interest rate differential, the exchange rate is expected to appreciate at a rate that is comparable to the decline in the interest rate differential, as reflected by the largely insignificant response of excess currency returns.[16]

Following an external shock that leads to a 0.25% impact decline in the interest rate differential, the exchange rates appreciates on impact and then experiences a sustained depreciation towards its steady state. These exchange rate dynamics run contrary to the prediction of UIP. UIP predicts that in response to the initial decline in interest rate differentials the exchange rate should experience positive rates of appreciation. On the contrary, the exchange rate fails to appreciate and, in fact, depreciates. This violation of UIP is accounted for by large and persistent negative excess returns on the domestic currency.

The different conditional patterns of UIP violations are so large that they generate opposite comovement between the interest rate differential and the level of the exchange rate across domestic and external shocks. Conditional on domestic shocks, low interest rate differentials are associated with a depreciated domestic currency. Conditional on external shocks, low interest rate differentials are associated with an appreciated currency. To see how the patterns of excess currency returns contribute to the level of the exchange rate, one can iterate Eq. (3) forward and obtain:

$$s_t = -\sum_{j=0}^{\infty} \mathrm{E}_t \left(r_{t+j} - r^{\star}_{t+j} \right) - \sum_{j=0}^{\infty} \mathrm{E}_t \, x_{t+j+1} + \lim_{j \to \infty} \mathrm{E}_t \, s_{t+j} \tag{5}$$

The level of the exchange rate s_t is thus shaped by the expected path of interest rate differentials and excess returns. A decline in the path of the interest rate differential implies

[16] The short-run excess returns following the domestic shock account for the hump-shaped response of the exchange rate. The resulting "exchange rate delayed overshooting" is, however, small and short-lived.

a depreciated currency, *ceteris paribus*. This is what we observe under domestic shocks, where excess returns are generally small. Conditional on external shocks, low interest rate differentials are associated with an appreciated currency. This relationship obtains because of the large and persistent excess currency returns following external shocks. While also the expectation of the long-run value of the exchange rate affects the current exchange rate level, its relative contribution is negligible since, conditional on a shock, the VAR generates stationary time series.

To summarize, we find that domestic sources of fluctuations in SOEs produce exchange rate dynamics that are generally in line with UIP. To the contrary, we find that one external shock contributes to a significant fraction of the variation in SOEs' exchange rates and excess currency returns, and it is responsible for the emergence of the forward premium puzzle. The size and patterns of excess returns imply that this single external shock is associated with a positive comovement between interest rate differentials and exchange rates. A natural question is whether this external shock has an appealing interpretation. To answer this question, we trace out the effects of this external shock on key U.S. macroeconomic financial variables.

3 External shocks are global risk aversion shocks

Our decomposition approach is agnostic about the structural nature of domestic and external shocks. In fact, it imposes no assumptions on the economy's underlying structural shocks or propagation mechanisms. The resulting empirical evidence indicates that one external source of fluctuations is responsible for a large fraction of the observed variation and predictability of excess currency return. It is natural at this point to ask whether this one shock generates comovements that can be characterized by a parsimonious model. To answer this question, we explore the dynamics effects of this external shock on a number of U.S. macroeconomic and financial variables that are typically included in the related literature.

In particular, we extend our VARs to study the effects of the identified external shock on U.S. industrial production, U.S. Consumer Price Index (CPI) inflation, and the Chicago Board Options Exchange Volatility Index (VIX), a forward-looking measure of uncertainty and risk aversion. These variables are available at monthly frequencies, and provide a

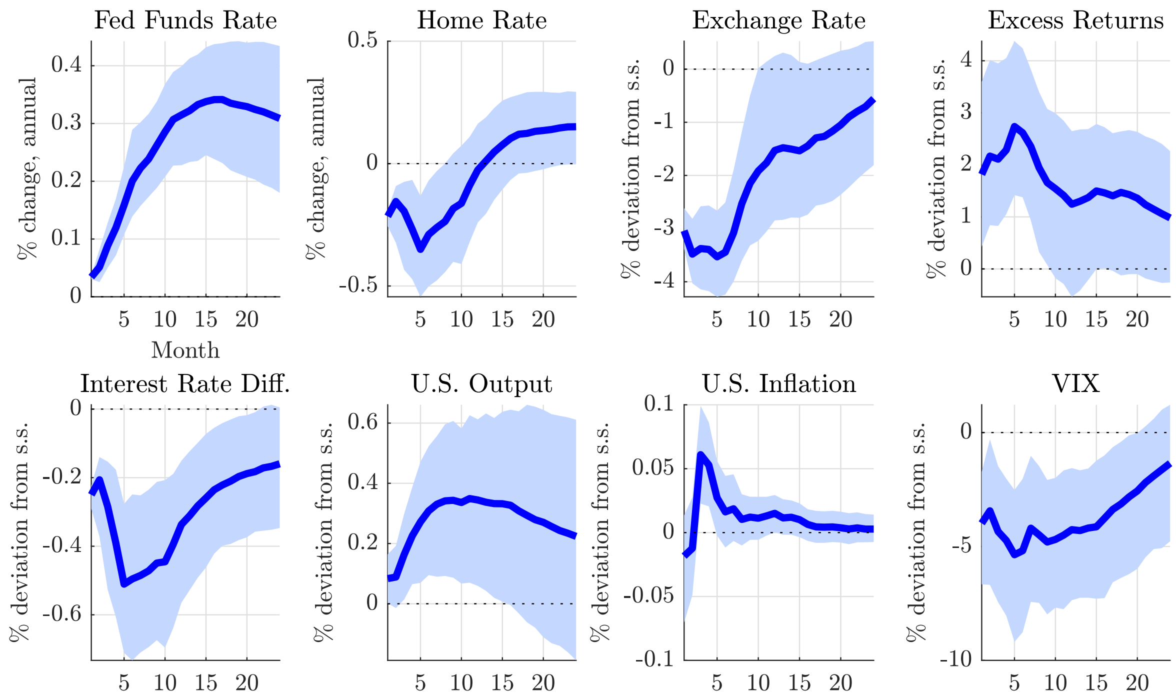


Figure 4: Empirical impulse responses to an external shock (extended VARs)

Note: This figure depicts the estimated IRFs to an external shock in VARs that include a set of external variables. We run four-variable VARs that include the three baseline variables and either U.S. industrial production, U.S. CPI inflation, or the VIX ordered fourth. The lines denote median IRFs across countries and VAR specification. The external shock is normalized to have the same one-year-ahead response on the Federal Funds rate across all countries. The shaded areas are the corresponding 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR. Excess returns are one-year ahead expected excess returns on the foreign currency.

sufficient information set to gauge the nature of this external shocks.[17]

Figure 4 shows that the external shock leads to an increase in U.S. output, U.S. inflation and the Federal Funds rate – a comovement that is typical of demand-driven expansions. In addition, these dynamics are associated with a temporary decline in the VIX, and generate significant appreciations of SOEs' exchange rates against the U.S. dollar. The interest rates of SOEs declines in the short run.

