The International Monetary Transmission Mechanism*

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Abstract

Time series analysis shows that a US monetary tightening leads to economic contractions in non-US countries. We develop small economy models that capture these spillover effects onto Advanced Economies (AE) and Emerging Market Economies (EME). Using counterfactual experiments, we identify the decline in US imports as the primary mechanism by which a US monetary contraction affects other economies. We also document that EMEs exhibit more pronounced contractions compared with AEs. Counterfactual experiments attribute this to a lower share of dollar borrowing in AEs. We find that financial frictions (including frictions needed to explain deviations from uncovered purchasing power parity) are essential to understanding the propagation of US monetary shocks. Finally, our findings suggest that FX interventions are relatively ineffective at insulating an economy against US monetary policy shocks, though they are very effective for dealing with 'noise' shocks in financial markets.

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1 Introduction

1.1 Background

Research over the past two decades has altered the consensus about international macroeconomics, summarized by the Mundell-Fleming model (M-F).[1] The new consensus, which remains in flux, reflects many developments. Recent advances in the measurement of exogenous US monetary policy shocks are particularly important. Reliable measurement of these shocks make it possible to trace out with some confidence the effects of a US monetary policy contraction.[2] As a result, much is known about how monetary shocks affect the US economy and there has emerged a relatively settled consensus about the monetary transmission mechanism within the US.[3] More recently, the literature has begun to explore the international effects of US monetary policy shocks and this has produced evidence that is sharply at variance with M-F. A consensus is emerging that the key to the international transmission of US monetary shocks is financial frictions (see, e.g., Rey (2013) and Miranda-Agrippino and Rey (2020), Degasperi et al. (2020) and Basu and Gopinath (2024)). However, the new consensus assigns a relatively small role to trade in the transmission of monetary shocks.

1.2 Our Main Finding

Our results suggest that a US monetary contraction generates a large decline in US imports[4], and that it is primarily via this decline that a US monetary contraction affects the rest of the world. Informally, we reach this conclusion because we observe that the rest of the world experiences large export declines in response to a US monetary policy contraction. Absent a shift down in non-US countries' export demand one would expect foreign exports to increase or at least stay the same when the dollar appreciates in the wake of a US monetary tightening.[5][6]

[1] See Fleming (1962) and Mundell (1963).

[2] The literature on monetary policy shock identification stretches back over many decades. The recent literature on high frequency identification (which actually starts around the turn of the century with Rudebusch (1998) and Kuttner (2001)) has injected new energy into shock identification. Ramey (2016) offers an excellent introduction and overview to the modern approach and our work most closely follows Bauer and Swanson (2023b).

[3] This research is an important reason for the prominence of the New Keynesian macroeconomic model.

[4] Others have documented a decline in US imports following a contractionary US monetary policy shock. For example, Miranda-Agrippino and Ricco (2021, Figure 7) and Degasperi et al. (2020, Figure 2) show that the peak decline US in imports is more than twice the peak decline in US industrial production after a US monetary contraction.

[5] In principle, the fall in US imports could reflect tighter financial conditions for non-US exporters (see, e.g., Bruno and Shin (2021)). To decide whether the drop in imports reflects a fall in demand or supply, we look at the impact on an export price index of a US monetary tightening. We conclude that US imports drop because of a decline in US demand because the price index falls (see Figure 1).

[6] The point that a decline in US imports after a US monetary contraction could account for a fall in non-US country exports is also made in Cesa-Bianchi et al. (2024). While our two papers overlap in many ways, the modeling strategies and questions asked are different. We stress the central role played in the international monetary transmission mechanism by the decline in US imports.

We begin by fitting a Vector Autoregression (VAR) to US data and estimating the impulse responses to a monetary shock. In our baseline analysis, we use the monetary shock produced by Bauer and Swanson (2023b). We also compute the response of a collection of Advanced Economies (AEs) and Emerging Market Economies (EMEs), as well as Peru, because its Central Bank is known to engage actively in FX interventions. We use the impulse responses to characterize key facts about the international monetary transmission mechanism. Included among these facts are some (we believe) novel observations about the failure of interest rate parity conditions. We then apply the impulse response matching procedure in Christiano et al. (2005) and Christiano et al. (2011b) to parameterize small open economies for Peru, as well the AEs and EMEs. Our models require as input the impulses to a US monetary tightening of three US variables: the US price level, the US interest rate, R_t^*, and US GDP. These are the three US variables that matter for the residents of our AE, EME and Peruvian models. They care about the US price level because it helps determine the terms of trade. They care about $R_{d,t}^*$ because they borrow and lend dollar assets. Finally, they care about US GDP indirectly because it shifts the demand for their exports. So, from the perspective of foreigners, a US monetary tightening represents three shocks: an $R_{d,t}^*$ shock, a terms of trade shock and an export demand shock. We exploit the linearity of the VAR and of our linear approximation of the AE and EME models to represent the foreign impact of a US monetary tightening as the sum of the impact of these three shocks. We find that the US price shock has a negligible effect on the AEs and EMEs. The $R_{d,t}^*$ shock has a small impact. The overwhelming effect of a US monetary tightening on the AEs and EMEs appears to operate through export demand. The precise details about how a shock to US imports could have a nontrivial effect on the world economy is beyond the scope of our paper. The analysis in Di Giovanni and Hale (2022) suggests that the impact of a US trade shock may be substantial due to amplification effects associated with the global network of production.

1.3 The Role of Financial Frictions

Our analysis differs from the conventional wisdom by giving trade a key role in the international transmission of a US monetary policy shock. At the same time, our analysis confirms the emerging conventional view that financial frictions play an important role in the international transmission mechanism.

Recent research on the transmission of monetary shocks considers a variety of factors such as the effects of balance sheet frictions;[7] sticky-in-dollar export prices;[8] deviations from interest rate parity and noise trading in FX markets; [9] foreign exchange (FX) interventions;[10] and other

[7]see Di Giovanni et al. (2022) and Akinci and Queralto (2024).

[8]see Goldberg and Tille (2008) and Gopinath et al. (2020).

[9]see Jiang et al. (2023), Eichenbaum et al. (2021), Kalemli-Özcan and Varela (2021), Kekre and Lenel (2021), Devereux et al. (2023), Fukui et al. (2023) and Greenwood et al. (2023), Itskhoki and Mukhin (2023).

[10]see Gabaix and Maggiori (2015), Cavallino (2019) and Itskhoki and Mukhin (2023).

factors.[11] We require structural SOE models because understanding the role of trade and other frictions in the international monetary transmission mechanism requires contemplating counterfactuals: ‘what if US imports did not respond to a US monetary policy shock?’, ‘what if there were no balance sheet frictions?’, etc.

To describe the role of financial frictions in our analysis, it is useful to first consider a stylized analysis of the foreign impact of a US interest rate rise in a benchmark version of the M-F model. In this model, expenditure switching in response to a change in the exchange rate is a primary factor driving the US and foreign response to a US monetary policy shock.[12] Other factors, like financial frictions, are absent from the model. The M-F model implies that the US exchange rate appreciates following an increase in US interest rates and that the resulting expenditure switching effects drive US exports down and US imports up. With demand switching away from the US, US GDP drops and GDP in the rest of the world expands. In contrast, the conventional view for at least a decade is that a US monetary contraction also has a contractionary impact on the rest of the world, a striking rejection of the M-F paradigm. A dramatic example of this shift in consensus is the so-called “Taper tantrum” in June 2013, when the markets came to believe that the Fed intended to raise interest rates soon. In contrast to the rosy scenario implied by the simple M-F analysis, observers outside the US (especially in the EMEs) came to expect financial instability, currency depreciation and recession (Eichengreen and Gupta (2015)). VAR evidence below provides support for the view that a rise in US interest rates leads to a reduction in rest-of-the-world output. The range of frictions listed above - balance sheet effects, interest parity frictions and others - play an important role in the international monetary transmission mechanism.

Our VAR analysis suggests that when a US monetary policy shock perturbs the rest of the world, the latter effects do not rebound significantly back onto the US. For this reason, and to facilitate the additive decomposition of a US monetary tightening described above, we model non-US economies as small open economies that take the US as an exogenous source of US interest rate, US price and export demand shocks. By not adopting a single general equilibrium model of the world economy, we avoid specifying the detailed path that a US monetary shock takes through the global trading network as it makes its way to the countries we study. This frees us to consider small open economy models with a wide range of frictions.[13] We estimate our models to see which combination of frictions allows our models to reproduce our reduced form representation of the international monetary transmission mechanism.

We now briefly summarize the financial frictions in the model and their role in the monetary transmission mechanism. We introduce balance sheet effects by adopting a version of the costly state verification model in Bernanke et al. (1999). In this framework, there are entrepreneurs who

[11] See Adrian et al. (2021), Basu and Gopinath (2024) and Cesa-Bianchi et al. (2024) for other models that incorporate all these and other factors.

[12] See, for example, the baseline M-F model described in Krugman et al. (2023).

[13] Cesa-Bianchi et al. (2024) work with a general equilibrium model of the world economy, but they only have two countries and thus avoid adopting an empirically founded model of the global trading network.

need to borrow to finance expenditures which drive investment. Entrepreneurs' ability to borrow is a function of their net worth. Their loans are funded in part by dollar borrowing. In this way, when a currency depreciation occurs in response to a US monetary tightening, entrepreneurs suffer capital losses, destruction of part of their net worth and an increase in interest rate spreads. This limits their ability to borrow and drives investment down, contributing to a contraction. An outcome of our estimation exercise is that EME entrepreneurs fund a larger portion of their debt in dollars than do their counterparts in the AEs. This helps the models explain why EMEs contract more than AEs in response to the depreciation caused by a US monetary tightening.

While the balance sheet considerations move the model in the right direct direction, they do not move it far enough. The literature reports extensive evidence against UIP (see, for example, Gabaix and Maggiori (2015), Eichenbaum et al. (2021), Gourinchas et al. (2022), Itskhoki and Mukhin (2023) and Dalgic (2024)). Our VARs suggest UIP violations may be even larger than is generally recognized. Not only do we report the well-known delayed overshooting observation (see, e.g., Eichenbaum and Evans (1995)), but we also document that the overall level of the exchange rate depreciates substantially more than can be justified by standard fundamentals. The UIP parameters are introduced to allow our models to address both the delayed overshooting and what we call excessive overshooting. For example, we include a parameter that captures an idea in the literature, that when $R^*_{d,t}$ jumps then risk appetite falls and people have a greater desire for dollars (see, e.g., Özcan (2019) and Miranda-Agrippino and Rey (2020) and the references they cite). This desire amplifies the exchange rate depreciation in EMEs and AEs when US monetary policy tightens. So, the UIP frictions are important for explaining our excessive overshooting result for the exchange rate. But, they are also important for GDP. That is because without the large depreciation the balance sheet effects and the fall in US export demand are not sufficient to generate a fall in output as large as the one observed. The AE entrepreneurs are much less exposed in our model to dollar debt. This is why the AEs do not contract as much in the wake of a US monetary tightening as the EMEs do.

Motivated by evidence in Gopinath et al. (2020), we also include sticky-in-dollar export prices. This factor undercuts roughly one-half of the expenditure switching channel in the M-F model, by preventing firms from cutting dollar export prices when the currency depreciates.

The interest parity frictions in our model imply that foreign exchange (FX) interventions have real effects. So, the analysis allows us to assess whether a standard FX policy rule such as the one in Castillo and Medina (2021) insulates an economy from a US monetary tightening. Our counterfactual experiments suggest that FX intervention helps relatively little in the case of US monetary shocks. However, we show that FX intervention can be very helpful in smoothing out noise shocks in foreign exchange markets.

In section 2 we describe our econometric procedure for identifying the effects of a US monetary contraction, using high frequency monetary policy shocks computed in Bauer and Swanson (2023b). Section 3 describes our small open economy model. Section 4 discusses our small open economy model fitting exercises. Section 5 discusses how we use our models to draw inferences about the economic frictions underlying the estimated impulse response functions. In addition, in that section we examine the impulse responses of data not used in the fitting exercise. In particular, we look at AE and EME data on interest rate spreads and equity prices. The EME model performs well because the financial system is somewhat volatile due to the exposure to dollar debt. The AE model does well on spread data but not so well on equity markets because of that models lower exposure to dollar borrowing. Section 6 offers conclusions. We do a number of robustness exercises on our VAR analysis, and some of this is relegated to an Appendix. In other cases, technical details are put in the Appendix too.

2 US and International Impact of a US Monetary Policy Shock

This section reports our baseline VAR analyses of the international impact of US monetary policy shocks, proxied by the shocks, ε_t^m, constructed in Bauer and Swanson (2023b).[14] Subsection 2.1 reports VAR results for the US which, for the most part, mirrors results already reported elsewhere: US interest rates rise and the US dollar appreciates, while US GDP, inflation and the stock market fall. We draw special attention to the substantial and persistent drop in US imports. Because we find that a price index for imports falls, we infer that the decline in US imports reflects a decline in US demand for foreign goods as the US economy slows in response to the monetary tightening.

Our analysis requires that we do counterfactual simulations, and for this we use small open economy (SOE) structural representations for non-US economies. In responding to a US monetary tightening, people in foreign SOEs must forecast the response of key US variables. We use our estimated US VAR to construct a simple, recursive representation of those impulse responses (see subsection 2.1.2 below). This section also explains how we handle a timing mismatch between our VAR and SOE analyses. The time period in the former is monthly, while the time period in the latter is quarterly.

Subsection 2.2 turns to the VAR analysis of the foreign impact of a US monetary tightening. We stress three results: (1) AE GDP falls; (2) the percent decline in EME GDP is greater than the percent decline in AE GDP; and (3) EME and AE exports fall by a larger percent than the decline in their GDP. We also look at the impact on Peru. That country is interesting because it is very open about the fact that it actively engages in FX operations.

[14] The monetary policy shock is computed in Bauer and Swanson (2023b) in two steps. First, the first principle component of the four time series, $ED1, ..., ED4$, is computed. Here, EDi denotes the change, from 10 minutes before to 20 minutes after an FOMC announcement, in the three-month Eurodollar futures rate on a loan starting $i-1$ quarters in the future, $i = 1, ..., 4$. Second, the first principle component is orthogonalized with respect to information available at the time of the FOMC announcement. For extensive discussion, see Bauer and Swanson (2023b)

Our baseline VAR strategy in subsection 2.2 finds that EME GDP falls (in percent terms) by as much as three times the fall in US GDP. We check the robustness of our results to a variety of alternative estimation procedures. Section C in the Appendix redoes the calculations using the monetary policy shocks constructed by Jarociński and Karadi (2020) and also finds (1)-(3), as well as that EME GDP drops by more than US GDP. The Jarociński and Karadi (2020) results also takes a VAR approach to identification. Still, their shock allows us to test the robustness of our results because their method of identifying a US monetary policy shock differs substantially from Bauer and Swanson (2023b)'s. Section B in the Appendix redoes the calculations in a way that makes no use of VARs at all, by doing local projections, as in Jordà (2005). The results of that analysis are consistent with (1)-(3) and, consistent with our baseline results, they suggest that EME GDP falls by more than US GDP.

We explore two variations on our baseline panel data VAR approach and these imply that the fall in EME GDP, while greater than the fall in AE GDP, is about equal to the fall in US GDP. Both variations relax the restrictions in our panel VAR, without completely abandoning the VAR framework. One variation is reported in subsection 2.3 below and the other is reported in section A.1 in the Appendix.

All our robustness analyses support our central conclusions, (1), (2) and (3), listed above.

2.1 US Economy

Here, we do two things with the US data. First, in subsection 2.1.1 we estimate the response of US data to a shock in ε_t^m using a 9 variable US VAR with 12 monthly lags and treating ε_t^m as an exogenous variable, as in Paul (2020). The effects of monetary policy shocks on the US economy have been studied extensively. However, we include some variables, like imports, that do not usually appear in these studies. US imports play a key role in our analysis.