Several recent papers have documented that global asset prices display significant comovement with the VIX, a common proxy of global risk aversion (see, e.g., Bruno and Shin, 2015, Rey, 2013, Miranda-Agrippino and Rey, 2020, Lustig et al., 2011). In Figure 5 we report the historical series of our external shock, along with the innovation in the VIX, computed as the residual of an AR(1) process. We find that our estimated external shocks

[17] Unfortunately, time series of SOE industrial production or CPI inflation are not consistently available at monthly frequency.

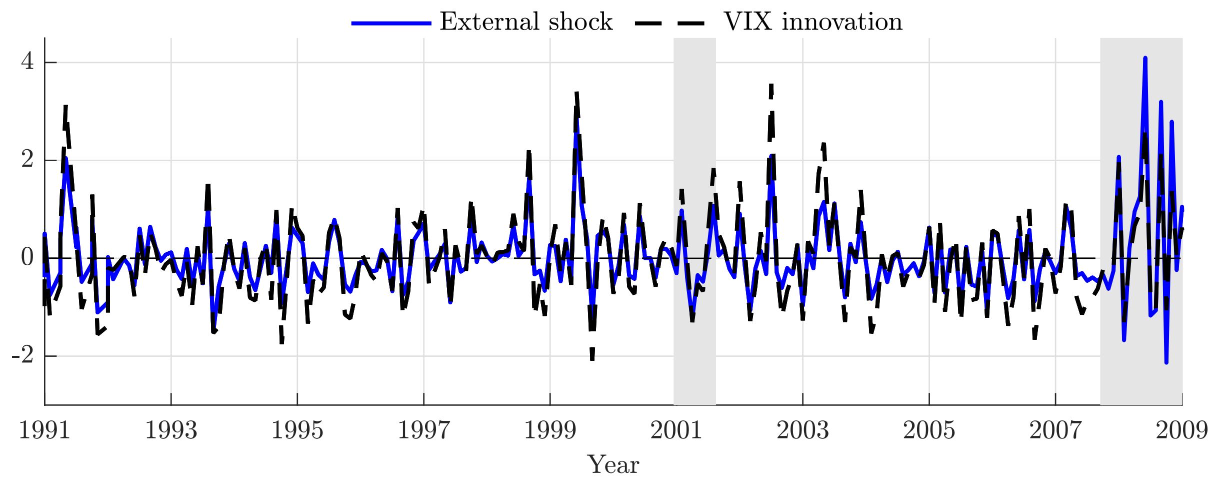


Figure 5: Identified external shocks and the VIX

Note: The figure plots the median of the identified series of external shocks and the innovation in the VIX. The latter is computed as the residual of an AR(1) process for the VIX.

are intimately associated with movements in global risk aversion. In fact, the correlation between our identified series of external shocks and the innovation in the VIX is around 0.8.

Overall, this evidence suggests that the external variation in the SOEs' exchange rates may be the result of fluctuations in risk aversion in international asset markets that also give rise to U.S. demand-like business cycles. We next formalize this interpretation in a dynamics two-country SOE model.

4 A SOE model with global risk aversion shocks

The above empirical findings place a new set of restrictions for models of open-economy fluctuations and exchange rate dynamics. We present a two-country SOE dynamic general equilibrium model with global risk aversion shocks, and show that it reproduces the documented conditional properties of UIP violations, provided that fluctuations in global risk aversion drive the external variation in SOE's exchange rates.[18]

4.1 Environment

Our model economy consists of two countries: the SOE and a large economy, where the latter is interpreted as the U.S.. The core of our model belongs to the international macroeconomic tradition initiated by Obstfeld and Rogoff (1995), in that it consists of a dynamic

[18] Appendix C contains the full derivation of the model.

general equilibrium open-economy model with monopolistically competitive producers, sticky prices, and complete exchange rate pass-through.[19] To characterize the SOE, we follow De Paoli (2009) in 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.

Asset markets are both incomplete and segmented. The only assets available in the economy are two nominal riskless bonds denominated in home and foreign currency. We assume that households in each economy can only trade the bond of their respective country, and all international transactions are intermediated by a set of U.S. financial traders who are averse to taking risky positions (c.f. Jeanne and Rose, 2002, Gabaix and Maggiori, 2015, Itskhoki and Mukhin, 2017). In our model, financial traders are a subset of U.S. households, and their risk aversion is time-varying.[20]

4.1.1 Households and the financial sector

The world economy consists of a continuum of agents of unit mass, where the population in the segment $[0,n)$ belongs to the home (H) country and the population in the segment $(n,1]$ belongs to the foreign (F) country.

Home economy The home economy is populated by a representative household whose preferences are given by

$$\mathrm{E}_t \sum_{j=0}^{\infty} \beta^j \left[\frac{C_t^{1-\omega}}{1-\omega} - \frac{N_t^{1+\eta}}{1+\eta} \right] \tag{6}$$

where N_t denotes hours worked, and C_t is a composite consumption index defined by

$$C_t \equiv \left[(\nu)^{\frac{1}{\theta}} (C_{H,t})^{\frac{\theta-1}{\theta}} + (1-\nu)^{\frac{1}{\theta}} (C_{F,t})^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

where $C_{H,t}$ is an index of consumption of home goods given by the CES function

$$C_{H,t} \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\iota}} \int_0^n C_{H,t}(i)^{\frac{\iota-1}{\iota}} \mathrm{d}i \right]^{\frac{\iota}{\iota-1}}$$

where $i \in [0,1]$ denotes the good variety. $C_{F,t}$ is an index of goods imported from the

[19] Complete exchange rate pass through obtains because prices are set in the producer's currency.

[20] Because financial traders are a subset of U.S. households, the U.S. is interpreted as the center of the international financial system.

foreign country given by an analogous CES function:

$$C_{F,t} \equiv \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\iota}} \int_n^1 C_{F,t}(i)^{\frac{\iota-1}{\iota}} \mathrm{d}i \right]^{\frac{\iota}{\iota-1}}$$

Parameter $\iota > 1$ denotes the elasticity of substitution between varieties (produced within any given country). Parameter $1 - \nu \in [0,1]$ governs the home consumers' preferences for foreign goods, and is a function of the relative size of the foreign economy, $1-n$, and of the degree of openness, λ, namely $1-\nu = (1-n)\lambda$. Parameter $\theta > 0$ measures the substitutability between home and foreign goods, from the viewpoint of the home consumer.

Home households can trade only a one-period nominal bond, which is denominated in home currency. The home household's flow budget constraint is given by

$$\frac{B_{t+1}}{R_t} + P_t C_t = W_t N_t + B_t$$

where B_{t+1} denotes the nominal balance of home bonds, R_t is the nominal interest rate on the home bond, P_t is the price index of the composite consumption good, C_t, and W_t is the nominal wage rate. The problem of the home household consists in maximizing its utility (Eq. 6) subject to the budget constraint (Eq. 7). The first-order conditions of this problem are standard and therefore relegated to Appendix C.

Foreign economy The foreign economy is populated by a continuum of households. At the beginning of each period, all members of a household are identical and share the household's assets. During the period, the members are separated from each other, and each member receives a shock that determines her role in the period. A member will be a trader with probability m_t, and a worker with probability $1 - m_t$. These shocks are i.i.d. among the members. We assume that the share of members that operate as traders in the international financial market is proportional to the output of the home economy (that is, $m_t = \mu n P^{\star}_{H,t} Y_t$). This assumption entails that traders devote a larger part of their balance sheets to bonds issued by larger economies. The members' preferences are aggregated and represented by the following utility function of the household:

$$\mathrm{E}_t \sum_{j=0}^{\infty} \beta^{\star j} \left[m_t \mathscr{U}(\widetilde{C}^{\star}_t) + (1 - m_t) \mathscr{U}(C^{\star}_t, N^{\star}_t) \right]$$

where

$$\mathscr{U}(\widetilde{C}_t^\star) \equiv \frac{\left(\widetilde{C}_t^\star\right)^{1-\omega_t^\star}}{1-\omega_t^\star} \tag{7}$$

and

$$\mathscr{U}(C_t^\star, N_t^\star) \equiv \frac{\left(C_t^\star\right)^{1-\omega_t^\star}}{1-\omega_t^\star} - \frac{\left(N_t^\star\right)^{1+\eta}}{1+\eta}$$

Here, $\widetilde{C}_t^\star$ is the consumption of traders, $C_t^\star$ is the consumption of workers, and $\omega_t^\star$ governs the degree of (relative) risk aversion of both household's members. We assume that foreign households' risk aversion is time varying. In particular, $\omega_t^\star = \omega^\star \exp(\xi_t)$ and its time-varying component evolves according to the following autoregressive process:

$$\xi_t = \rho_\xi \xi_{t-1} + \varepsilon_{\xi,t} \tag{8}$$

where $\varepsilon_{\xi,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviation σ_ξ. The problem of the worker-members of the foreign household is standard, and analogous to the one of the home household. Her intertemporal budget constraint reads

$$\frac{B_{t+1}^\star}{R_t^\star} + P_t^\star C_t^\star = B_t^\star + W_t^\star N_t^\star - \frac{m_t}{1-m_t} T^\star$$

where the last term is an intrahousehold transfer that accrues to the trader-members of the households, and ensures that their consumption is always positive. The other foreign variables are interpreted analogously to their home counterparts. The first-order conditions of this problem are standard and therefore relegated to Appendix C.

Traders on the foreign exchange market The trader-members of the foreign household are the only agents who can trade bonds internationally. Traders collectively take a zero-capital position $\widetilde{D}_{t+1}$ in home-currency bonds and short $\widetilde{D}_{t+1}^\star = -\widetilde{D}_{t+1}/S_t$ foreign-currency bonds, or *vice versa*. Here, S_t is the nominal exchange rate, defined to be the price of the foreign currency unit, as in the empirical section. The exchange rate is relevant for the balance sheet of international traders because each economy offers a bond in its own currency. A one U.S.-dollar position generates a U.S.-dollar return of $\widetilde{R}_{t+1} = R_t^\star - R_t \frac{S_t}{S_{t+1}}$.

The problem of each individual trader consists in choosing a position $d_{t+1}^\star$ to maximize (7) subject to the budget constraint $P_t^\star \widetilde{C}_t^\star = T^\star + \widetilde{R}_{t+1} d_{t+1}^\star$, where $T^\star$ denotes a constant intra-household transfer that ensures that each trader's consumption is always non-negative.

In Appendix C.1, we show that the individual trader's problem is approximately equivalent to maximizing a mean-variance utility of returns. The resulting demand for home-currency bonds by the financial traders is then:

$$\widetilde{D}^{\star}_{t+1} = \frac{m_t}{\omega^{\star}_t} \frac{\mathrm{E}_t \widetilde{R}_{t+1}}{\mathrm{Var}_t(\widetilde{R}_{t+1})} \Rightarrow \frac{\widetilde{D}_{t+1}}{S_t} = -\frac{m_t}{\omega^{\star}_t} \frac{\mathrm{E}_t \widetilde{R}_{t+1}}{\mathrm{Var}_t(\widetilde{R}_{t+1})}. \tag{9}$$

The financial market clears when the interest rates R_t and $R^{\star}_t$ are such that $B_{t+1} + D_{t+1} = 0$ and $B^{\star}_{t+1} + D^{\star}_{t+1} = 0$. Thus, in equilibrium the net foreign asset position of home equals net foreign liabilities of foreign, $nB_{t+1} = -(1-n)B^{\star}_{t+1}S_t$, in aggregate per-capita terms.[21] Thus, Eq. (9) becomes:

$$\frac{B_{t+1}}{P_{H,t}Y_t} = \frac{\mu}{\omega^{\star}_t} \frac{\mathrm{E}_t \left(R^{\star}_t - R_t \frac{S_t}{S_{t+1}} \right)}{\mathrm{Var}_t(\widetilde{R}_{t+1})}. \tag{10}$$

We follow De Paoli (2009) in taking the limit for $n \to 0$ to portray the SOE. This feature implies that economic developments in the large economy affect the SOE, but the reverse is not true. Under this assumption, the mass of household-traders $m_t \to 0$, $\forall t$. As a result, traders influence the model's behavioral equations only through their pricing of the exchange rate. The resulting profits from their trading activity are infinitesimally small from the standpoint of the foreign economy, and don't affect the household's budget constraint.

We solve the model using a first-order approximation around a steady state that allows for non-zero NFA. Using the international bond market clearing condition, the linearized version of the traders' bond demand (Eq. 10) reads:

$$\mathrm{E}_t \Delta s_{t+1} - (r_t - r^{\star}_t) = \chi(\mathtt{b}\xi_t + b_{t+1}) \tag{11}$$

where $\chi \equiv \frac{\sigma_s^2}{\mu/\omega^{\star}}$ governs traders' steady-state risk bearing capacity, and $\mathtt{b} \equiv B/P_H Y$ is the steady-state NFA/GDP of the home economy (or SOE).

Eq. (11) represents the modified UIP condition of the model economy. As in Itskhoki and Mukhin (2017), the standard UIP condition obtains as a special case when the steady-state risk-bearing capacity of traders $\chi = 0$. In our model, $\chi = 0$ if traders are risk neutral

[21] Here, $nD_t = \widetilde{D}_t$ and $(1-n)D^{\star}_t = \widetilde{D}^{\star}_t$.

($\omega^\star = 0$), the size of the financial sector $\mu \to \infty$, or the exchange rate is non-stochastic, $\sigma_s^2 \equiv \text{Var}_t(\Delta s_{t+1}) = 0$.[22] Instead, if $\chi > 0$, the model economy features two sources of UIP violations: exogenous changes in global risk aversion ξ_t, and endogenous movements in NFA/GDP, b_{t+1}.[23]

First and foremost, global risk aversion shocks lead to fluctuations in excess currency returns. In our linearized model, the *direct* effect of global risk aversion shocks on a country's excess currency returns crucially depends on its *steady-state* NFA/GDP, $\mathtt{b}$. If $\mathtt{b} < 0$, the home country's imbalance requires financial traders to have a long position in the home currency (generating a positive steady-state expected excess return on this currency). In this case, a reduction in global risk aversion ($\xi_t < 0$) induces financial traders to require lower excess returns on the home currency, causing an *expected* depreciation of the home currency. To the contrary, if $\mathtt{b} > 0$, the home country features a positive external imbalance and its currency enjoys negative steady-state expected excess returns. After a reduction in global risk aversion ($\xi_t < 0$) financial traders require higher (or less negative) excess returns on the home currency, causing an *expected* appreciation of the SOE's exchange rate.