Second, in subsection 2.1.2 we construct a three variable, one lag VAR that provides a near-perfect approximation to the first three years' responses in the three variables to a US monetary policy shock. That representation is incorporated into the SOE models estimated in Section 4. We require this representation in the models because the people in our SOEs must have a view about how three US variables - US inflation, the US interest rate and US GDP - respond to ε_t^m.

2.1.1 US Vector Autoregression

Let Y_t denote the vector of endogenous US variables in the VAR. All variables are in levels and prices and quantities are expressed in log form. The $p-$lag VAR is expressed as follows:

$$Y_t = A\left(L\right) Y_{t-1} + C\varepsilon_t^{mp} + u_t, \tag{1}$$

where $Eu_tu_t' = V$, and $\varepsilon_t^{mp}, Y_{t-j},\ j > 0$ are orthogonal to the VAR disturbances, u_t. Also, L denotes the lag operator and

$$A(L) = A_1 + A_2L + ... + A_pL^{p-1}.$$

We estimate V, C and the A_i's using Bayesian methods with 'Minnesota' priors. These priors suppose that all elements of Y_t are independent random walks. That is, the mean of the prior on A_1 is the identity matrix and the priors on $A_i,\ i > 1$ are zero matrices. In addition, under the priors the means of the elements C are zero. The prior density of $A_1, ..., A_p, C$ conditional on V is Normal and the marginal density of V is inverse Wishart. So, the joint density of $V, A_1, ..., A_p, C$ is Normal Inverse Wishart (NIW).[15]

The VAR is monthly and covers the period, 2006-2019. This sample is chosen primarily because many of the EMEs in our sample are characterized by different monetary and fiscal regimes before 2000. The 9 variables in Y_t include gross domestic product (GDP), the excess bond premium first constructed in Gilchrist and Zakrajsek (2012) (EBP), a default-free borrowing rate for firms, $R_{d,t}^*$, the personal consumption expenditures deflator (PCE), Exports, Imports, a trade-weighted measure of the nominal exchange rate[16], the S&P 500 and an index of import prices (see note to Figure 1 for additional details).

Our measure of $R_{d,t}^*$ is the sum of the 2-year US Treasury bond rate plus the EBP.[17] The EBP is the excess of the interest rate paid by firms on loans over what the US Treasury pays, after adjusting for firm default risk. We assume that the EBP reflects various non-pecuniary liquidity services provided by Treasury securities, which are not provided by private debt.[18] In principle we could have computed $R_{d,t}^*$ by adding the 3-month US Treasury rate or the Federal Funds rate to EBP. This would have been more coherent with the SOE models we use to interpret the impulse response functions (IRFs), in which the interest rate is a quarterly return. However, we found that with shorter term rates, the rise in $R_{d,t}^*$ associated with a monetary tightening is much smaller. Indeed, in the case of one month Treasury yields we found that $R_{d,t}^*$ actually drops. We attribute these results in part to the fact that Treasury rates with maturities shorter than 2 years are nearly constant and close to zero for a substantial part of our sample. This is why, consistent with much of the literature, we decided to work with 2-year US Treasuries.

GDP, Exports, Imports and the S&P 500 are converted into real terms by dividing by the consumer price index (CPI). We convert the data in this way because it facilities matching the data results with our model where data are measured in units of the model CPI.[19] Finally, the

[15] After demeaning all variables, the VAR analysis is done using the code Dieppe et al. (2016). This code and demeaning procedure is used for all VARs reported in this paper.

[16] When the trade weighted exchange rate rises, this corresponds to an appreciation in the dollar.

[17] The 2 year Treasury bond rate is sampled on the last business day of the month and is obtained from the Federal Reserve Bank of St. Louis' online database, FRED.

[18] See, for example, Devereux et al. (2023).

[19] In the US case, GDP data are only available on a quarterly basis. We use Stock and Watson (2010)'s monthly

quantity data are converted to logs when we estimate the VARs. All variables fed to the VARs are in levels or log-levels.

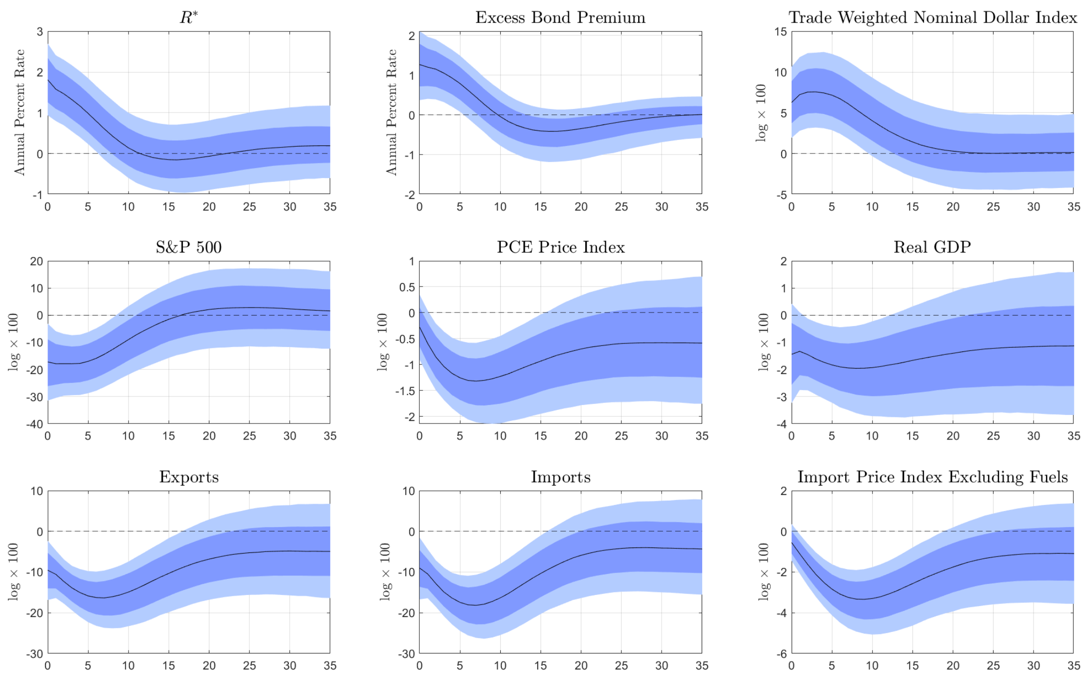
The estimated IRFs to the ε_t^{mp} are displayed in Figure 1. The dark lines are the mean of the posterior distribution of the IRFs to (not-normalized) ε_t^{mp} and the dark and light shaded areas correspond to 68 and 90 percent probability intervals. There are several things worth noting about this figure. First, for variables that overlap with other studies, the IRFs are qualitatively similar.[20] GDP, equity prices and the price level drop. The exchange rate appreciates for a few periods, before depreciating. We discuss this delayed overshooting feature of the exchange rate in section 5.5 below. Consistent with our interpretation of the EBP, that variable rises in the wake of a monetary tightening because a tightening is implemented by making liquidity scarce and thus increasing its marginal value. Second, note that the decline in imports is large by comparison with the percent decline in GDP. Moreover, the probability interval around the mode is very tight and far from zero. Third, when we estimate the model with only one lag in the VAR, we get very similar results. In addition, when we further reduce the system to the three variables, $R_{d,t}^{*}, GDP$ and PCE, we also get similar results for those variables.

The final feature worth noting about the results in Figure 1 is the decline in the price index for imports. As discussed in the introduction, the result for the price index suggests that the fall in imports is driven by US demand. It is not predominantly driven by a reduction in the supply of imported goods, caused by, say, an increase in financial frictions in non-US economies due to the US monetary tightening.

GDP data obtained by multivariate interpolation of the monthly real GDP series. So, our US GDP data are not measured in CPI units.

[20] Note that the impact of the contemporaneous impact of the monetary shock on GDP is relatively large. This is puzzling because the Bauer and Swanson (2023b) shocks are orthogonalized with respect to information available at the start of an FOMC meeting. This means that the drop in GDP in the month of a meeting must occur in the remaining time during the month of the meeting. This is implausible, especially for meetings that occur at the end of the month. We suspect that our results reflect that the Bauer and Swanson (2023b) monetary policy shocks are correlated with subsequent revisions in the data. For example, suppose the statistical agencies apply the smoothing method suggested in Sargent (1989) to revise data over time. Seasonal adjustment also involves two-sided smoothing which may inject a 'look-ahead feature' into the data. Suppose that a contractionary monetary policy shock drives true GDP down in the months after the FOMC meeting. Two-sided smoothing then implies that later revisions of the data will adjust the reported GDP numbers down in the month of the monetary contraction.

Figure 1: Response to Contractionary US Monetary Policy Shock, United States



Notes: (1) Figure displays the response in US variables to a US monetary policy shock measured in Bauer and Swanson (2023b). The dark lines are the median of the posterior distribution of the IRFs and the dark and light shaded areas correspond to 68 and 90 percent probability intervals. (2) The underlying twelve lag, 9 variable VAR is described in the text and is based on monthly data covering the period, 2006-2019. The Federal Reserve Bank of St. Louis' website, FRED, is the source for all variables except R^*, the excess bond premium, and the $S\&P$ 500. The mnemonic for the Import Price Index in Fred is IREXFUELS. R^* denotes an estimate of the interest rate paid on loans by private firms, after subtracting the component of their interest reflecting default risk (see the text for additional discussion). The excess bond premium is obtained from Favara et al. (2016). Monthly average data on the $S\&P$ 500 were obtained from Yahoo finance. (3) The $S\&P$ 500 is converted to real terms using the consumer price index, as are exports and imports. (4) US real GDP series are available on a quarterly basis. We use Stock and Watson (2010)'s monthly GDP data obtained by multivariate interpolation of monthly real GDP series.

2.1.2 Three Variable US VAR

In our model analysis we require that people be able to forecast the impact of a US monetary tightening on three US variables, $R^*_{d,t}, GDP$ and PCE. Our computational strategy for analyzing the SOE models requires that we provide the IRFs in recursive form. In principle, we could simply insert our US VAR into the model. However, the empirical results reported above suggest that there exists a much simpler recursive representation for the IRFs.[21]

The variables that are of interest for people in foreign economies responding to a US monetary tightening are:

$$\hat{Y}_t = \begin{pmatrix} 100\log\left(\pi_t^f/\pi^f\right) \\ 400\left(R^*_{d,t} - R^*_d\right) \\ 100\log\left(y_t^f/y^f\right) \end{pmatrix}.$$

[21] Recall the third result reported for the US VAR in section 2.1.1.

Here, $\pi_t^f \equiv P_t^f/P_{t-1}^f$, where P_t^f denotes the US PCE price index. Also, y_t^f is a variable in our SOE model which corresponds to a transitory component of US GDP.[22] In each case, the variables are measured in log deviation from steady state. The middle term in $\hat{Y}_t$ is measured in annual percent. We adopt the following recursive representation of $\hat{Y}_t$:

$$\hat{Y}_t = A\hat{Y}_{t-1} + D\varepsilon_t^{mp}, \tag{2}$$

where D is a 3×1 column vector and ε_t^p denotes the Bauer and Swanson (2023b) monetary policy shock index.

Setting $\hat{Y}_0 = 0$, we compute n responses, $\hat{Y}_1, ..., \hat{Y}_n$ to $\varepsilon_1^{mp} = 1$ and $\varepsilon_t^{mp} = 0$ for $t > 1$using equation (2). Then,

$$\hat{Y}_1 = D.$$

Also,

$$\hat{Y}_j = A^{j-1}\hat{Y}_1 = A^{j-1}D,$$

for $j = 2, ..., n$. In this way, we obtain the n IRFs, $\left[\hat{Y}_1, ..., \hat{Y}_n\right]$, are a function of D and A.

We convert the sequence, $\left[\hat{Y}_1, ..., \hat{Y}_n\right]$, into $\left[\hat{\mathcal{Y}}_1, ..., \hat{\mathcal{Y}}_n\right]$, where the second two terms in $\hat{\mathcal{Y}}_j$ coincide with the second two terms of $\hat{Y}_j$, while the first element of $\hat{\mathcal{Y}}_j$ is the cumulative sum of the first element of $\hat{Y}_j$, $j = 1, ..., n$. In this way, the first and third elements of $\hat{\mathcal{Y}}_j$ correspond to the response of $\log P_j^f$ and $\log GDP_j$, respectively. The way we handle GDP is determined by the assumption in our SOE model that GDP is the product of a temporary component, y_t^f, which is affected by ε_t^m and a permanent component, $\mathcal{Z}_t$, which is not affected by ε_t^m.

The empirical VARs that we estimate are based on monthly data, while the SOE models are quarterly. So, each of the n quarters is divided into three months. The first month of quarter t is $t - 2/3$, the second month is $t - 1/3$ and the third month is t, for $t = 1, ..., n$.

Let $\{\xi_t\}$ denote the $3n$ monthly IRFs from the VAR analysis (i.e., Figure 1). Here the elements of ξ_t correspond to the monthly log price, the monthly annualized interest rate and monthly log GDP. Let ξ_t^Q, $t = 1, ..., n$ denote the corresponding quarterly data. We assume that quarterly price and GDP are well-approximated by the geometric average over the months in the quarter. The interest rate is the arithmetic average. Thus,

$$\xi_t^Q = \frac{1}{3}\left[\xi_t + \xi_{t-1/3} + \xi_{t-2/3}\right],$$

for $t = 1, ..., n$.

Conditional on A and D we can compute the model's impulse response functions, $\left[\hat{\mathcal{Y}}_1, ..., \hat{\mathcal{Y}}_n\right]$, as described above. The empirical counterparts of $\left[\hat{\mathcal{Y}}_1, ..., \hat{\mathcal{Y}}_n\right]$ are $\left[\xi_1^Q, \xi_2^Q, ..., \xi_n^Q\right]$. We set $D = \xi_1^Q$, where $t = 1$ denotes the period of the US monetary tightening shock. Now, we only need A to

[22]See equation (15) below.

compute $\left[\hat{\mathcal{Y}}_1, ..., \hat{\mathcal{Y}}_n\right]$. We choose A to minimize a measure of distance between $\left[\xi_1^Q, ..., \xi_n^Q\right]$ and $\left[\hat{\mathcal{Y}}_1, ..., \hat{\mathcal{Y}}_n\right]$. Let σ_j denote the 3×1 column vector containing the standard deviations, under the posterior distribution, of each of the elements of ξ_j^Q, $j = 1, ..., n$. Then, A solves

$$\min_A \sum_{j=1}^{n} \left(\xi_j^Q - \hat{\mathcal{Y}}_j\right)' \mathbf{\Lambda}_j^{-1} \left(\xi_j^Q - \hat{\mathcal{Y}}_j\right),$$

were $\mathbf{\Lambda}_j$is a 3×3 diagonal matrix with the vector, σ_j, along its diagonal. . In effect in choosing the values of A we downplay the VAR IRFs which are imprecisely measured.

The outcome of our algorithm for computing D, A with $n = 12$ based on the responses in Figure 1 is:

$$D = \begin{bmatrix} -0.58 \\ 0.41 \\ -1.42 \end{bmatrix}, \; A = \begin{bmatrix} 0. & -1.40 & -.08 \\ 0.22 & 0.98 & 0.02 \\ 0.43 & -0.35 & 0.95 \end{bmatrix}, \tag{3}$$

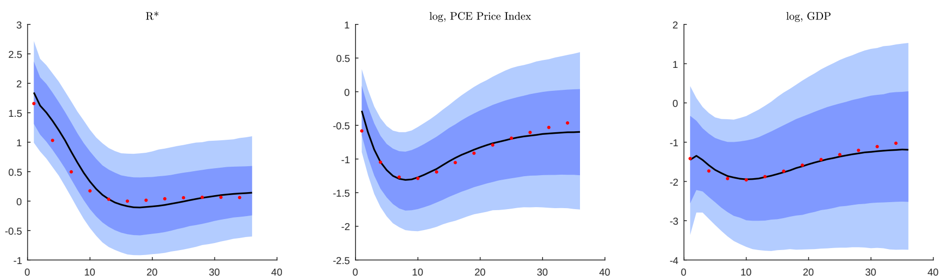
where A has three eigenvalues, $0.5 \pm 0.31i$, 0.92. Consistent with the assumption in our SOE model, the three-variable VAR model we provide to it for the foreign variables is covariance stationary. Because all eigenvalues of A lie inside the unit circle, the impact of an ε_t^m shock eventually go to zero.