Second, for a given level of risk aversion, endogenous *changes* in NFA/GDP also generate movements in excess currency returns. If the equilibrium imbalance of the home economy worsens ($b_{t+1} < 0$), traders take a longer position in the home currency and demand higher excess returns on this currency. While this channel leads to qualitative fluctuations in excess currency returns after potentially any shock, it will play a quantitatively minor role in our calibrated model.

To summarize, traders need to be compensated for holding currency risk, and this compensation is proportional to their risk aversion (see Gabaix and Maggiori, 2015). In this context, a reduction in traders' risk aversion induce them to change the required compensation on the overall stock of bonds that they hold. As a result, a reduction in traders' risk aversion causes a decline in excess returns for SOEs with NFA/GDP<0, and an increase in excess returns for SOEs with NFA/GDP>0. Moreover, the magnitude of fluctuations in excess returns following global risk aversion shocks is proportional to the extent of the SOE external imbalance ($|\mathtt{b}|$).

[22] The variance of the innovation to the nominal exchange rate, σ_s^2, is endogenously determined.

[23] b_{t+1} denotes the equilibrium deviation of NFA/GDP relative to its steady state value. That is $b_{t+1} \equiv B_{t+1}/P_{H,t}Y_t - B/P_H Y$

4.1.2 Firms

Each country features a continuum of firms that produce output under a constant-returns-to-scale production function. The economy-wide production functions are thus $Y_t = AN_t$ and $Y_t^\star = AN_t^\star$ for the home and foreign goods, respectively.

We assume that each producer sets its price in her own currency. In this case the law of one price holds. Under these conditions, $P_{H,t} = S_t P_{H,t}^\star$ and $P_{F,t} = S_t P_{F,t}^\star$ for each t. However, the home bias specification leads to deviations from purchasing power parity; that is, $P_t \neq S_t P_t^\star$. Prices follow a partial adjustment rule as in Calvo (1983). Producers of differentiated goods know the form of their individual demand functions, and maximize profits taking aggregate market prices as given. In each period a fraction, $\alpha \in [0,1)$, of randomly chosen producers is not allowed to change the nominal price of the goods they produce. The remaining fraction of firms, given by $1-\alpha$, chooses prices optimally by maximizing the expected discounted value of profits.

4.1.3 Monetary authorities

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

$$r_t^\star = \rho_r r_{t-1}^\star + (1-\rho_r)\phi\pi_t^\star + \varepsilon_{r^\star,t} \qquad r_t = \rho_r r_{t-1} + (1-\rho_r)\phi\pi_t + \varepsilon_{r,t}$$

where $\varepsilon_{r^\star,t}$ and $\varepsilon_{r,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviations $\sigma_{r^\star}$, and σ_r, respectively.[24] In line with central banks' practices, we assume that they target a measure of consumer price (CPI) inflation.

4.2 Solution, calibration and equilibrium conditions

In our model, the size of traders' balance sheet depends on risk perceptions. To account for risk in the computation of the model, we follow Coeurdacier et al. (2011) in deriving the "risky" steady state – a steady state in which agents expect future risk and the realization of shocks is zero at the current date. The risky steady state differs from the deterministic steady state only by second order terms related to variances and covariances of the endogenous variables. These second moments pin down the size of traders' long-run balance sheet. To obtain a non-zero steady-state NFA/GDP ($\mathtt{b} \neq 0$), we follow Ghironi et al. (2008)

[24] Monetary authorities are assumed to target a zero inflation steady state.

in allowing different discount factors across countries (that is $\beta \neq \beta^\star$). To analyze model dynamics, we then look at a first order log-linear approximation around the risky steady state.

Calibration The calibration is presented in Table 1, with one period in the model representing one month. Our benchmark value for b is a NFA to (annual) GDP of -13.5%, the average value in our sample of SOEs.[25] We set $\beta^\star = 0.9967$ 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 ($\alpha = 0.9$) implies an average duration of price contracts of about one year. We set the consumption share of imports $\lambda = 0.3$, and the trade elasticity $\theta = 1$. The Taylor-rule coefficient on consumer price inflation, ϕ, equals 1.5, while the parameter that governs the degree of interest rate smoothing, ρ_r, equals 0.90, in line with typically estimated values in the DSGE literature. We set $\rho_\xi = 0.90$. We set $\xi = 0.05$, so that the model reproduces the empirical autocorrelation of NFA/GDP in our sample of countries. [26]

Parameter	Description	Value
β	Home time discount	0.9977
$\beta^\star$	Foreign time discount	0.9801
ω	Home CRRA parameter	1
$\omega^\star$	Foreign CRRA parameter	1
η	Inverse Frisch elasticity	1
α	Calvo parameter	0.9
λ	Trade openness	0.3
θ	Trade elasticity	1
ρ_r	Taylor rule smoothing	0.9
ϕ	Taylor rule inflation response	1.5
χ	Coefficient on b_{t+1} in UIP	0.05
ρ_ξ	Autocorrelation risk aversion	0.9

Table 1: Calibration
One period in the model represents one month.

Equilibrium conditions We report below the model's log-linear equilibrium conditions,

[25] Annual data on NFA/GDP positions are from the updated and extended version of the dataset constructed by Lane and Milesi-Ferretti (2007).

[26] Without loss of generality we normalize the steady state so that $\ln(C^\star) = 1$.

evaluated at the risky steady state.[27] The equilibrium conditions that govern economic dynamics in the large (foreign) economy read:

$$\omega^\star \mathrm{E}_t \Delta c^\star_{t+1} + \omega^\star \mathrm{E}_t \Delta \xi_{t+1} = \beta^\star r^\star_t - \mathrm{E}_t \pi^\star_{t+1} \tag{12a}$$

$$\pi^\star_t = \beta^\star \mathrm{E}_t \pi^\star_{t+1} + \kappa^\star((\eta + \omega^\star)c^\star_t + \omega^\star \xi_t) \tag{12b}$$

$$r^\star_t = \rho r^\star_{t-1} + (1-\rho)\phi \pi^\star_t + \varepsilon_{r^\star,t} \tag{12c}$$

Given the exogenous processes, the economic dynamics in the large economy are fully described by the consumption Euler equation (Eq. 12a), the New Keynesian Phillips curve (Eq. 12b), and the monetary policy rule (Eq. 12c).[28] Both Eqs. (12a) and (12b) are influenced by shocks to foreign households' risk aversion ("global risk aversion shocks"), which act as "risk premium" shocks in the foreign household's Euler equation (cf. Smets and Wouters, 2007).

Home variables are determined according to the following system of log-linear equations:

$$\omega \mathrm{E}_t \Delta c_{t+1} = \widetilde{\beta} r_t - \mathrm{E}_t \pi_{t+1} \tag{13a}$$

$$\pi_{H,t} = \beta \mathrm{E}_t \pi_{H,t+1} + \kappa(\omega c_t + \eta y_t + \lambda(1-\lambda)^{-1} q_t) \tag{13b}$$

$$r_t = \rho r_{t-1} + (1-\rho)\phi \pi_t + \varepsilon_{r,t} \tag{13c}$$

$$\pi_t = (1-\lambda)\pi_{H,t} + \lambda(\Delta s_t + \pi^\star_t) \tag{13d}$$

$$y_t = \theta\lambda(1-\lambda)^{-1} q_t + (1-\lambda)(1+\mathrm{b}-\widetilde{\beta}\mathrm{b})c_t + \left[1-(1-\lambda)(1+\mathrm{b}-\widetilde{\beta}\mathrm{b})\right]\left(c^\star_t + \theta q_t\right) \tag{13e}$$

$$\widetilde{\beta}\left(b_{t+1} - \widetilde{\beta}\mathrm{b} r_t\right) - b_t + \mathrm{b}\left(\pi_{H,t} + \Delta y_t\right) = (1+\mathrm{b}-\widetilde{\beta}\mathrm{b})\left(y_t - c_t - \lambda(1-\lambda)^{-1} q_t\right) \tag{13f}$$

$$\Delta s_t = \Delta q_t - \pi^\star_t + \pi_t \tag{13g}$$

Since the SOE is effectively open to trade in goods and assets, it is affected by the dynamics of the exchange rate and foreign demand, as in the canonical model with complete exchange rate pass-through.[29] The key difference relative to the standard framework con-

[27] All variables are expressed as log deviations from their steady state, except for NFA/GDP (b_t) and interest rates (r_t and $r^\star_t$), which are expressed as percent changes from their steady state values. Also, $\widetilde{\beta} \equiv 1/\mathrm{R}$.

[28] The curvature parameter of the foreign economy's Phillips curve is given by $\kappa^\star \equiv \frac{(1-\beta^\star\alpha^\star)(1-\alpha^\star)}{\alpha^\star}$.

[29] Complete exchange rate pass-through implies that nominal exchange rate fluctuations directly translate into changes in home CPI (Eq. 13d), exactly because import prices are denominated in the (foreign) producer's

sists in the international asset market structure and the determination of exchange rates (see Eq. (11), described above).

There are three structural shocks in this environment: home and foreign monetary policy innovations ($\varepsilon_{r,t}$ and $\varepsilon_{r^\star,t}$), and shocks to global risk aversion ($\varepsilon_{\xi,t}$).

4.3 Equilibrium dynamics following a shock to global risk aversion

Figure 6 depicts the IRFs to a temporary reduction in global risk aversion. Consider first the response of the foreign (U.S.) economy. In the foreign economy, lower risk aversion induces households to increase current consumption, while firms' faced with higher demand raise their prices. The foreign central bank responds to the ensuing inflationary pressure by raising the nominal interest rate. In the foreign economy, a decline in global risk aversion is therefore associated with rising output, inflation, and the nominal interest rate.[30]

Consider now the response of the SOE to the reduction in global risk aversion. A global risk aversion shock affects the home SOE economy through its effect on the foreign demand for home goods and on the exchange rate, which primarily depends upon the SOE external position. In our baseline calibration we set NFA/GDP = −13.5%, which is the average NFA/GDP value in our sample. Since the baseline SOE is a net debtor, financial traders have a long position in the home currency. As a result, a decline in global risk aversion induces them to require lower excess returns on the home currency. This in part decreases the interest rate differential, and in part causes an expected depreciation of the home currency. Thus, the exchange rate appreciates on impact and gradually reverts back to its original level. In turn, the appreciation of the SOE's currency brings about a contemporaneous fall in (local-currency) import prices, putting downward pressure on home CPI inflation (see Eq. 13d). In our calibrated model, the deflationary forces implied by lower (home-currency) prices of imported goods govern the short-run dynamics of home CPI inflation, and lead to a reduction in the home interest rate.

Overall, our baseline model produces impulse responses to a global risk aversion shock that provide a natural interpretation of the comovement induced by the main external shock documented in Figure 4.

currency, and these adjust sluggishly.

[30] Since the SOE is infinitely small relative to the foreign economy, the SOE's NFA/GDP level does not influence economic dynamics in the foreign economy.

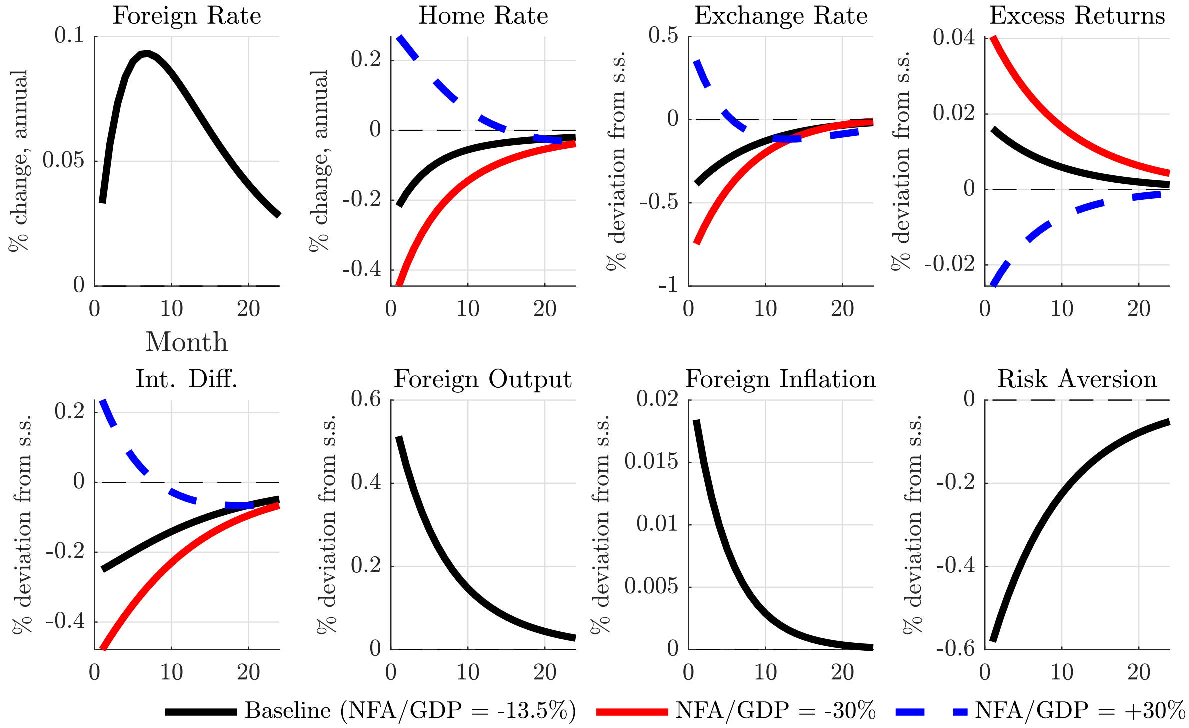


Figure 6: Theoretical IRFs to a temporary reduction in global risk aversion

Note: The impulse is an unanticipated reduction in the foreign economy's degree of risk aversion. The baseline calibration features $\mathtt{b} = -13.5\%$, that is the average NFA/GDP in our sample. Besides, we report IRFs for calibrations to the average NFA/GDP among net debtor countries ($\mathtt{b} = -30\%$), and to the average NFA/GDP among net lender countries ($\mathtt{b} = +30\%$). The impulse responses are rescaled to deliver a 0.25% impact decline in the interest rate differential under the baseline calibration. Excess returns are one-year ahead expected excess returns on the foreign currency.