The eigenvalues of the empirical VAR also lie, with one exception, inside the unit circle. The exception is an eigenvalue equal to 1.001. So, technically, the impact of shocks, including ε_t^m, eventually diverge in the estimated VAR underlying Figure 1. Still, there are three reasons that we are comfortable providing the covariance stationary representation, equation (2), to our SOE models. First, Figure (2) shows that at the three year horizon, shocks appear to be converging. Second, though the impact of shocks diverge eventually, they remain centered at zero in the sense that probability intervals, while also diverging, include a zero response. Third, we also estimated a three-variable, one period lag, VAR for ξ_t using monthly data. That estimated VAR produces IRFs for ξ_t very similar to the ones in Figure 1 but they have all eigenvalues lying inside the unit circle. These three observations convince us that equation (2) provides a useful recursive representation of the response of US data over one or two year horizon that our analysis focuses on.

Figure 2 graphs the impulse response of the foreign interest rate, the log level of the PCE price index and log, GDP. The dots correspond to the simulations from the constructed model, equation (2). The solid lines are taken from Figure 1, as are the dark (68%) and light (90%) shaded areas. The dots are 'close' to the solid line in the sense that they are only barely distinguishable, visually, from the solid line.

Note that integer values of t in Figure 2 corresponds to months, which is inconsistent with the treatment elsewhere in this section where integer values of t correspond to quarters. Throughout this paper we adopt the following convention. When VAR and SOE data are presented in the same graph, the time interval is monthly. When SOE data are displayed in a graph not including VAR data, then the time interval is quarterly.

Figure 2: Responses to US Monetary Shock Implied by SOE Model



Note: Solid line - IRFs in Figure 1 with the associated probability intervals in dark and light shade. Dots - IRFs to $\varepsilon_t^m = 1$ for $t = 1$ and $\varepsilon_t^m = 0$ for $t > 1$, with $\hat{Y}_0 = 0$. The dots correspond to the simulated $\hat{Y}_t$'s, after converting to $\hat{\mathcal{Y}}_t$ as discussed in the text.

2.2 Non-US Economies

In this section we estimate the average impact of a contractionary US monetary policy shock on a set of AE's and EME's. In addition, we report results for Peru.

In the case of each non-US VAR, we include data on the three US variables: the interest rate, inflation and GDP. Including these US variables allows a monetary policy shock to have both a direct impact on non-US economies' data and an indirect impact via dynamic responses in the three US variables. In addition, we potentially allow non-US countries' variables to feedback onto the US economy. In our SOE model analysis we abstract from the latter form of feedback. Comparing the IRFs to a US monetary policy shock in the three US variables - the interest rate, inflation and GDP - with the corresponding IRFs in Figure 1 sheds light on the appropriateness of our no-feedback assumption. We do see differences, but they appear to be quantitatively small.

In Sections 2.2.1 we present our baseline VAR results. To understand what is robust in our VAR analysis, we present a variety of alternative empirical estimates of the

2.2.1 Panel VAR

Our VAR for the i^{th} non-US economy is

$$Y_{i,t} = A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + C\varepsilon_t^{mp} + \varepsilon_{i,t}, \tag{4}$$

where

$$Y_{i,t} = \begin{bmatrix} \tilde{Y}_t \\ Y_t^i \end{bmatrix}, \tag{5}$$

and $\tilde{Y}_t$ denotes the 3×1 vector of US variables composed of $\log GDP$, R^* and PCE. These are the US variables that affect foreign economies captured by our small open economy models below. As noted above, we found that when the US analysis in Section 2.1 was redone with a US 3-variable, 1-lag VAR the IRFs to the Bauer and Swanson (2023b) shock are very similar to what we see in Figure 1.

Also, Y_t^i denotes an 8×1 vector of variables for country i : GDP; nominal exchange rate (foreign currency per dollar); domestic monetary policy rate; consumer price index (CPI); gross private domestic investment; exports; imports; and a measure of Central Bank FX intervention, as a percent of the three-year moving average in GDP. The purpose of dividing by a backward-looking moving average of GDP is to reduce endogeneity of the denominator in the share, at least for the first few months after a shock. Apart from the FX intervention variable and the policy rate, all variables are measured in log levels and the sample mean is removed, thus setting the constant terms VARs to zero. We obtain the Central Bank FX intervention data from Adler et al. (2024).[23]

When we estimate the system in equation (4) we do not zero out the top right 3×8 blocks in A_1 and A_2, which govern feedback from movements in the foreign variables, Y_t^i, to the US variables, $\tilde{Y}_t$. This fact allows us to evaluate our assumption in the US VAR and in our model analysis that the rebound effect on the US from the foreign impact of US monetary policy shocks is small.

The panel VAR is structured as follows:

$$\begin{bmatrix} Y_{1,t} \\ Y_{2,t} \\ \vdots \\ Y_{N,t} \end{bmatrix} = \begin{bmatrix} A_1 & 0 & \cdots & 0 \\ 0 & A_1 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & 0 & \cdots & A_1 \end{bmatrix} \begin{bmatrix} Y_{1,t-1} \\ Y_{2,t-1} \\ \vdots \\ Y_{N,t-1} \end{bmatrix} + \begin{bmatrix} A_2 & 0 & \cdots & 0 \\ 0 & A_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & 0 & \cdots & A_2 \end{bmatrix} \begin{bmatrix} Y_{1,t-2} \\ Y_{2,t-2} \\ \vdots \\ Y_{N,t-2} \end{bmatrix} + \begin{bmatrix} C \\ C \\ \vdots \\ C \end{bmatrix} \varepsilon_t^{mp} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \vdots \\ \varepsilon_{N,t} \end{bmatrix}, \tag{6}$$

where N denotes the number of countries and the dimension of C conforms with the dimension of $Y_{i,t}$. We apply a similar Bayesian method to estimate equation (6) as in the case of the US VAR in equation (1). The difference here is the zero restrictions in equation (6) as well as the assumption that A_1, A_2 and C are the same across countries. In words, we impose that for each i, Y_t^i (a) responds only to the country's own lagged data and lagged data on the three US variables in $\tilde{Y}_t$, and (b) the responses are the same for all i's among the AE's and for all i's among the EME's.

We impose (a) and (b) in part to minimize the number of parameters to be estimated. Our

[23] These data are intended to measure changes in reserves that reflect active purchases and sales by Central Banks in the FX market. They are not simply changes in Central Bank FX reserves. The latter changes can reflect changes in market valuation and changes in earnings on the underlying assets. There are other movements in Central Bank reserves are stripped from the measure of FX intervention. For example, reserves can change because banks must deposit a portion of their dollar liabilities with the Central Bank and these enter Central Bank reserves. Adler et al. (2024) also attempt to include Central Bank activity in futures markets in their measure of FX interventions.

effective data sample is short. As noted above, this is due only in part to data limitations. We think that the monetary and regulatory regimes in place, especially in the EMEs, were very different before the 2000s, and we exclude this data plus a few years to accommodate a transition, from the analysis. We interpret our IRFs for the AE and EME countries as an average over the individual country responses, which is perhaps more reliably estimated than the individual responses. Later, we show evidence that this interpretation is valid.

2.2.2 Impulse Responses of Estimated Panel VARs

The official IMF list of AEs is provided in IMF (2023). With one exception, we use data taken from the IMF's International Financial Statistics (IFS) to ensure cross-country comparability. The exception is that we take the FX intervention data from Adler et al. (2024) for the reasons explained above. In the case of AEs we exclude some countries. In particular, we only include one country, Germany, from the Euro area.[24] Similarly, we exclude Denmark because it pegs its exchange rate to the Euro. Iceland, Taiwan and Singapore are not included in our data analysis because their nominal GDP data do not appear in the IFS. New Zealand also does not appear because the IFS does not provide monthly data for that country's price indices. Monthly data on the Australian consumer price index are not available so we used their monthly data on the producer price index instead. Our AE panel consists of equation (6) with $N = 10$ countries: Australia, Canada, UK, Germany, Israel, Japan, South Korea, Norway, Switzerland, and Sweden.[25]

Turning to emerging markets, Duttagupta and Pazarbasioglu (2021) report that the IMF does not have an official definition of an EME. We work with the designation suggested in Duttagupta and Pazarbasioglu (2021), except that we also include Peru.[26] That county is of special interest to us because it is very transparent about its active intervention in the FX market.[27] We exclude China because their nominal GDP is not included in the IFS. Our EME panel has $N = 14$ countries: Brazil, Chile, Colombia, Hungary, India, Indonesia, Mexico, Peru, Philippines, Poland, Russia, South Africa, Thailand, Turkey. Our dataset is monthly and covers the period, 2006-2019.

We begin by reporting the results for AEs displayed in Figure 3. The top row of the figure displays the responses of the three US variables in $\tilde{Y}_t$. The model responses (the mode of the posterior distribution, the dark line) are similar to the corresponding responses in Figure 1 in the sense that they lie inside the latter figure's 68 percent probability intervals. As noted above, the

[24] We do not model the entire Euro area as one economy because it is not a small open economy.

[25] We would include New Zealand, but the IFS does not provide monthly data for that country's price indices. Monthly data on the Australian consumption price index are not available so we used their monthly data on the producer price index instead.

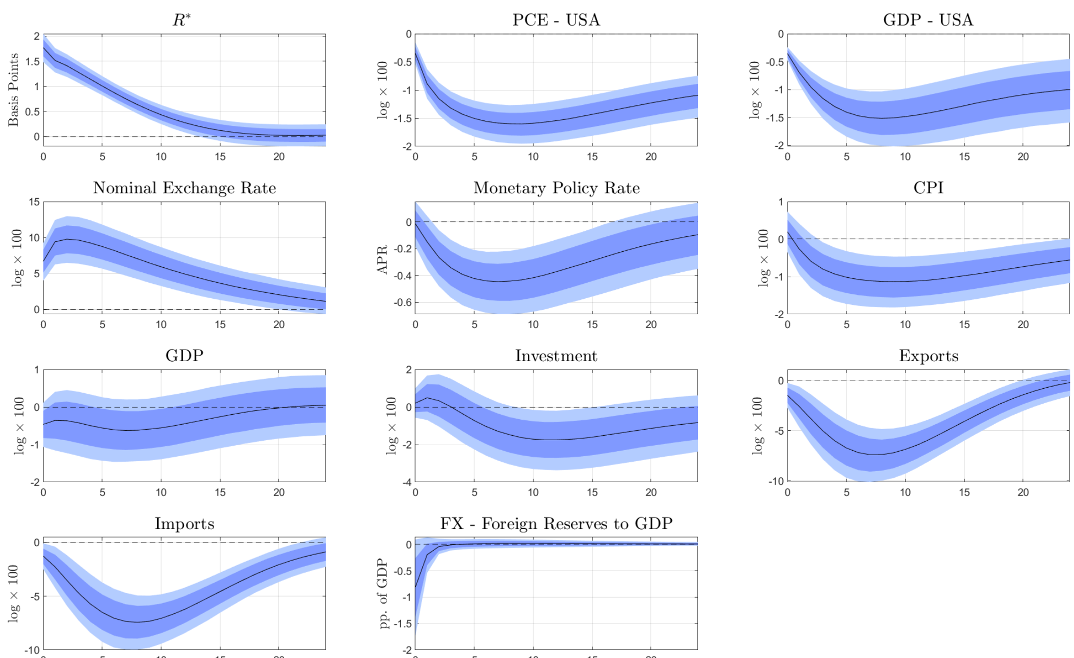
[26] Duttagupta and Pazarbasioglu (2021) identify the following countries as emerging markets: Argentina, Brazil, Chile, China, Colombia, Egypt, Hungary, India, Indonesia, Iran, Malaysia, Mexico, the Philippines, Poland, Russia, Saudi Arabia, South Africa, Thailand, Turkey, and the United Arab Emirates.

[27] The unofficial list of EMEs constructed in Duttagupta and Pazarbasioglu (2021) is: Argentina, Brazil, Chile, China, Colombia, Egypt, Hungary, India, Indonesia, Iran, Malaysia, Mexico, Philippines, Poland, Russia, Saudi Arabia, South Africa, Thailand, Turkey, and the United Arab Emirates.

US IRFs in Figure 3 are allowed to respond to lagged values of individual country variables. The similarity of the US responses across Figures 1 and 3 is consistent with the idea that the rebound effect of US monetary shocks back onto the US via their impact on non-US AEs is small.[28]

There are five other features of the results in Figure 3 worth noting. First, the AE's exchange rate depreciates substantially after a US monetary tightening, as one would expect. In percent terms the magnitude is somewhat larger than the results for the trade-weighted US exchange rate reported in Figure 1. This may reflect the absence from our dataset of some countries that the US trades with, especially China. Second, the mode of our results suggest that AE central banks sell dollars after a monetary tightening. But, the probability intervals are sufficiently wide that they include the case of no response. Third, although the modal impulse response of GDP indicates that GDP falls, the percent drop is substantially smaller than the nearly 2 percent drop in US GDP. Fourth, the drop in exports is substantially larger, in percent terms, than the drop in GDP. Fifth, the relatively weak fall in GDP may reflect the estimated significant accommodative response by the AE monetary authorities (see the 2,2 panel of Figure 1).

Figure 3: Response to Contractionary US Monetary Policy Shock, Advanced Economies

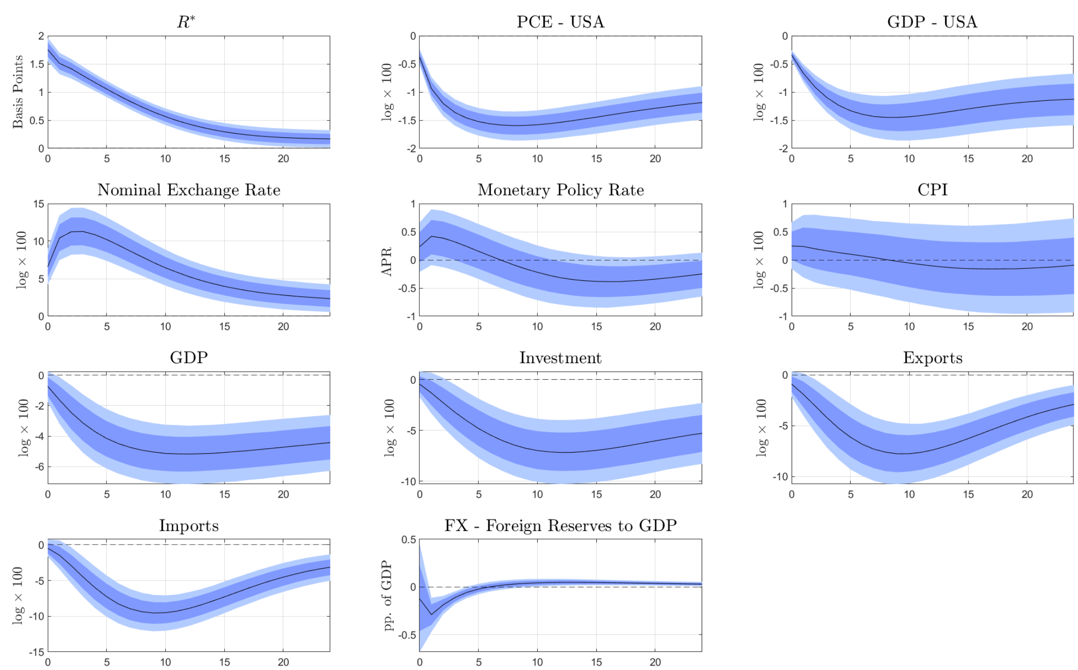


Note: Impulses from the panel VAR estimation for the AE countries: Australia, Canada, UK, Germany, Israel, Japan, South Korea, Norway, Switzerland, and Sweden. Solid lines correspond to the mode of the Bayesian posterior, dark shaded areas correspond to the 68 percent probability intervals and the light shaded areas correspond to 90 probability intervals. The data sample is monthly, 2006-2019. FX intervention, relative GDP, obtained from Adler et al. (2024). The first row of graphs display the response of US variables to the monetary policy shock, when lagged values of the foreign variables are included in the VAR (see section 2.2 for discussion). Differences in the first-row responses from the corresponding impulse responses in Figure 1 indicate feedback effects from the rest of the world to the US, which we ignore in our modeling analysis. We interpret the graphs as indicating little (but, not zero) feedback.