The role of NFA/GDP To further examine the transmission mechanism of global risk aversion shocks, Figure 6 reports the impulse responses across SOEs with different steady-state NFA/GDP. In particular, the red line denotes a SOE with NFA/GDP = −30%, the average NFA/GDP among net debtor countries in our sample, while the blue line reports impulse responses for a SOE with NFA/GDP = 30%, the average NFA/GDP among net lender countries in our sample.

The SOE with a large and negative steady-state NFA/GDP (−30%) features economic responses that are qualitatively similar but significantly more pronounced relative to those obtained in the benchmark economy. In fact, while the sign of excess return fluctuations primarily depends on the *sign* of the steady-state NFA/GDP, their magnitude is largely determined by the *absolute value* of the steady-state NFA/GDP. [31]

[31] The fluctuations in real variables are also more pronounced in the economy with larger imbalances (not reported) as the exchange rate fluctuations do not play a shock-absorbing role.

Unlike the net debtor SOEs, the SOE with positive steady-state NFA/GDP (30%) experiences an increase in excess returns on its currency following a reduction in global risk aversion. The net external surplus requires traders to have a short position in the home currency. While this is associated with negative steady-state excess currency returns, a reduction in global risk aversion induces traders to require higher (or less negative) excess returns on the home currency. This is accounted for in part by a higher interest rate differential, and in part by an expected depreciation of the home currency. In fact, in the net lender SOE, the exchange rate depreciates on impact and gradually reverts back to its original level. The depreciation of the home currency is associated with an increase in (local-currency) import prices, which contribute to higher home CPI inflation, and lead to a increase in the home interest rate.

To summarize, the external imbalances of the SOE govern the transmission of global risk aversion shocks. In particular, the sign of the steady-state NFA/GDP of the SOE determine the qualitative responses of interest rates and interest rate differentials, exchange rates, and excess currency returns to global risk aversion shocks. This provides a natural, testable prediction of our model: following a reduction in global risk aversion exchange rates appreciate (depreciate), interest rates and interest rate differentials increase (decrease), and excess currency returns decline (increase) in net debtors (net lender) SOEs. We will test this empirical prediction in Section 5.

It is worth noting that the sign of the covariance of interest rate differentials and expected excess currency returns does not depend on a country's steady-state NFA/GDP. Thus, conditional on global risk aversion shocks the β of the Fama (1984) regression is negative for both group of countries, in line with our empirical finding that $\beta < 0$ conditional on external shocks in virtually all countries (see Figure 2).

Conditional UIP deviations We examine the response of excess currency returns conditional on different structural shocks in our model. Figure 7 depicts the theoretical IRFs of a home monetary policy shock and global risk aversion shock.

In our model, an unexpected domestic interest rate increase leads to a domestic currency appreciation, an exchange rate response that is largely in line with the its UIP-consistent counterpart. Home monetary policy shocks (and, in fact, any shocks other than innovations in global risk aversion) lead to small fluctuations in excess currency returns. In fact, in our

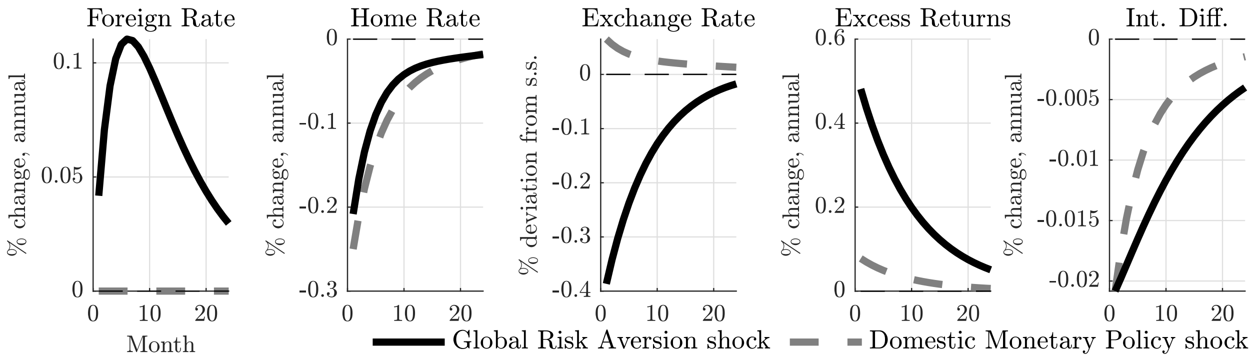


Figure 7: Theoretical impulse responses to domestic and external shocks

Note: Both shocks are scaled to deliver a 0.25% impact decline in the interest rate differential. Excess returns are one-year ahead expected excess returns on the foreign currency.

model the UIP violations due to the equilibrium *changes* of the SOE's NFA/GDP play a minor quantitative role because of the limited variation in NFA/GDP around its steady state.

To the contrary, excess currency returns fluctuations are sizable following a global risk aversion shock. These large UIP violations dominate over the interest rate differential in shaping the qualitative and quantitative response of exchange rates (cf. Eq. (5)).

Therefore, provided that global risk aversion shocks dominate the external variation in exchange rates, the model is thus able to reproduce the empirical patterns of conditional UIP deviations and interest rate-exchange rate comovement documented in Figure 3.

5 Net foreign assets and exchange rate dynamics

In the model presented in Section 4, a country's steady-state NFA/GDP governs the international transmission of global risk aversion shocks. To reiterate, if $\mathtt{b} < 0$ financial trader sells dollars and buys the SOE's currency in the foreign exchange market. As a result, financial traders require lower excess returns on the SOE's currency in response reduction in global risk aversion. Furthermore, in our general equilibrium model the SOE's currency appreciates and the interest rate (differential) declines. The exact opposite responses obtain in a SOE with $\mathtt{b} > 0$ (see Figure 6). This is a central prediction of the model.

If global risk aversion shocks drive the external variation in SOEs' exchange rates, the empirically identified external shock should feature these comovement properties across countries with different NFA/GDP. To test this prediction, we separate countries depending on their average NFA/GDP. In particular, we separately report empirical impulse responses to an external shock for countries with positive and negative average NFA/GDP. The results are reported in Figure 8.

The qualitative responses of interest rates, exchange rates, and excess returns across NFA positions conform with the qualitative predictions of our model. Countries with negative average NFA/GDP exhibit an exchange rate appreciation, a decline in interest rate (differentials), and negative excess currency returns following an expansionary external shock. To the contrary, countries with positive average NFA/GDP experience opposite responses in all these variables. This evidence indicates that external imbalances play a major role in the international transmission of external shocks to SOEs. These comovement patterns favor our interpretation that global risk aversion shocks in imperfect international asset markets drive the external variation in SOEs' exchange rates and are the main source of UIP violations.