[28]The results do not prove the absence of rebound effects, because they could well be fully encoded in the parameters of the US VAR.

Next, we turn to Figure 4, which displays our results for the EMEs. First, note that as in the case of the AE's, there is a substantial currency depreciation. Second, the estimate of Central Bank FX interventions is fairly tightly centered on zero, with the 90 percent probability interval ranging from -0.5 to 0.5 percent of GDP. This is somewhat surprising, in light of the evidence in Adler et al. (2024) which shows that EMEs conduct larger FX interventions than AEs. Third, the modal percent drop in GDP is substantial, roughly 3 times the drop in the US. Fourth, another difference between EMEs and the AEs is that the former actually raises the local currency units (LCU) policy rate while, as noted above, the latter reduce that rate. Fifth, by comparing Figures 3 and 4 we can see that the LCU expected return on a round trip through the dollar exchange market rises by the same amount in the AEs and the EMEs. As a result, the rise in the EME interest rate premium relative to the rise in the AE interest rate premium can be inferred by the relative movement of their policy rates. In particular the relative rise in the EME premium is in the neighborhood of 20 - 40 basis points. While interesting, this magnitude is small by comparison with the roughly 175 basis point rise in R^*.

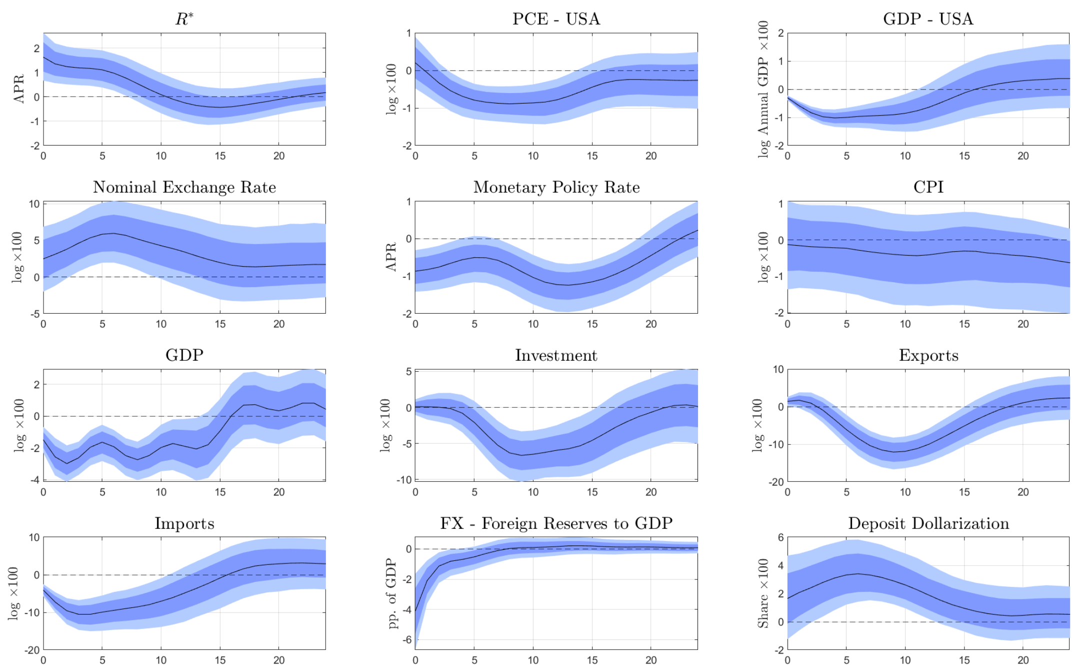
Figure 4: Response to Contractionary US Monetary Policy Shock, Emerging Markets



Notes: response to a unit shock in ε_t^m in panel VAR results for emerging market economies, Brazil, Chile, Colombia, Hungary, India, Indonesia, Mexico, Peru, Philippines, Poland, Russia South Africa, Thailand, Turkey. For more information, see note to Figure 3.

We also report results for estimating equation (4) when i corresponds to Peru. We do this in part because we are interested in analyzing the effects of FX intervention. According to data published by the Peruvian Central bank, we can see that Peru frequently intervenes in foreign exchange markets (see Figure 27 in the Appendix). Note that the initial response of FX intervention to a US monetary tightening is to reduce FX reserves by about 4 percent of GDP. This mode for FX intervention is much larger than what we obtained based on all EMEs (see Figure 4), where the mode of the drop is small and the probability interval is also small. Also, the probability interval of the Peruvian data is tight enough to easily exclude zero. To have a sense of the size of this number, recall that we have not re-normalized the US monetary tightening shock, and that R^* rises by about 170 basis points at an annual rate. So, if we think of a 25 basis point US tightening then we must scale all the IRFs by approximately 7.

Figure 5: Response to Contractionary US Monetary Policy Shock, Peru



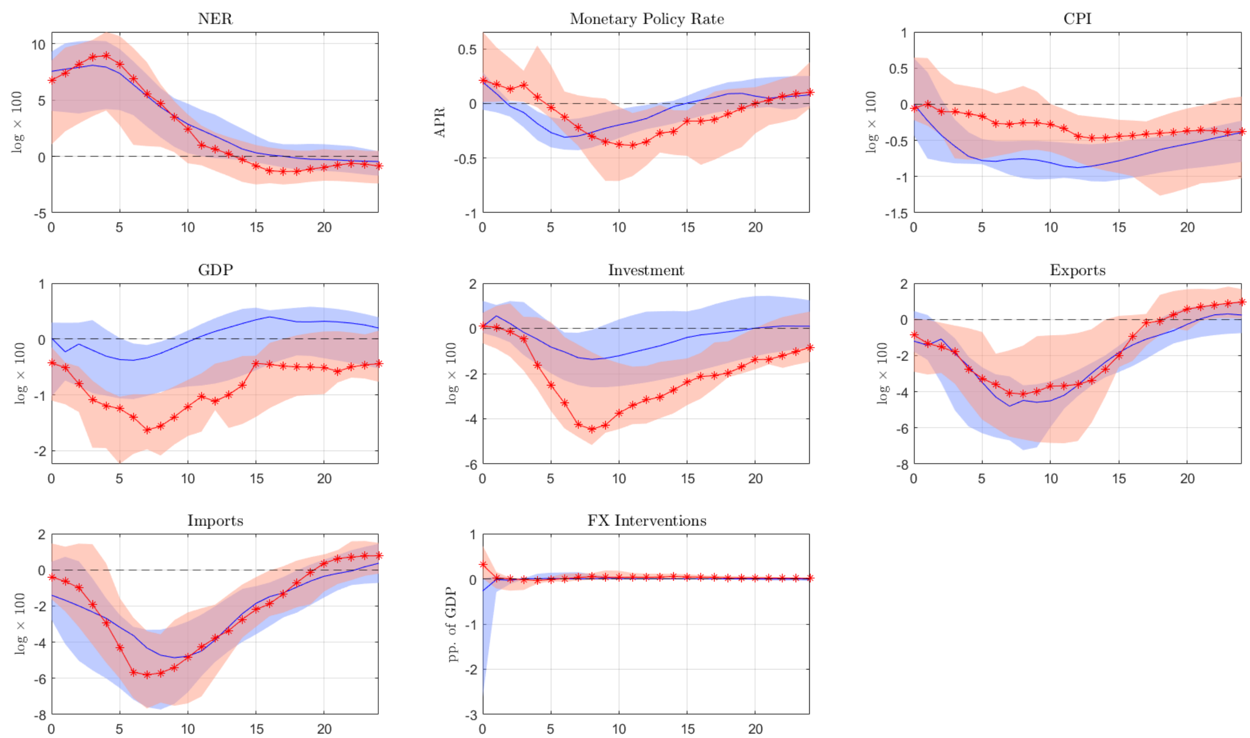
Note: for more information, see note to Figure 3. Response to unit shock in ε_t^m in equation (4) for i corresponding to Peru. Parameters estimated on monthly data, 2006-2019. Solid lines correspond to the mode of the Bayesian posterior, dark shaded areas correspond to the 68 percent probability intervals and the light shaded areas correspond to 90 probability intervals.

2.3 Country by Country Impulse Responses

The panel VARs studied in the previous section do not fully satisfy the assumptions underlying the derivation of the likelihood for the Bayesian VAR. In deriving the likelihood, Dieppe et al. (2016) assume that $E\varepsilon_{i,t}\varepsilon'_{j,t} = 0$ for $i \neq j$. At the same time, we include the US data in each $Y_{i,t}$ in equation (5) for each i, so that the covariance assumption on the disturbances cannot be satisfied. In addition, it seems implausible that shocks to different countries within the AEs and within the EMEs are uncorrelated. We avoid violating these covariance assumptions by estimating equation (4) separately for each country, i, in our sample. In addition, we delete the first three equations in equation (4), so that no covariance assumption is obviously violated in the VAR.

We compute impulse response functions for each country in our data set, except the US. We then group the IRFs according come from an EME or an AE. The responses to a US monetary tightening are displayed in Figure 6. The blue lines indicate the median, across countries in the AEs, of the median response at each horizon. The blue shaded area presents the interquartile range of median responses at each horizon. Similarly, the red line with stars corresponds to EMEs and the red shaded area indicates the associated interquartile range of responses. The figures convey roughly the same message as Figures 3 and 4. GDP and investment falls by more in EMEs than in AEs while the price level falls somewhat less in EMEs compared to what happens in AEs. There is one quantitative difference. The average fall in EME GDP after a US monetary contraction is smaller in Figure 6 than is reported in Figure 4. That fall is roughly equal to the fall in US GDP in the first year, and less so afterward.

Figure 6: Country by Country Impulse Responses within EMEs and AEs



Note: IRFs over 24 months to a US monetary tightening shock as measured in Bauer and Swanson (2023b). We estimate a version of equation (4) separately for each country, i. The version of equation (4) that we use drops the first three equations but keeps the lagged US data as exogenous variables in the other equations. For each country we compute the median under the posterior distribution, of the IRFs. The line in the above figure with red stars (solid blue line) is the cross-country average of the median impulse response across the EME (AE) economies. At each lag, the red (blue) region indicates the interquartile range across responses among EMEs (AEs). With one exception, the results convey a similar message as Figures 3 and 4. An exception is that EME GDP, while falling more than AE GDP, falls roughly the amount that US GDP falls in Figure 1. All data are the same as the data underlying Figure 1. Here, NER corresponds to 'nominal exchange rate'.

3 Model

The model we use is a fairly standard New Keynesian small open economy model. It is closest to a streamed-down version of Christiano et al. (2011b) which in turn builds on Adolfson et al. (2007). The model is closely related to other models, including Gertler et al. (2007) and Castillo and Medina (2021). The discussion below summarizes agents' problems and the market clearing conditions. For details about how a set of equilibrium conditions is derived and solved, see the Online Appendix.

3.1 Households

There is a representative household with preferences,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ u\left(C_t\right) - \frac{\ell_t^{1+\varphi}}{1+\varphi} - h_t\left(\Theta_t\right) \right\},$$

where ℓ_t denotes employment, C_t denotes consumption and Θ_t denotes the households share of financial wealth held in dollars. Also, $h_t\left(\Theta_t\right)$ denotes a non-pecuniary cost of deviating from a target portfolio, Υ_t. In particular,

$$\Theta_t \equiv \frac{S_t D_t^*}{S_t D_t^* + D_t}, \quad h_t\left(\Theta_t\right) = \frac{\gamma}{2}\left(\Theta_t - \Upsilon_t\right)^2, \; \Upsilon_t = \Upsilon + \gamma_{R^*}\left(R_{d,t}^* - R^*\right) + \gamma_{\Theta}\left(\bar{\Theta}_t - \bar{\Theta}_{t-1}\right) + e_t^{\Upsilon}. \quad (7)$$

Here, Υ_t denotes the time t target portfolio share of dollars, and Υ denotes the value of that target in steady state. The term involving $\bar{\Theta}_t - \bar{\Theta}_{t-1}$ with *portfolio inertia parameter,* $\gamma_\Theta < 0$, is a reduced form representation of adjustment costs in adjusting portfolios frictions. Such adjustment costs were proposed by Bacchetta et al. (2022) to explain features of capital flows and asset prices. The object, e_t^{Υ}, is a 'noise' shock to the household's target, which has a first order autoregressive representation. Also, the *risk appetite parameter,* $\gamma_{R^*} > 0$, captures the idea that when $R_{d,t}^*$ is high people prefer dollar assets, perhaps because of a decrease in 'risk appetite', or 'flight to safety'. The *target portfolio cost parameter* is given by $\gamma > 0$. The variable, D_t^*, denotes the household's end-of-period t holdings of dollar assets which pay $R_{d,t}^*$ gross interest in dollars in period $t+1$. The variables, S_t and D_t denote the number of LCU per dollar and D_t denotes the end-of-period t holdings of LCU domestic assets which pay $R_{d,t}$ gross interest in LCU in period $t+1$. The household's flow budget constraint is:

$$S_t D_t^* + D_t + P_t^c C_t + E_t Q_{t,t+1} a_{t,t+1} = S_t R_{d,t-1}^* D_{t-1}^* + R_{d,t-1} D_{t-1} + W_t \ell_t + \Pi_t - T_t + a_{t-1,t}. \quad (8)$$

The terms on the left and right of the equality correspond to the household's period t purchases and receipts in LCU. In equation (8), W_t denotes a competitive wage. Also, Π_t and T_t denote lump sum profits and taxes, respectively. In period t the household purchases $a_{t,t+1}$ units of LCU to be delivered conditional on the state of nature in period $t+1$.[29] The price of one such unit of LCU, scaled by the period t conditional density of its state of nature, is denoted $Q_{t,t+1}$. The conditional expectation is a convenient way to express the total cost of all possible $t+1$ Arrow securities in period t. The object, $a_{t-1,t}$ on the right of the above equality represents the payoff on the Arrow-security purchased in $t-1$, given the realized state of nature in t. The Arrow security market is one in which households participate with domestic banks, and is discuss further below. For later purposes, it is useful to note that household optimality requires that household consumption satisfy:

$$\upsilon_{t+1} \equiv \frac{\beta u'(C_{t+1})}{\pi^c_{t+1} u'(C_t)} = Q_{t,t+1}. \tag{9}$$

As is well known, one can derive the model's implications for interest parity from the optimality condition associated with the household's choice of Θ_t. After linearizing this expression about nonstochastic steady state,

$$E_t \log(S_{t+1}) - \log(S_t) + \log\left(R^*_{d,t}\right) + \Lambda_t = \log(R_{d,t}) \tag{10}$$

where, the *UIP deviation*, Λ_t, has the following form:

$$\Lambda_t = \gamma\left(\Upsilon_t - \Theta_t\right). \tag{11}$$

The object on the left of the equality in (10) is the total return (i.e., the pecuniary and non-pecuniary parts) on holding dollar assets, in LCU. The first part, involving the prospective log change in the exchange rate corresponds to the return on the round trip through the exchange market. The next term is the dollar return. Finally, the UIP deviation, Λ_t is the non-pecuniary return on dollars. Note that when the share of dollars in the household's portfolio exceeds target then the non-pecuniary return is negative. UIP corresponds to $\gamma = 0$ and is violated in the impulse response functions presented above. For example, a period t US monetary tightening creates an anticipated depreciation from t to $t+1$ and simultaneously raises the premium on the US interest rate, $R^*_{d,t} - R_{d,t}$, so that $\Lambda_t < 0$.

3.2 Homogeneous Domestic Goods

A homogeneous non-tradable good, Y_t, is produced using domestic capital and labor using the Dixit-Stiglitz structure typical in closed economy NK models. In particular, Y_t is produced using a continuum of intermediate inputs, $Y_{i,t}$, $i \in [0,1]$ as follows:

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}, \varepsilon > 1. \tag{12}$$

[29]In this paper, the only states of nature we consider is different realized values of the foreign interest, R^*_{t+1}.

The representative, competitive firm that produces Y_t takes the output price and input prices, P_t and $P_{i,t}$, $i \in [0,1]$ as given. This firm maximizes profits and the first order necessary condition associated with the choice of $Y_{i,t}$ constitutes the demand curve faced by a monopoly producer of $Y_{i,t}$.

The monopoly producer of $Y_{i,t}$ chooses a point, $Y_{i,t}$ and $P_{i,t}$, on the demand curve which maximizes profits subject to the production technology

$$Y_{i,t} = \tilde{K}_{i,t}^{\alpha} \left(A_t \ell_{i,t}\right)^{1-\alpha}, \ 0 < 1 < \alpha. \tag{13}$$

Here, $\tilde{K}_{i,t}$ and $\ell_{i,t}$ denote the quantity of capital labor services hired by the i^{th} monopoly producer in period t. Also, A_t denotes the period t state of technology. In this paper we only consider foreign monetary policy shocks and we assume these have no impact on A_t, so A_t grows at its constant steady state rate. That is, $\log\left(A_t/A_{t-1}\right) = \Delta a$, where $\Delta a > 0$ represents the steady state growth rate of A_t. The assumptions about preferences and technology guarantee balanced growth and we exploit that when solving the model.

In equilibrium, the aggregate capital services used by monopoly producers must be equal to supply, $\int_i \tilde{K}_{i,t} di = K_{t-1}$. The latter has time subscript $t-1$ because the time t supply of capital services is determined in period $t-1$ (see Section (3.4)).

Monopoly producers are subject to Calvo-price frictions:

$$P_{i,t} = \begin{cases} \tilde{P}_t & \text{with probability } 1-\theta \\ P_{i,t-1} & \text{with probability } \theta \end{cases}. \tag{14}$$

Monopoly producers are competitive in the input markets where they pay r_t and W_t for capital and labor services, respectively. They choose their price to maximize discounted profits subject to its demand curve, equations (13) and (14), and the given factor prices.

3.3 Final Goods

Three final goods are produced using CES production functions that combine domestic nontradable (the homogeneous good) and imports. Each production function is operated by a profit-maximizing representative, competitive producer taking the output and input prices as given. In equilibrium, these producers make zero profits. The first subsection discusses the consumption and investment goods. The second discusses the export good.

3.3.1 Consumption and Investment

The production functions are given by:

$$I_t = \left[\gamma_I^{\frac{1}{\nu_I}} I_{d,t}^{\frac{\nu_I - 1}{\nu_I}} + (1-\gamma_I)^{\frac{1}{\nu_I}} I_{m,t}^{\frac{\nu_I - 1}{\nu_I}} \right]^{\frac{\nu_I}{\nu_I - 1}}$$

$$C_t = \left[(1-\omega_c)^{\frac{1}{\eta_c}} (C_{d,t})^{\frac{\eta_c - 1}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}} (C_{m,t})^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}}$$

where I_t and C_t denote investment and consumption goods, respectively. Also, ν_I and η_c denote the elasticities of substitution between the domestically produced homogeneous and imported goods. These are indicated by the subscripts, d and m, respectively. The prices of consumption and investment goods are P_t^c and P_t^I, respectively. The price of the domestic input is P_t in both cases, as discussed in Section 3.2. The price of the imported good is $S_t P_t^f$, where P_t^f denotes the dollar price of foreign goods.

3.3.2 Exports and the Dominant Currency Paradigm

Foreign GDP, Y_t^f, is modeled as the product of a permanent component, $\mathcal{Z}_t$, and a transitory component, y_t^f, as follows:

$$Y_t^f = y_t^f \mathcal{Z}_t. \tag{15}$$

The monetary shock is assumed to affect Y_t^f exclusively via its transitory component, y_t^f, (see section 2.1.2 below) while leaving $\mathcal{Z}_t$ undisturbed. In a version of the model with more shocks, $\mathcal{Z}_t$ would be affected by technology shocks which we assume are orthogonal to the monetary shock. Since our focus is on IRFs to monetary policy shocks, we can abstract from those other shocks.[30] We assume that $\mathcal{Z}_t$ grows at its steady state rate, which we denote by Δa. The demand for exports, X_t, is given by:

$$X_t = \left(\frac{P_t^X}{P_t^f} \right)^{-\eta_f} \left[\left(\frac{y_t^f}{y^f} \right)^{\gamma_f} \mathcal{Z}_t \right], \tag{16}$$

where P_t^X / P_t^f denotes the terms of trade; $\eta_f > 0$ denotes the elasticity of demand with respect to the terms of trade; and γ_f denotes the elasticity of the export demand shifter (the term in square brackets in equation (16)) with respect to the transitory component of GDP.

The domestic production function for exports is

$$X_t = \left[\gamma_X^{\frac{1}{\eta_x}} (X_{d,t})^{\frac{\eta_x - 1}{\eta_x}} + (1-\gamma_X)^{\frac{1}{\eta_X}} (X_{m,t})^{\frac{\eta_X - 1}{\eta_X}} \right]^{\frac{\eta_X}{\eta_X - 1}}, \tag{17}$$

[30] This argument relies on the accuracy of the linear approximation to the model, which is what we work with in practice.

where X_t denotes the quantity of exports. The quantities of the domestically produced good and imports are indicated by the subscripts d and m, respectively. The prices of the output good, P_t^X, and of the domestically produced good, $P_t^{d,X}$ and the imported good, P_t^f, are all denominated in dollars. Taking these as given, the representative exporter chooses inputs and output to maximize profits. In equilibrium, those profits are zero.

Gopinath et al. (2020) and others report that not only is much of world trade invoiced in dollars, but the price of traded goods are actually sticky in dollars. To capture this observation, we adopt a version of the Calvo-sticky price mechanism in section 3.2, which implies that $P_t^{d,x}$ is sticky in dollars. We suppose that $X_{d,t}$ is produced by a representative competitive firm using a production function similar to equation (12):

$$X_{d,t} = \left[\int_0^1 X_{i,t}^{\frac{\varepsilon_X - 1}{\varepsilon_X}} di\right]^{\frac{\varepsilon_X}{\varepsilon_X - 1}}, \ \varepsilon_X > 1.$$

This production function is operated by a representative, competitive firm which takes the output price, $P_t^{d,X}$, and input prices, $P_{i,t}^{d,X}$, $i \in [0,1]$, as given. The i^{th} input, $X_{i,t}$, is produced by a monopolist using $X_{i,t}$ units of the homogeneous good, taking its price, P_t, as given. This monopolist faces a version of the Calvo-sticky price mechanism, equation (14), with probability of not changing its price, θ^X.[31]

The total amount of homogeneous goods, $X_{d,t}^*$, required to produce a given amount of $X_{d,t}$, depends in the usual Calvo way on the dispersion of $P_{i,t}^{d,X}$ for $i \in [0,1]$. In the special case of flexible prices, $\theta^X = 0$, then $P_{i,t}^{d,X} = \frac{(1-\tau_X)\varepsilon_X}{\varepsilon_X - 1} P_t = P_t$ for all $i \in [0,1]$. Here, τ_X is a lump sum subsidy which we assume neutralizes the markup, $\varepsilon_X / (\varepsilon_X - 1)$. Since $P_{i,t}^{d,X}$ is the same for all i when $\theta^X = 0$, it follows that all inputs into producing $X_{d,t}$ are used at the same scale, so that $X_{d,t} = X_{d,t}^* = \int_0^1 X_{i,t} di$. When $\theta^X > 1$ and there is some inflation in $P_t^{d,X}$, then $X_{d,t} < X_{d,t}^*$.

3.4 Entrepreneurs and Banks

To capture balance sheet effects of exchange rate changes and accelerator effects, we adopt an open economy version of the costly state verification (CSV) adopted in Bernanke et al. (1999).[32] Entrepreneurs acquire capital and rent it to the intermediate good producers in the homogeneous good sector. Entrepreneurs find it desirable to leverage their own resources (net worth) by acquiring funds from a lender ('bank'). After the entrepreneur's capital is acquired and put to work, it experiences an idiosyncratic productivity shock, ω. Ex ante, there is no asymmetric information between bankers and entrepreneurs. Each knows the net worth of the entrepreneur and they know the common distribution, F, from which all entrepreneurs will independently draw ω. Ex post,

[31] An alternative model of sticky in dollar exports would assign the production function to the intermediate good producer with the Calvo price frictions. That would make P_t^x more sticky, by insulating P_t^x from shocks to P_t^f.

[32] To our knowledge, the first paper to introduce CSV into a closed economy macroeconomics model is Williamson (1987a; 1987b). Another early influential contribution is Carlstrom and Fuerst (1997).

the realized value of ω is observed by the entrepreneur, but is only observable to the bank at a cost. Under these circumstances a sharing contract between entrepreneur and bank does not work and the model assumes that entrepreneurs instead receive a *standard debt contract*: the entrepreneur receives a loan and must then pay a specified interest rate in the next period. If the entrepreneur cannot pay because its ω is too low, then it goes into default and, after being monitored by the bank, the entrepreneur must transfer all its assets to the bank. The interest rate in the standard debt contract is higher than the risk-free rate because loans to entrepreneurs are risky: entrepreneurs who draw a high value of ω must pay enough to cover the costs to the banks of defaulting entrepreneurs. Naturally, entrepreneurs with low net worth ('bad balance sheets') are restricted in the amount of debt they receive. This creates a *balance sheet effects* and these are potentially very large when there is a currency depreciation. To the extent that entrepreneurial loans are financed by dollar liabilities, entrepreneurial net worth falls when the exchange rate depreciates and this reduces their capacity to borrow, forcing them to cut back on the purchase of capital, producing a fall in investment.

The CSV financial friction was first used in an open economy setting by Chang and Velasco (2001) and Céspedes et al. (2004). The friction was later introduced into NK open economy models by Gertler et al. (2007) and Christiano et al. (2011b). The latter papers take extreme positions on the currency composition of entrepreneur loan liabilities, with either all entrepreneurial funding obtained in foreign currency or all in LCU. The data requires something intermediate and Dalgic (2024) works out a model in which entrepreneurs choose endogenously the currency composition of their liabilities. Here, for simplicity we adopt the approach developed in Castillo and Medina (2021) in which the currency composition of liabilities is exogenous (see also De Leo et al. (2022)).

3.4.1 Entrepreneurs

We assume that entrepreneurs are members of the household and infinite-lived. Each entrepreneur has a history of idiosyncratic shocks, which determines its current net worth. To preserve our representative household assumption, we suppose that each household has a large number of entrepreneurs. The entrepreneurs in each household have the same distribution of net worth as in the economy as a whole.

Consider an entrepreneur with end-of-period t net worth, N_t. That entrepreneur goes to a bank and receives a loan contract, $\left(\overline{B}_t^e, \{Z_{t+1}\}\right)$. Here, $\overline{B}_t^e$ is a quantity of LCU money and Z_{t+1} is the LCU gross rate of interest the entrepreneur pays, which potentially depends on the period $t+1$ realized aggregate state of nature. Combining its net worth and loan, the entrepreneur purchases K_t units of capital:

$$N_t + \overline{B}_t^e = P_t^k K_t, \tag{18}$$

where P_t^k is the period t market price of capital.

After purchasing a unit of capital, the entrepreneur's effective capital becomes ωK_t. The idiosyncratic shock is drawn from a log Normal distribution with $E\omega = 1$ and $var(\log\omega) = \sigma^2$. The entrepreneur rents out its effective capital in period $t+1$ at the competitive rental rate, r_{t+1}. The entrepreneur sells the effective capital left over at the end of period $t+1$ for $(1-\delta)\,\omega K_t P_{t+1}^k$, where δ denotes the capital depreciation rate. So, the entrepreneur that buys K_t units of raw capital in t receives the following income in period $t+1$:

$$
\begin{aligned}
K_t \omega r_{t+1} + (1-\delta)\,\omega K_t P_{t+1}^k = {} & K_t P_t^k \omega \left[\frac{r_{t+1} + (1-\delta)\,P_{t+1}^k}{P_t^k}\right] \\
= {} & K_t P_t^k \omega R_{t+1}^k,
\end{aligned}
\tag{19}
$$

where R_{t+1}^k denotes the rate of return on a unit of effective capital, in LCU units. This rate of return is exogenous to the entrepreneur.

The standard debt contract specifies that the entrepreneur must pay the bank $Z_{t+1}\overline{B}_t^e$ in period $t+1$. Let $\bar{\omega}_{t+1}$ denote the cutoff value of ω which gives the entrepreneur just enough income to cover the interest and principal on its debt. That is,

$$
\bar{\omega}_{t+1} = \frac{Z_{t+1}\overline{B}_t^e}{P_t^k K_t R_{t+1}^k}. \tag{20}
$$

That the cutoff is indexed by $t+1$ reflects that it is a function of the period $t+1$ aggregate state of nature. Entrepreneurs with $\omega < \bar{\omega}_{t+1}$ go into default in $t+1$ and must turn over all their resources to the bank, after those resources have been verified by the bank at a cost. The entrepreneur receives full consumption insurance from its household. In exchange, the household expects the entrepreneur to choose a debt contract that maximizes:

$$
E_t \upsilon_{t+1} \int_{\overline{\omega}_{t+1}}^{\infty} \left[P_t^k K_t \omega R_{t+1}^k - Z_{t+1}\overline{B}_t^e\right] dF(\omega), \tag{21}
$$

where υ_{t+1}, taken as exogenous by the entrepreneur, denotes the usual asset pricing kernel, defined in equation (9).

3.4.2 Banks

The entrepreneur chooses a standard debt contract from a menu that is determined in a competitive market equilibrium. To explain this, we need to examine the circumstances of the banks. For simplicity, consider a representative bank that specializes in making loans to entrepreneurs with net worth, $N_t > 0$. Since the bank has no funds of its own, it must issue liabilities to finance $\overline{B}_t^e$ units of LCU loaned to entrepreneurs. Following Castillo and Medina (2021), we assume that the bank finances ϕ of its borrowing needs in an LCU credit market and $1-\phi$ in dollars:

$$B_t^{LCU} = \phi \overline{B}_t^e,\ S_t B_t^{\$} = (1-\phi)\,\overline{B}_t^e, \tag{22}$$

where B_t^{LCU} denotes the quantity of LCU borrowed at the gross interest rate, $R_{d,t}$. This interest rate must be paid in period $t+1$ and is non-state contingent. Also, $B_t^{\$}$ denotes dollars borrowed at the non-state contingent dollar rate, $R_{d,t}^*$. The bank can borrow as much as it wants at the risk free rates, $R_{d,t}$ and $R_{d,t}^*$, and there is no circumstance in which it cannot pay its liabilities. This is because the bank makes loans to a large population of entrepreneurs with net worth, N_t. The population is large enough that the distribution of ω across the bank's borrowers matches the distribution, F.