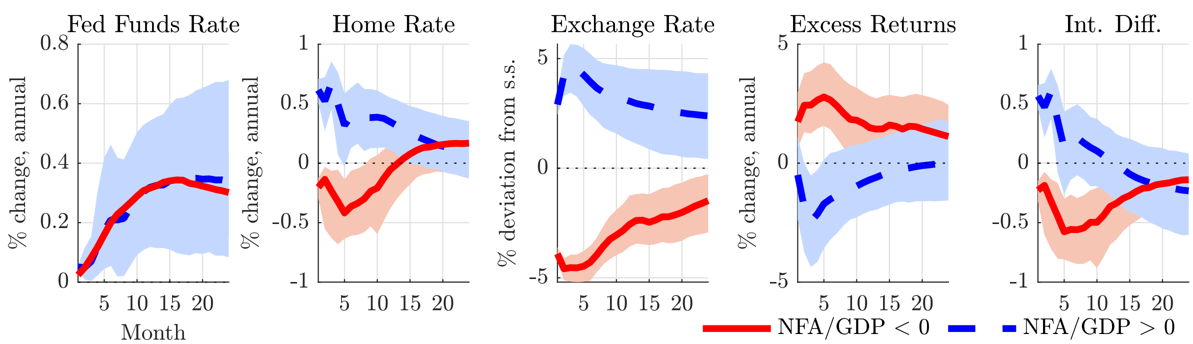


Figure 8: Empirical impulse responses to an external shock, by NFA/GDP

Note: The lines denote median IRFs by group of countries with corresponding 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR. Countries are grouped depending on whether their period average NFA/GDP position is positive or negative. Excess returns are one-year ahead expected excess returns on the foreign currency.

6 Conclusions

Motivated by understanding the sources of exchange rate fluctuations in SOEs, we asked how domestic and external shocks shape exchange rate fluctuations in SOEs. Using minimal assumptions that hold in any class of SOE models, we found that domestic and external shocks give rise to substantially different exchange rate dynamics. In particular, domestic shocks generate exchange rate fluctuations that are largely in line with the predictions of UIP. To the contrary, external shocks cause large and predictable deviations from uncovered interest parity, and one external source exchange rate variation – associated with fluctuations in global risk aversion and U.S. macroeconomic aggregates – is primarily responsible for the occurrence of UIP violations and their predictability.

We interpreted these empirical findings using a general equilibrium two-country SOE model with imperfect capital markets and global risk aversion shocks. In the proposed model, global risk aversion shocks are the primary source of UIP violations and excess currency returns predictability, while other shocks play a limited role along these dimensions. Global risk aversion shocks reproduce the comovement in U.S. variables that we document empirically, while their effects on SOEs is fundamentally shaped by the SOE's external imbalance. Because global risk aversion shocks influence exchange rates through the required compensation on the overall stock of bonds that FX traders hold, the exchange rate response to global risk aversion shocks depends on the external position (NFA/GDP) of the SOE. We verified this central empirical prediction of the model, and found that indeed a country's response to external shocks depends on whether it is a net lender or a net borrower.

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A Dataset

Nominal exchange rates (s_t, monthly) 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. The main data source is the International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF).

Short-term interest rates (r_k, monthly) These 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 main data source is the International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF). The U.S. short-term interest rate ($r^\star$, monthly) is measured by the Federal Funds rate, retrieved from FRED, Federal Reserve Bank of St. Louis.

Exchange rate regimes Exchange rate regimes are determined according to the historical exchange rate classification in Reinhart and Rogoff (2004), recently updated by Ilzetzki et al. (2017). A country is deemed to have a flexible exchange rate regime if, in a given year, its exchange rate was either (i) within a moving band that is narrower than or equal to +/2 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). We follow Hnatkovska et al. (2016) in including high-income OECD countries irrespective of their exchange rate classification. Table A.1 reports the countries and time periods included in the dataset.

U.S. industrial production (monthly) U.S. industrial production is from the Board of Governors of the Federal Reserve System (U.S.), Industrial Production Index [INDPRO], retrieved from FRED, Federal Reserve Bank of St. Louis.

U.S. CPI inflation (monthly) U.S. CPI inflation is from the U.S. Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers: All Items in U.S. City Average [CPIAUCSL], retrieved from FRED, Federal Reserve Bank of St. Louis.

VIX (monthly) The VIX is the Chicago Board Options Exchange, CBOE Volatility Index: VIX [VIXCLS], retrieved from FRED, Federal Reserve Bank of St. Louis.

Net foreign asset positions to GDP (annual) Data on net foreign asset positions to GDP is from the updated and extended version of dataset constructed by Lane and Milesi-Ferretti (2007).

Country	Time period	Avg. NFA/GDP	Country	Time period	Avg. NFA/GDP
Australia	1974:1-2010:11	-41.70%	Austria	1974:1-1998:12	-10.20%
Belgium	1974:1-1998:12	-4.5%	Brazil	1999:2-2007:12	-39.20%
Canada	1974:1-2010:11	-28.20%	France	1974:1-1998:12	12.90%
Germany	1975:7-1998:12	9.60%	Indonesia	1997:8-2007:12	-67.60%
Italy	1977:3-1998:12	-7.10%	Japan	1974:1-2010:11	18.90%
Korea, Rep. of	1997:12-2007:12	-14.70%	Mexico	1995:1-2007:12	-35.40%
New Zealand	1978:1-2010:11	-69.20%	Norway	1974:1-2009:5	1.6%
Philippines	1997:7-1999:11	-52.10%	South Africa	1995:3-2007:12	-13.70%
Switzerland	1980:1-2010:11	99.90%	United Kingdom	1974:1-2010:10	-2.5%

Table A.1: List of countries in the dataset

B Block Exogeneity test

This section presents the results from the Block Exogeneity tests on individual countries VARs. The details of the test can be found in Lütkepohl (2005).

Within the context of our three-variate VARs, we aim to test the null hypothesis of joint insignificance of domestic variables, namely the logarithm of the bilateral nominal exchange rate and the domestic interest rate, in help predicting the Federal Funds rate. Thus, the block exogeneity test is a special case of Granger causality test: under the null hypothesis domestic variables do not Granger cause one or more external variables. The table below reports the p-values for each country of the following F-statistic:

$$F = \frac{(SSR_{rest} - SSR_{full})/q}{SSR_{full}/(T-k)}$$

where q is the number of parameters restricted to zero, and $T-k$ is the number of degrees of freedom in the unrestricted reduced form equation for the Federal Funds Rate.

Country	P-value	Country	P-value
Australia	0.31	Austria	0.00
Belgium	0.52	Brazil	0.22
Canada	0.56	France	0.75
Germany	0.01	Indonesia	0.72
Italy	0.04	Japan	0.00
Korea, Rep. of	0.01	Mexico	0.06
New Zealand	0.04	Norway	0.07
Philippines	0.08	South Africa	0.06
Switzerland	0.13	United Kingdom	0.00

Table B.1: P-values of the Block Exogeneity test

C Additional model details

C.1 Traders's decision problem

This section shows that a CRRA utility has a mean-variance representation. The problem of the international trader reads as follows:

$$\max_{d_{t+1}} \mathrm{E}_t\left[\frac{(T^\star+\widetilde{R}_{t+1}d_{t+1})^{1-\omega_t^\star}}{1-\omega_t^\star}\right]=\mathrm{E}_t\left[\frac{\exp\left\{(1-\omega_t^\star)\log(T^\star+\widetilde{R}_{t+1}d_{t+1})\right\}}{1-\omega_t^\star}\right] \tag{14}$$

where $T^\star$ is such that $(T^\star+\widetilde{R}_{t+1}d_{t+1})>0$.

Take second order Taylor expansion around $\widetilde{R}=0$:

$$\log(T^\star+\widetilde{R}_{t+1}d_{t+1})\approx\log(T^\star)+\frac{d_{t+1}}{T^\star}\widetilde{R}_{t+1}-\frac{d_{t+1}^2}{2(T^\star)^2}\widetilde{R}_{t+1}^2$$

$$\approx\log(T^\star)+\frac{d_{t+1}}{T^\star}\widetilde{R}_{t+1}-\frac{d_{t+1}^2}{2(T^\star)^2}\mathrm{Var}_t(\widetilde{R}_{t+1})$$

where $\widetilde{R}_{t+1}^2$ is replaced by the conditional variance of $\widetilde{R}_{t+1}$.[32,33] Then Eq. (14) is approximated by:

$$\max_{d_{t+1}} \mathrm{E}_t\left[\frac{\exp\left\{(1-\omega_t^\star)\left(\log(T^\star)+\frac{d_{t+1}}{T^\star}\widetilde{R}_{t+1}-\frac{d_{t+1}^2}{2(T^\star)^2}\mathrm{Var}_t(\widetilde{R}_{t+1})\right)\right\}}{1-\omega_t^\star}\right]$$

$$\approx\max_{d_{t+1}}\exp\left\{(1-\omega_t^\star)\left(\log(T^\star)-\frac{d_{t+1}^2}{2(T^\star)^2}\mathrm{Var}_t(\widetilde{R}_{t+1})\right)\right\}\mathrm{E}_t\left[\exp\left\{(1-\omega_t^\star)\left(\frac{d_{t+1}}{T^\star}\widetilde{R}_{t+1}\right)\right\}\right].$$

Assume normal distribution of $\widetilde{R}_{t+1}$, then

$$\approx\max_{d_{t+1}}\log(T^\star)-\frac{d_{t+1}^2}{2(T^\star)^2}\mathrm{Var}_t(\widetilde{R}_{t+1})+(1-\omega_t^\star)\frac{d_{t+1}^2}{2(T^\star)^2}\mathrm{Var}_t(\widetilde{R}_{t+1})+\frac{d_{t+1}}{T^\star}\mathrm{E}[\widetilde{R}_{t+1}]$$

$$\approx\max_{d_{t+1}}\mathrm{E}_t[\widetilde{R}_{t+1}]d_{t+1}-\frac{\omega_t^\star}{2T^\star}\mathrm{Var}_t(\widetilde{R}_{t+1})d_{t+1}^2$$

[32] Note that $\mathrm{E}_t[\widetilde{R}_{t+1}]^2\approx 0$.

[33] As the time interval shrinks, the higher order terms that are dropped from (14) become negligible relative to those that are included, and the deviation of $\widetilde{R}_{t+1}^2$ from $\mathrm{Var}_t(\widetilde{R}_{t+1})$ also become negligible. In particular in the limit of continuous time the approximation is exact and can be derived using Ito's Lemma.

In equilibrium, the individual trader's asset decisision reads

$$d_{t+1} = \frac{T^\star \, \mathrm{E}_t[\widetilde{R}_{t+1}]}{\omega_t^\star \, \mathrm{Var}_t(\widetilde{R}_{t+1})}$$

Without loss of generality, we set $T^\star = 1$. Then, aggregating over the m_t measure of traders, the overall demand for domestic bonds from traders is

$$\widetilde{D}_{t+1} = \frac{m_t}{\omega_t^\star} \frac{\mathrm{E}_t \widetilde{R}_{t+1}}{\mathrm{Var}_t(\widetilde{R}_{t+1})}$$

which is Eq. (9) in the text.

C.2 Model equilibrium equations

Besides each country's Phillips Curve, the model's equilibrium equations in levels are given by:

$$\beta^\star \, \mathrm{E}_t \left[\left(C_{t+1}^\star\right)^{-\omega^\star \exp(\omega_{t+1}^\star)} \frac{R_t^\star}{\Pi_{t+1}^\star} \right] = \left(C_t^\star\right)^{-\omega^\star \exp(\omega_t^\star)}$$

$$\frac{R_t^\star}{R^\star} = \left(\frac{R_{t-1}^\star}{R^\star}\right)^{\rho_R} \left(\frac{\Pi_t^\star}{\Pi^\star}\right)^{(1-\rho_R)\phi} \exp(\varepsilon_{r^\star,t})$$

$$\beta \, \mathrm{E}_t \left[(C_{t+1})^{-\omega} \frac{R_t}{\Pi_{t+1}} \right] = (C_t)^{-\omega}$$

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho_R)\phi} \exp(\varepsilon_{r,t})$$

$$\Pi_t = \left(\Pi_{H,t}\right)^{1-\lambda} \left(\frac{S_t}{S_{t-1}} \Pi_t^\star\right)^{\lambda}$$

$$Y_t = Q_t^{\frac{\theta\lambda}{1-\lambda}} \left\{ (1-\lambda) C_t + \lambda Q_t^\theta C_t^\star \right\}$$

$$\frac{B_{t+1}/P_{H,t} Y_t}{R_t} - B_t/P_{H,t-1} Y_{t-1} \frac{1}{\Pi_{H,t} Y_t / Y_{t-1}} = 1 - Q_t^{-\frac{\lambda}{1-\lambda}} \frac{C_t}{Y_t}$$

$$S_t = Q_t \frac{P_t}{P_t^\star}$$

$$-B_{t+1}/P_{H,t}Y_t = \frac{\mu \mathrm{E}_t \left(R_t - R_t^\star \frac{S_{t+1}}{S_t} \right)}{\mathrm{Var}_t \left(R_t - R_t^\star \frac{S_{t+1}}{S_t} \right)}$$

C.3 Model solution

We can represent the model outlined in Appendix C.2 as the following system of equations:

$$\mathrm{E}_t [f(X_{t+1})] = 0$$

where X_{t+1} contains all the variables in the model (including variables dated at time t and $t-1$) and f has as many rows as endogenous variables in the model. The risky steady state (Coeurdacier et al., 2011) is obtained by taking a second-order approximation of f around $\mathrm{E}_t X_{t+1}$:

$$\Phi(\mathrm{E}_t X_{t+1}) = f(\mathrm{E}_t X_{t+1}) + \mathrm{E}_t \left[f'' [X_{t+1} - \mathrm{E}_t X_{t+1}]^2 \right]$$

where f'' is also evaluated at $\mathrm{E}_t X_{t+1}$. The risky steady state, $\mathtt{X}$, is then characterized by $\Phi(\mathtt{X}) = 0$, and the second moments $\mathrm{E}_t \left[f'' [X_{t+1} - \mathrm{E}_t X_{t+1}]^2 \right]$ are generated by the linear dynamics around $\mathtt{X}$.

The model's solution thus consists in a log-linear approximation around a risky steady state that is consistent with the second moments generated by the log-linear dynamics around it. This is achieved through an iterative algorithm, along the lines of Coeurdacier et al. (2011).