Let $A_{t,t+1}$ denote bank receipts from entrepreneurs, net of monitoring costs and repayment of bank liabilities:

$$\begin{aligned} A_{t,t+1} = {} & \left[1 - F\left(\overline{\omega}_{t+1}\right)\right] \overline{B}_t^e Z_{t+1} + (1-\mu)\, G\left(\overline{\omega}_{t+1}\right) P_t^k K_t R_{t+1}^k \\ & - R_{d,t}\phi \overline{B}_t^e - s_{t+1}\,(1-\phi)\,\overline{B}_t^e R_{d,t}^*, \end{aligned} \tag{23}$$

where $s_{t+1} \equiv S_{t+1}/S_t$ denotes the rate of depreciation, $F\left(\overline{\omega}_{t+1}\right)$, denotes the period $t+1$ fraction of non-performing entrepreneurs and

$$G\left(\overline{\omega}_{t+1}\right) = \int_0^{\overline{\omega}_{t+1}} \omega dF\left(\overline{\omega}_{t+1}\right). \tag{24}$$

The first term after the equality in equation (23) corresponds to payments by the $1-F\left(\overline{\omega}_{t+1}\right)$ non-defaulting entrepreneurs. The next term corresponds to the resources, net of monitoring costs, recovered from defaulting entrepreneurs. Total monitoring costs, in LCU units, are $\mu G\left(\overline{\omega}_{t+1}\right) P_t^k K_t R_{t+1}^k$. Under the assumption of free entry, the ex ante value of banking must be zero:

$$E_t \upsilon_{t+1} A_{t,t+1} = 0. \tag{25}$$

In the presence of complete markets this is the only restriction on profits. In particular, as of period t it is possible for the bank to have a 'deficit', $A_{t,t+1} < 0$, in one period $t+1$ continuation state and a surplus, $A_{t,t+1} > 0$, in another period $t+1$ state. Household optimality in the Arrow securities market requires only that the prices, $Q_{t,t+1}$, equal υ_{t+1} (see equation (9)). With prices set in that way, households are willing to take a position opposite to the bank so that each period $t+1$ Arrow security market clears in period t, i.e., $A_{t,t+1} + a_{t,t+1} = 0$ for each state of nature possible in $t+1$ conditional on t.

3.4.3 Equilibrium Contract

We assume that under competition, bankers offer a menu of contracts, $\left(\overline{B}_t^e, \{Z_{t+1}\}\right)$, which satisfy equation (25). So, the equilibrium contract is the one that solves the problem in equation (21) subject to equation (25). In principle the entrepreneur could choose a contract in which Z_{t+1} is not contingent on the period $t+1$ state of nature. But, this would come at a cost to the bank since it would force the bank to enter the Arrow security markets and potentially pay a high price for funds in a bad period $t+1$ state in exchange for funds in a good $t+1$ state which have a lower relative price. This cost to the bank would be passed on to the entrepreneur in the form of a higher non-state contingent interest rate, Z_{t+1}. In our computations we find that Z_{t+1} responds sharply to shocks, so that little use is made of Arrow securities in equilibrium.

As in Bernanke et al. (1999), the assumptions in the model allow us to determine aggregate capital, net worth and borrowing without having to keep track of the distribution of these variables across individual entrepreneurs. An important property of the model is that the amount of loans an entrepreneur takes in a realized state of nature in period $t+1$ is, other things the same, an increasing function of its net worth in that state of nature. That is determined in part by the realization of its idiosyncratic shock in period $t+1$. In terms of aggregate variables, if R_{t+1}^k is realized to be high, because of a high realization of r_{t+1} or P_{t+1}^k, then the entrepreneur will be in a better position to borrow in that state of nature (see equation (19)). A high r_{t+1} means capital purchased in period t brings in more income in period $t+1$, while a high P_{t+1}^k means that the entrepreneur earns a capital gain on capital purchased in t. In practice, capital gains and losses play an important role in the model because of the large coefficient, $1-\delta$, on P_{t+1}^k(see equation (19)). When a shock causes P_{t+1}^k to go down, then the loss to entrepreneurs puts them in a bad position to borrow. There is a partially moderating factor to this capital gain effect. Because the price of capital is trend reverting, a fall in P_{t+1}^k triggers an expected capital gain from $t+1$ to $t+2$. Other things the same, this allows the entrepreneur to increase its leverage and borrow more. In practice, the dominant effect of a drop in P_{t+1}^k is the capital gains effect.

Now suppose that Z_{t+1} is high in $t+1$, say because the exchange rate depreciates. Then, the entrepreneur will, other things the same, have less net worth in period $t+1$ and will thus be driven to cut back borrowing. This is suggested by equation (23). Suppose that Arrow securities are used very little in equilibrium, so that $A_{t,t+1} \simeq 0$. Then, if s_{t+1} jumps, other things the same, Z_{t+1} must jump too. If, as is suggested by our numerical calculations, the equilibrium has the property that Arrow securities are not used, then effectively the entrepreneur borrows partially in dollars and partially in LCU if $0 < \phi < 1$ (recall equation (22)). In LCU units, when s_{t+1} jumps, dollar debt is a drain on entrepreneurial net worth. This effect can be quite large in this model.

It is a property of the equilibrium that in period t the net aggregate earnings of all entrepreneurs can be expressed as a share, $1-\Gamma(\overline{\omega}_t)$, of the aggregate gross earnings of all entrepreneurs, $P_{t-1}^k K_{t-1} R_t^k$. Here, $\Gamma : [0,\infty] \to [0,1]$ and $\Gamma(\overline{\omega}_t)$ is increasing in $\overline{\omega}_t$. Note from equation (20) that, other things the same, $\overline{\omega}_t$ is increasing in Z_t. It is not surprising that with a higher Z_t, entrepreneurs receive a smaller share of their gross profits.

We assume that an exogenous fraction, γ^e, of an entrepreneur's period t earnings is transferred to its household while the entrepreneur keeps the rest. In addition, each entrepreneur receives a small LCU lump sum transfer from households in the amount, W_t^e. The transfer ensures that even bankrupt entrepreneurs in period t, who receive income from their standard debt contract, nevertheless still have a small amount of net worth. It is a property of the model that if an entrepreneur has no net worth, then it cannot borrow at all. If $W_t^e = 0$ then, because all entrepreneurs experience bankruptcy at some point, all entrepreneurs would eventually be unable to borrow. It follows that the aggregate amount of net worth held by all entrepreneurs during period t after period t uncertainty is resolved and production has occurred is given by:

$$N_t = \gamma^e \left[1 - \Gamma\left(\overline{\omega}_t\right)\right] P_{t-1}^k K_{t-1} R_t^k + W_t^e. \tag{26}$$

where W_t^e denotes a transfer of net worth from households to entrepreneurs. The period t transfer to households from entrepreneurs is $\left(1-\gamma^e\right)\left[1 - \Gamma\left(\overline{\omega}_t\right)\right] P_{t-1}^k K_{t-1} R_t^k - W_t^e$ and this term is part of Π_t in the household's budget constraint, equation (8).

Additional technical details about the model are provided in the Online Appendix to this paper.

3.5 Government Policy

3.5.1 Government Purchases of Goods and Services

We assume that the local government purchases domestic homogeneous goods:

$$G_t = g\mathcal{Z}_t \tag{27}$$

where $\mathcal{Z}_t$ denotes the same trend term that appears in equation (15).

3.5.2 Interest Rate Policy

The central bank has two policy tools. The first is the traditional Taylor monetary policy rule:

$$\begin{aligned}\log\left(\frac{R_{d,t}}{R_d}\right) = & \rho_R \log\left(\frac{R_{d,t-1}}{R_d}\right) \\ & + (1-\rho_R)\left[r_\pi \log\left(\frac{\pi_t}{\pi}\right) + r_y \log\left(\frac{y_t}{y}\right) + r_S \log\left(\widetilde{S}_t\right)\right] + \epsilon_{R,t}.\end{aligned}$$

Here, $\pi_t = P_t/P_{t-1}$ denotes homogeneous good inflation, y_t denotes Y_t/A_t, where Y_t denotes aggregate homogeneous good output.[33] We assume that the monetary authority targets local prices (rather than the consumer price index) in part because of our finding that the estimated rise in consumer price inflation is relatively strong after a US monetary tightening, while the response of local monetary authorities is relatively weak. Our decision to include π_t rather than π_t^c in the interest rate rule was also motivated by the argument in Egorov and Mukhin (2023) which suggests that this specification of the rule may be welfare-improving. In addition, central banks tend to focus on 'core inflation', a variable that is not sensitive to transitory shocks, and π_t may satisfy that condition because it is relatively insensitive to shocks in the exchange rate. We include y_t in the policy rule as a rough indicator of natural output. Also, $\tilde{S}_t$ corresponds to $S_t/\left(\psi^t \bar{S}\right)$, where $\bar{S} > 0$ is a parameter. We indicate the nonstochatic steady state of a time series variable by deleting its time subscript. We include $r_S > 0$ in the monetary policy rule because of our VAR evidence (see Figures 1, 3 and 4) that exchange rates appear to return to their unshocked levels after a US monetary policy shock.[34]

3.5.3 FX Interventions

In addition to the traditional monetary policy, we allow a central bank to conduct FX interventions. We assume that the central bank uses a Taylor-type intervention rule following Castillo and Medina (2021):

$$\frac{F_t^*}{\overline{F}_t^*} = \left(\frac{F_{t-1}^*}{\overline{F}_{t-1}^*}\right)^{\rho_{fx}} \left(\frac{R_{d,t}^* - 1}{R_d^* - 1}\right)^{-\theta_{R^*}}, \tag{28}$$

where F_t^* denotes the central bank holdings of dollar assets and $\overline{F}_t^*$ denotes a long run target value the central bank's target holdings of reserves. We construct $\overline{F}_t^*$ following the conventional wisdom about what the suitable foreign reserve target should be for a central bank (see, e.g., Greenspan (1999)). According to this approach, the period t target for reserves is proportional to the gross dollar liabilities of the country at the start of period t. In our model this is the term in the square brackets:

$$\overline{F}_t^* = \left(\upsilon^{cb}\right)^{1-\vartheta} \left[R_{t-1}^* B_{t-1}^{\$} + \overbrace{P_t^m \left(I_{m,t} + C_{m,t}\right)/S_t}^{\text{imports in units of dollars}}\right]^{1-\vartheta} \left(\overline{F}_{t-1}^*\right)^{\vartheta} \tag{29}$$

[33]Homogeneous good output is essentially GDP in this model. The difference between Y_t and GDP is only that the former include monitoring costs for banks, which does not appear in GDP. Bank monitoring costs are very small, as they presumably are in actual economies.

[34]We simulated the VARs out 600 periods and the upper and probability interval for the EME IRFs for the exchange rate blows up, but includes zero in the interior. But, in the case of the AE's the lower bound of the probability interval blows up in a negative direction, but appears bounded above by a negative number. So, the EMEs are more consistent than the AEs with the idea that the exchange rate returns to its unshocked level after a US monetary contraction. See section J of the Appendix for further discussion.

In practice, we choose a value for υ^{cb} so that the model's steady state is consistent with the average dollar reserves to GDP ratio of a country. We assume that FX interventions are sterilized in the following sense:

$$S_t\left(F_t^* - F_{t-1}^*\right) = B_t - B_{t-1}. \tag{30}$$

The central bank's FX strategy generates profits and losses on its balance sheet depending on movements in the exchange rate and interest rates. We assume these are rebated in lump-sum form to households. In our model, FX interventions have zero effect without the presence of UIP restrictions. For example, the frictions are turned off with $\gamma = 0$, then sterilized FX interventions are exactly undone by households, who willingly accept the dollar assets offered by the central bank in exchange for LCU bonds, without any change in market prices. The reason has to do with the fact that the households receive, in lump sum form, any gains or losses that the central bank experiences on its portfolio. For example, if the central bank sells a lot of dollars to households, then household portfolios have a lot more exchange rate risk. They don't mind because their overall exposure to exchange rate risk, which takes into account the transfers from the government, has not changed. When $\gamma > 0$ then households have a particular interest in the composition of their own portfolio and then sterilized interventions do have an effect. There is continuity, so that when $\gamma > 0$ but small, then the household buys nearly all of any amount of dollar assets the central bank sells, and they need only a very small market incentive to absorb those dollars. This could be some combination of a fall in $R_{d,t}$ or a rise in $R_{d,t}^* + E_t \log S_{t+1} - \log S_t$. Since $R_{d,t}^*$ is exogenous to the SOE, the latter would involve some combination of a fall in $\log S_t$ or rise in $E_t \log S_{t+1}$.

3.6 Capital Production

Capital is produced by competitive capital producers. These producers buy investment goods from investment good producers (see Section 3.3.1) at a given price, $P_{I,t}$. Capital accumulation in the model is subject to Christiano et al. (2005) type investment adjustment costs. In period t the representative capital producer uses 'old capital', x, and investment goods, I_t, to produce 'new capital', k:

$$k = x + \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t,$$

where $S(z) = S'(z) = 0$ and $S''(z) = \kappa > 0$, for $z = I_t/I_{t-1}$ along a steady state growth path. Here, S' and S'' denote the first and second derivatives, respectively, and κ is a model parameter. The price of a unit of old capital, x, is the same as the price, P_t^k, of a unit of new capital, k. So, costs for the capital producer are $P_t^k x + P_t^I I_t$. The representative capital producer solves for sequences of x_{t+j}, I_{t+j} to optimize profits,

$$E_t \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} \left\{ P_{t+j}^k \left[x_{t+j} + \left(1 - S\left(\frac{I_{t+j}}{I_{t+j-1}}\right)\right) I_{t+j} \right] - P_{t+j}^k x_{t+j} - P_{t+j}^I I_{t+j} \right\},$$

where υ_{t+j} for $j \geq 0$ denotes the multiplier on the household's period $t+j$ flow budget constraint.

In equilibrium, $k = K_t$ the total quantity of capital purchased in period t. Also, $x = (1-\delta) K_{t-1}$, the quantity of capital that was rented out in period t and depreciated by δ.

3.7 Market Clearing, Balance of Payments and GDP

3.7.1 Financial Market Clearing

The supply of peso loans comes from households, D_t. The demand for pesos comes from banks, B_t^{LCU}, and government, B_t. We assume that foreigners do not participate in the market in local currency so that market clearing implies:

$$D_t = B_t^{LCU} + B_t. \tag{31}$$

The supply of dollars comes from households, D_t^*, and government, F_t^*, foreigners, F_t^o and the demand, $B_t^{\$}$, comes from domestic banks. So, market clearing implies

$$D_t^* + F_t^* + F_t^o = B_t^{\$}. \tag{32}$$

We also have clearing in the Arrow securities markets:

$$A_{t,t+1} = a_{t,t+1}, \tag{33}$$

where $a_{t,t+1}$ is pesos purchased by households (or, sold if negative) in period t for a realized state in $t+1$. Similarly, $A_{t,t+1}$ denotes LCU sold by banks in period t for delivery in a realized state of nature in $t+1$.

3.7.2 Homogeneous Goods Market Clearing

Supply, Y_t, equals demand in the homogeneous goods market requires:

$$Y_t = I_{d,t} + C_{d,t} + X_t^{d,*} + g\mathcal{Z}_t + \overbrace{\frac{\mu G(\overline{\omega}_t) P_{t-1}^k K_{t-1} R_t^k}{P_t}}^{\text{homog goods for monitoring by banks}}, \tag{34}$$

where $I_{d,t}$ and $C_{d,t}$ denote homogeneous goods used in the production of investment and consumption, respectively (see Section 3.3.1). Also, $X_t^{d,*}$ denotes the quantity of homogeneous goods used to produce the domestic input into exports (see Section 3.3.1) and the next term denotes government purchases (see equation (27)). Finally, the last equation corresponds to the total amount of homogeneous goods purchased by banks to monitor defaulting entrepreneurs (see Section 3.4.2). The object, $G(\overline{\omega}_t)$, is defined in equation (24).

3.7.3 Balance of Payments

The balance of payments is derived by starting with the household budget constraint and substituting out for profits and the government budget constraint. This leads to the following expression:

$$P_t^x X_t - P_t^m \left(C_{m,t} + I_{m,t} + X_{m,t}\right) = F_t^* - R_{d,t-1}^* F_{t-1}^* + D_t^* - R_{d,t-1}^* D_{t-1}^* - B_t^\$ + B_{t-1}^\$ R_{d,t-1}^* \quad (35)$$

Let $R_{d,t}^* = 1 + r_{d,t}^*$, so that the current account, CA_t, is net exports plus net interest earned from abroad:

$$CA_t = P_t^x X_t - P_t^m \left(C_{m,t} + I_{m,t} + X_{m,t}\right) + r_{d,t-1}^* \overbrace{\left(F_{t-1}^* + D_{t-1}^* - B_{t-1}^\$\right)}^{-F_{t-1}^o}. \quad (36)$$

Then, we have that (35) can be written as follows:

$$CA_t = F_t^* + D_t^* - B_t^\$ - \left(F_{t-1}^* + D_{t-1}^* - B_{t-1}^\$\right), \quad (37)$$

which states that the current account equals the change in net foreign assets. Since these assets have maturity one period, the change in net foreign assets is not affected by valuation effects. Given clearing in the dollar market, equation (32), the expression on the right of the equality in equation (37) can also be written as $-\left(F_t^o - F_{t-1}^o\right)$.

3.7.4 Gross Domestic Product

GDP is defined as domestic value added, or, $C + I + G + X -$ imports. We have a real concept of GDP, which is expressed in units of the consumption goods. Adding these terms and taking into account the zero profit conditions and first order optimality conditions that hold in competitive markets with constant returns to scale, we find that

$$GDP_t = \frac{P_t Y_t - \mu G\left(\overline{\omega}_t\right) P_{t-1}^k K_{t-1} R_t^k}{P_t^c}. \quad (38)$$

The numerator is the LCU value of the homogeneous goods and division byP_t^c converts GDP to consumption units. The quantity, Y_t, includes monitoring costs (see equation (34)), which is not part of GDP. That is why monitoring costs are subtracted in the numerator of equation (38).

3.8 Rest of the World

From the perspective of our SOE the foreign variables, y_t,π_t^f, $R_{d,t}^*$ evolve exogenously, according to the specification in equation (2). People in an SOE are interested in US inflation because it helps to determine their country's terms of trade and they use US GDP as a proxy for their country's export demand shifter. To people in the SOE the US interest rate, $R_{d,t}^*$, is of also interest because they treat it as a risk free rate in dollar terms, at which they can borrow and lend.

4 Parameter Values

We use an approximate Bayesian approach to estimate the model parameters. The approach is a variant on the Bayesian impulse response matching estimator implemented in Christiano et al. (2005). The Bayesian procedure is described in Christiano et al. (2010) and Christiano et al. (2016), and we apply the procedure using the code in version 6 of Dynare (see Adjemian et al. (2024)).[35] Our IRFs are monthly, while the time period in our model is quarterly. We address this mismatch by applying a version of the impulse response procedure implemented in Jarociński and Karadi (2020). In particular we associate the quarter j impulse response in the model with the estimated impulse response in the first month of quarter j. Our estimation in effect chooses values for the model parameters to optimize an objective subject to a penalty constraint. The estimation objective is the sum of squared deviations between estimated and model IRFs, weighted by the estimated sampling variance in the corresponding estimated IRF. The penalties correspond to Bayesian priors on the parameters.

4.1 Parameter Values Not Estimated

The rest-of-the-world variables, $\pi_t^f, y_t, R_{d,t}^*$, are assumed to evolve according to equation (2). The values of D and A as given in equation (3).

Other parameters whose values are not estimated are listed in Table 1. The values of these parameters are fairly standard in the macroeconomics literature. For example, they are similar to the ones reported in Christiano et al. (2011b) and Christiano et al. (2014). See those papers for discussion and for the related literature. One parameter that is somewhat non-standard is r_S, the coefficient on the exchange rate in the Taylor rule. When $r_S > 0$ the exchange rate is stationary about the trend, ψ^t.[36] That is, the level of the exchange rate eventually returns to where it would have been in the absence of a shock. The exchange rate IRFs in Figures 3, 4, and 5 suggest that at the 2-year horizon, the effect of a monetary policy shock on the level of the exchange rate small in the data. Section J in the Appendix looks at the longer term impact of a monetary policy shock on the exchange rate and the results are consistent with a zero long-term effect in the case of the EMEs, Peru and the US. We find some evidence of a non-zero, though small, long-horizon effect in the case of the AEs. For this reason we set $r_S = 0.02$ for the EMEs and Peru, and we set r_S to a much smaller, though positive, number for the AEs.[37]

[35] For another application of the impulse response procedure, see Cesa-Bianchi et al. (2024).

[36] We set $\psi = 1$, though we believe our results are unaffected by this assumption.

[37] Our model does not imply that the exchange rate is a random walk, as is suggested in much of the literature. Our results are not incompatible with that literature because we only look at the response of the exchange rate to one particular shock, a US monetary policy shock. Presumably, most movements in the exchange rate are due to other shocks.

Table 1: Common (not estimated) Model Parameters

Variable	Description	Value
β	Discount Factor	0.99
α	Capital Share	0.40
δ	Depreciation	0.02
φ	Inverse Frisch	1.00
γ^e	Net worth retained by Entrepreneur	0.95
σ	Entrepreneur idiosyncratic productivity std	0.22
μ	Monitoring Cost Rate	0.25
$100\frac{W^e}{N}$	Steady State transfers to Entrepreneurs	0.11
r_π	Taylor Inflation Coefficient	1.50
r_y	Taylor Output Coefficient	0.05
r_S	Taylor Exchange Rate Coefficient	0.02
ϵ	Elasticity of Substitution, intermediate goods	6.00
θ	Calvo Parameter, intermediate goods	0.75
ϵ^x	Elasticity of Substitution, export goods	6.00

Notes: parameters set a priori, as discussed in the text. In the case of $100W^e/N$, we in effect use the assumed value, 0.11, to determine the value of W^e conditional on the other model parameters. The idea was for W^e to be small, but positive. We set $r_S = 0.00000002$ in the AE model.

4.2 Estimated Parameters

For ease of comparison, our point estimates for the three SOE models are reported in Table 2. In the estimation we adjusted our priors somewhat for two reasons. First, in the case of the EMEs, the model has difficulty reconciling the substantial depreciation with the relative absence of movement in consumer price inflation and the very substantial drop in GDP. Second, we adjusted home bias priors in the AEs and EMEs, $1-\omega_c, \gamma_I, \gamma_x$, to help ensure empirically reasonable trade to GDP ratios for those economies. The latter objective could in principle have been accomplished by calibrating those parameters to ensure the trade targets are satisfied. Alternatively, the Bayesian 'endogenous prior' methods described in Christiano et al. (2011a) that integrate moments of the data into the priors could have been used.[38] We did not use these approaches. This is why we call our approach an *approximate Bayesian approach*.

The first three rows of Table 2 show that our models include a significant amount of UIP frictions. That such frictions are required is evident from the hump-shape response of AE, EME and Peruvian exchange rates to a US monetary tightening (see Figures 3, 4 and 5). Those exchange rate responses differ significantly from the Dornbusch (1976)-overshooting pattern one would expect in

[38] Dynare offers the option in Christiano et al. (2011a) as well an alternative. Under the alternative it offers the possibility of computing the posterior distribution of variables of interest, conditional on target variables (e.g., the share of trade in GDP) being in a region of particular interest.

the absence of UIP frictions. We discuss the detailed role of the frictions below.

The value of the curvature parameter in investment, κ, is small, like the value estimated in Christiano et al. (2005), but much smaller than the values estimated in Christiano et al. (2014) and Christiano et al. (2016). The table indicates that the FX coefficients associated with the AE's are set to zero because our IRFs suggests those economies do not engage in significant FX interventions after a US monetary tightening (see Figure 3).

Consider the elasticity of substitution between domestic and foreign inputs in the production of consumption, exports and investment. In the case of the EMEs these elasticities of substitution are relatively low, less than unity. As we explain below, these low elasticities help the SOE model explain the relatively large fall in economic activities in EMEs (see Figure 4). Consistent with this logic, elasticities of substitution are somewhat higher in Peru, where the drop in GDP after a US monetary tightening is not as great as it is in the EMEs more generally.[39] Empirical estimates of elasticities of substitution (see, e.g., Allen et al. (2020), Backus and Kehoe (1992), Eaton and Kortum (2002)) are generally higher than the values assigned in our estimation. That may reflect our relatively greater emphasis on the high-frequency component of the data. Auclert et al. (2021) and Bohr (2024) explain why elasticities of substitution may be much lower in the short run, than they are over a longer horizon.

The parameters, γ_f, η_f, control the response of export demand to shifts in US GDP and the terms of trade, respectively (see equation (16)). We expect the value of η_f to have little impact on the transmission of US monetary policy shocks. This is because, given the inertia in US prices and sticky-in-dollar export prices, we expect relatively little movement in the terms of trade. On the other hand, the substantial drop in US import demand that accompanies a US monetary tightening suggests that a large value of γ_f will be important for model fit. Indeed, Table 2 reports a large value of γ_f, between 4 and 5, for the different models. This means that when US GDP (i.e., Y_t^f in equation (16)) falls by one percent due to its temporary component, the export demand shifter in , the temporary component of Y_t^f, y_t^f in equation (15), falls 4-5 percent. Section L in the Appendix perturbs the values of γ_f, η_f in the EME model verify the intuition just described about the relative unimportance for model fit of variations in η_f and the importance of the value of γ_f.

Consistent with the Dominant Currency Paradigm, we specify SOE export prices to be Calvo-sticky in dollars (see Section 3.3.2). We include the relevant Calvo price stickiness parameter, θ^x, among the estimated parameters. The estimated values imply prices are sticky on average about 5 quarters, only a bit higher than the one year or so found in studies of price stickiness in US data.

Next we turn to the three home bias parameters. Notably, the home bias parameters take on relatively large values in the AEs. Not surprisingly, we show below that these large values imply

[39]According to Figure 5, Peruvian GDP falls by about 2 percent in the year after a US monetary tightening, while the drop is much larger in the EMEs (see Figure 4). This finding is robust to using the Jarociński and Karadi (2020) monetary policy shocks (see Section C in the Appendix).

counterfactually low trade shares in the AE's. A distinguishing feature of the VAR results is that GDP falls a relatively small amount in the AEs, compared with the US, in the wake of a monetary tightening. Initially, we conjectured that the counterfactual implication that AE economies are relatively closed is the reason for our AE model's success at matching the relatively small drop in AE GDP. Section F in the Appendix shows that this conjecture is incorrect. In the Appendix, we reduce the value of the AE home bias parameters and find that this has essentially no impact on the drop in GDP and exports in the AEs. The reason the estimation chose high values for the home bias parameters was to avoid excessive passthrough of the exchange rate into inflation as well as an excessive drop in investment.

The large magnitude of the smoothing parameter in the monetary policy rule is consistent with estimates reported elsewhere.[40] Turning to credit dollarization, $1-\phi$, we fixed this value at approximately zero for the AE model. In the case of Peru, we took the parameter value from Castillo and Medina (2021). For the EMEs, the parameter was included in the estimated parameters.

Table 2: Estimated Model Parameters

Parameter	Description	Peru	EME	AE
γ	Target Portfolio Cost (UIP Friction)	2.56	1.78	3.20
γ_{R^*}	Risk Appetite (UIP Friction)	22.46	29.46	44.78
γ_θ	Portfolio Inertia (UIP Friction)	-11.55	-19.47	-47.77
κ	Investment Adjustment Cost	3.16	5.85	1.78
θ_{R*}	FX Intervention Reaction Coefficient	0.42	0.16	0.00
ρ^{FX}	FX Intervention Persistence	0.78	0.21	0.00
η_c	C, Elasticity of Substitution	0.94	0.41	1.53
η_x	X, Elasticity of Substitution	1.58	0.70	1.18
ν_i	I, Elasticity of Substitution	1.17	0.91	1.73
η^f	Elasticity of Demand, Exports	2.11	1.53	2.67
γ_f	Demand Shifter, Exports	4.02	5.67	3.86
θ^x	Export Calvo Stickiness	0.77	0.80	0.80
$1-\omega_c$	Home Bias, C	0.83	0.98	0.90
γ_I	Home Bias, I	0.21	0.71	0.78
γ_x	Home Bias, X	0.51	0.44	0.77
ρ_R	MP Persistence	0.88	0.82	0.91
$1-\phi$	Credit Dollarization	0.50	0.45	0.01
Υ	Steady State Deposit Dollarization	0.40	0.47	0.05
$\frac{F^*}{4\times GDP}$	Steady State Reserves/GDP	0.30	0.15	0.05

Notes: (1) Steady State Reserves/GDP was estimated in the case of the EMEs, but was simply taken from Castillo and Medina (2021) in the case of Peru and was set exogenously to 0.05 in the case of the AEs; (2) Υ is estimated in the case of the EMEs and Peru, but simply set to 0.05 in the case of the AEs; in the case of ϕ, this parameter is not estimated for Peru or the AEs (see text for discussion).

[40] See, for example, Christiano et al. (2011b, page 2025).

4.3 Steady State Properties of the Model

Table 3 displays steady state properties of the estimated models. The first column indicates the variable in each row. Here, X, M, NX, NFA denote exports, imports, net exports and net foreign assets, respectively. The models' implications for the trade to GDP ratio, $(X + M)/GDP$, differ from the corresponding empirical estimates: the AE's understate that quantity and the EMEs and Peru overstate. See Section 4.2 above (and, Section F in the Appendix) for a discussion of this result.

Table 3: Estimated Model Steady States

	AE (Data)	EME (Data)	Peru (Data)
C/GDP	0.50 (0.53)	0.51 (0.61)	0.51 (0.63)
I/GDP	0.19 (0.24)	0.20 (0.24)	0.19 (0.23)
X/GDP	0.14 (0.37)	0.63 (0.34)	0.45(0.26)
M/GDP	0.15 (0.34)	0.64(0.33)	0.46(0.24)
NX/GDP	-0.00 (0.03)	-0.01 (0.01)	-0.01 (0.02)
G/GDP	0.30 (0.19)	0.30 (0.15)	0.30 (0.12)
NFA/GDP	0.10 (0.27)	0.34 (-0.28)	0.30 (-0.31)
K/GDP	2.01	2.03	2.01
L	2.58	2.56	2.58
100Bankruptcy	1.43	1.38	1.43
$400(Z - R)$	1.779	1.712	1.772
$400(Rk - R)$	7.738	7.509	7.715

5 Fit of the Models and Counterfactual Experiments

In this section, we begin by evaluating the ability of our models to account for the empirical IRFs reported in Section 2.2. The first three sections below present results for AEs, EMEs and Peru, respectively. In section 5.4 we explain the role played by different features of our models in accounting for the empirical IRF's.That the models account well for the empirical IRFs is important for the credibility of the counterfactual experiments that drive our conclusion about the importance of the trade channel.

We exploit the linearity of our VARs and of our linear approximation of the SOE models to construct an additive decomposition of the effects of a US monetary tightening on AE's and EME's. The total effect on an AE or EME economy of a US monetary tightening is the sum of a *Pure Interest Rate Effect*, a *Pure Price Level Effect* and a *Pure Trade Effect*. We identify the pure interest rate effect as the reaction of our SOEs to the IRFs in $R^*_{d,t}$, counterfactually holding constant the impulse responses in the US price level and GDP. The pure price and pure trade effects are defined analogously. By linearity, the actual response of an SOE to a monetary shock is the sum of three pure effects operating via the US interest rate, price and GDP (see Figure 2). We find that the pure price level effect is negligible and the pure interest rate effect is small. The primary mechanism by which a tighter US monetary policy affects the AEs and EMEs operates through the pure trade effect. This is the basis for the main conclusion of the paper: much of the transmission of a US monetary tightening operates via the reduction in US imports.

Subsections 5.4 and 5.5 perform additional counterfactual experiments. We evaluate the relative contribution to the SOE impulse response functions of financial frictions, UIP frictions, and sticky-in-dollar pricing on the response to a US monetary tightening. We find that financial frictions and UIP frictions play particularly important roles In the international transmission of a US monetary tightening.

Finally, as a further check on the credibility of our SOE models, section 5.6 examines the implications of the models for IRFs not used in model estimation. In particular we evaluate the models' implications for the response of equity markets and interest rate spreads.

5.1 Advanced Economies

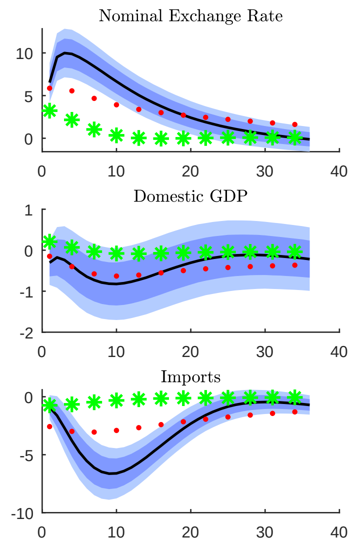
Figure 7 reproduces the IRFs and probability intervals for AEs presented in Figure 3. The corresponding IRFs from the estimated AE model are displayed in the red dots (IRFs for other model variables are discussed later). The time unit on the horizontal axis is months, and the quarterly data from the model are displayed for the first month in each quarter. The yellow stars present the model responses to a pure R^* shock.

Note that, overall, the model reproduces the solid black line reasonably well. The model does very well with GDP and investment. In the other cases the model reproduces the rough pattern of the black line. The CPI is an exception because it rises for the first year rather than falling (the red dots are partially obscured by the yellow stars because they roughly coincide). The model is characterized by too much passthrough from the exchange rate depreciation to domestic prices.[41]

A key thing to note is how different the yellow stars are from the red dots in all cases with the exception of the CPI. With a pure R^* shock, the responses look more like what one expects from M-F expenditure switching in response to the exchange rate depreciation. Investment and imports fall a small amount, and there is a (small) rise in GDP. The difference between an $R^*_{d,t}$ shock and a pure $R^*_{d,t}$ shock is particularly stark in the case of exports. As in the data, exports fall sharply in the estimated SOE model in response to an $R^*_{d,t}$ shock. But, exports rise in response to a pure $R^*_{d,t}$ shock. Despite the sticky-in-dollars export pricing, exports increase rather than falling substantiallyThe difference between an R^* shock and a pure R^* shock is primarily due to zeroing out imports (zeroing out the US price level has very little effect). Thus, the decline in output and exports is mostly due to the decline in US imports. Also, much of the decline in AE investment and imports is due to the decline in US imports. AE imports are pulled down by the decline in AE GDP. According to our analysis, the decline in US imports is the key channel by which a US monetary tightening affects AEs.

[41] The red dots and yellow stars virtually coincide in the 1,3 panel of Figure 7.

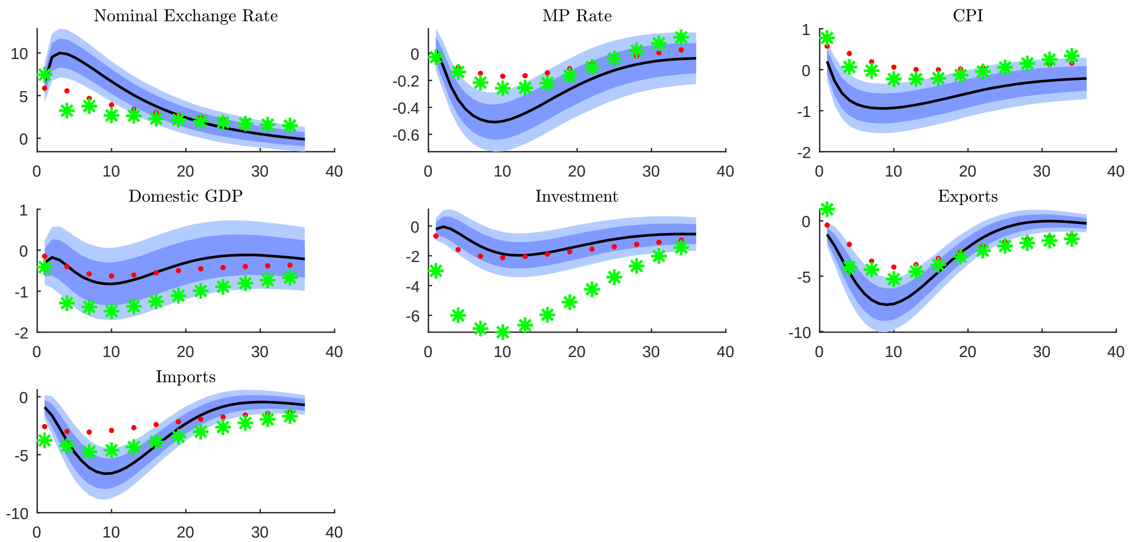
Figure 7: AE - VAR IRFs, SOE IRFs and SOE Responses to Pure R^* Shock



Notes: (1) The time unit on the horizontal axis is months. Model data are quarterly and are reported in the third month of each quarter; (2) the dark solid line and shaded areas taken from Figure 3; (3) dots correspond to IRFs implied by the estimated SOE model (for parameter values, see tables in Section 4); (4) stars correspond to responses in estimated SOE model to a pure R_t^* shock. Such a shock leaves the path of R_t^* at its estimated value reported in Figure 2, while zeroing out the response in the model's export demand shifter and foreign price.

Recall that the estimated portfolio friction parameters in Table 1 are substantially higher for the AEs than for the EMEs and Peru. In addition, AEs have little credit dollarization ($\phi \simeq 1$). The stars in Figure 8 show how the AEs would respond to a US monetary tightening if portfolio friction parameters (γ, γ_R and γ_θ) were set to their estimated values in the EMEs and $\phi = 0.7$ (i.e., 30% credit dollarization). Note that the small drop in GDP in the estimated model (see the dots) is amplified substantially (the stars), by nearly two percentage points in the first year, before reverting to trend. The large drop in GDP is mainly due to a substantial acceleration in the drop in investment. The perturbation in the portfolio friction parameters plays a very small role in this. When ϕ is positive and there is significant credit dollarization, entrepreneurs make substantial losses when the exchange rate depreciates in response to a US monetary tightening. This leads entrepreneurs to cut back on the demand for capital which in turn leads to the decline in investment demand that we see in Figure 8. A review of the economic logic underlying these effects appears in Section 3.4.

Figure 8: Impact of High Credit Dollarization in Advanced Economies



Notes: see notes (1)-(3) in Figure 7. Stars in the figure correspond to IRFs of the estimated AE SOE model in which the home bias parameters in consumption, investment and imports are set to their values in the AE model (see Table 2).

Our estimated parameters imply that AEs trade much less than EMEs in the steady state even though the amount of AE and EME trade openness is similar according to the data. In Section F of the Appendix we perturb the home bias parameter values in the estimated AE model so that they more closely resemble the home bias parameter values in the estimated EME model. When we do this, the perturbed AE model implies even more trade openness than we observe in the data. At the same time, the model's implication that GDP falls by a small amount after a monetary tightening is not changed. So, we conclude that the counterfactual implications of the AE model for trade openness are not the reason for the relatively modest decline in GDP after a US monetary policy shock. We show that the estimation procedure avoids the perturbed parameter values because smaller home bias increases passthrough from the exchange rate into inflation and magnifies the drop in investment. Overall, our results suggest that the main reason output falls more in EMEs than in AEs is that the former have more credit dollarization than the latter.

5.2 Emerging Market Economies

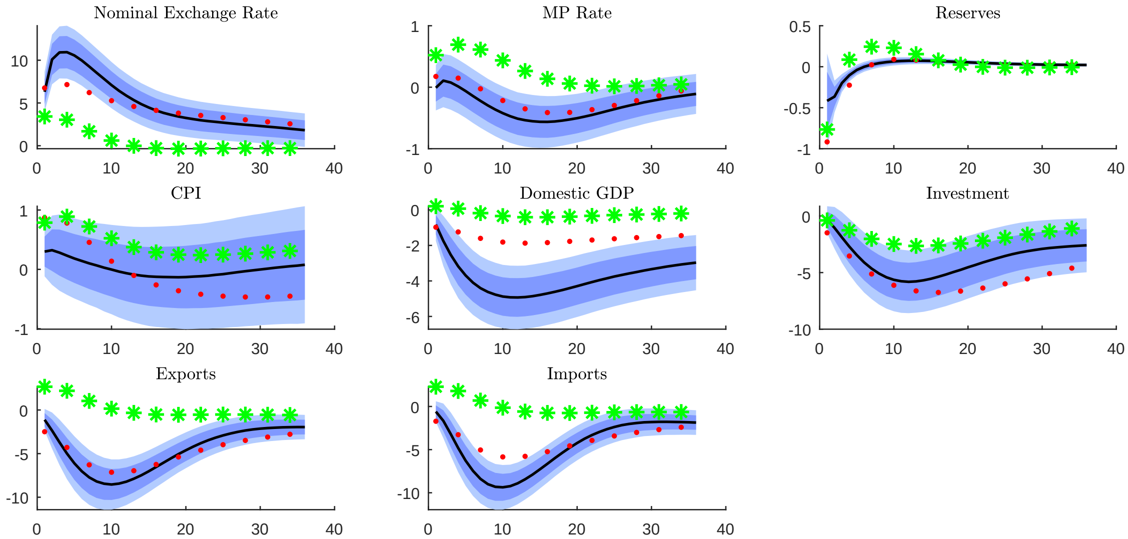
Our results for EMEs are displayed in Figure 9. For baseline model parameter values see Sections 4.1 and 4.2.

The estimated model reproduces the fact that EME GDP and investment fall substantially more than we observe in the AEs (recall Figure 7). The model understates our baseline VAR-based estimate of the drop in GDP (compare solid line with the red dotted line). This may not be a flaw. In the robustness tests for our VAR analysis we did find some evidence that our estimates of the decline in GDP after a US monetary contraction may be overestimated in our baseline VAR analysis.[42] Investment in the model falls more, in percent terms, than the decline in GDP. Model exports and imports closely follow the solid line. Bank reserves in the model and data match well too.

Consider the starred curves in Figure 9, which display the response of the model to a pure $R^*_{d,t}$ shock. As in the case of the AEs, responses to a pure $R^*_{d,t}$ have an M-F flavor. Exports increase in response to the exchange rate depreciation, despite sticky-in-dollar export pricing. Investment contracts, roughly canceling the positive effects of the rise in exports, so that the response of GDP is roughly flat, after a modest, temporary increase. The central bank sells reserves, to support the exchange rate. Because the FX intervention rule is dominated by feedback onto $R^*_{d,t}$, reserves follow a similar path when there is an $R^*_{d,t}$ shock or a pure $R^*_{d,t}$ shock. There is substantial passthrough from the exchange rate and into local prices, though model inflation does not go substantially outside the probability interval. The difference between red dots and yellow stars is dominated by the impact $R^*_{d,t}$ on the foreign demand for exports. The impact of monetary tightening As in the AE analysis, the model responses to the US monetary tightening (the red dots) are dominated by the fall in the demand for AE exports.

[42] The introduction to Section 2 provides a summary of our robustness analysis.

Figure 9: EME - VAR IRFs, SOE IRFs and SOE Responses to Pure R^* Shock



See notes to Figure 7.

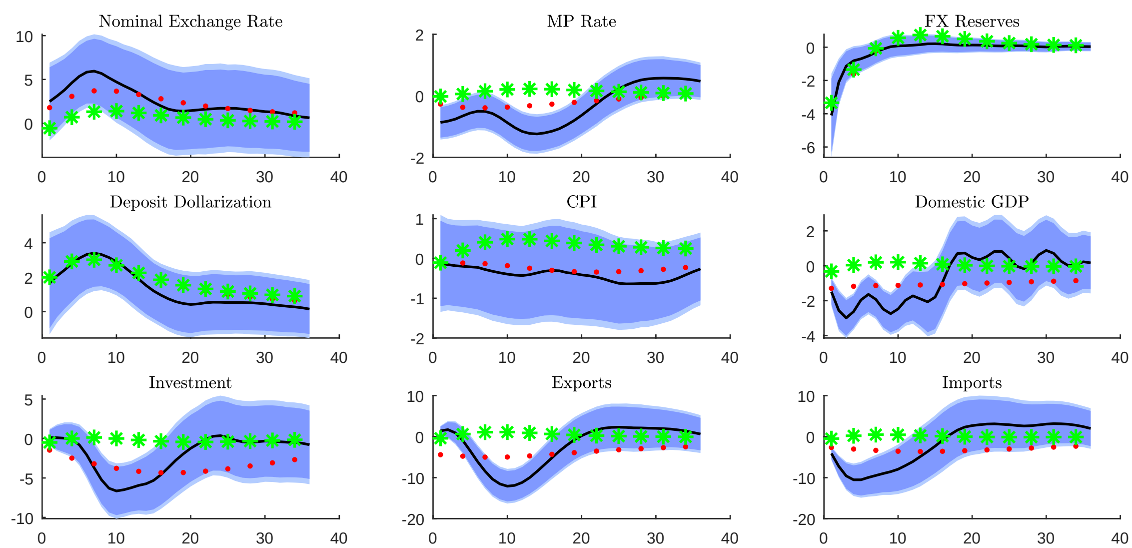
We do not include household consumption in our analysis, because consumption data is either not available or it also includes durables and so would not be a good match with our model. Figure 30 in Section H in the Appendix displays the response of the variables in Figure 9 and also additional variables like consumption. There, we show that even though our fitted elasticity of substitution is somewhat low, $\eta_c = 0.41$, it still the case that consumption rises for a year before going down. We reduced the elasticity of substitution further to $\eta_c = 0.25$, in which case consumption falls. This is consistent with the results in Auclert et al. (2021). Because it is harder to substitute away from consumption goods, a given rise in the exchange rate raises the price of the good by more than if the elasticity of substitution were higher. Our fitting exercise would not have liked the lower elasticity because it also drives up the CPI which is already near the upper bound of the 90 percent posterior interval. It also drives investment down and it is on the boundary of the lower bound of the 90 percent posterior interval.

5.3 Peru

Table 2 lists estimated parameters for the Peru model. In Figure 10, the dark solid line indicates the median estimated responses from the VAR analysis, and the shaded areas represent 68 and 90 percent probability intervals. The dots correspond to the IRFs in the estimated model. The match between model impulses and data impulses is reasonably good. The rise in $R^*_{d,t}$ is associated with a fall in the domestic interest rate and a short run expected depreciation of the currency (compare the periods 0 and 1 values of the log exchange rate in Panel 1,1). Households respond to the increase in $R^*_{d,t}$ by increasing the share of assets held in dollars, Θ_t (see Panel 2,1).

The yellow starred lines indicate the response of the estimated model to a pure $R^*_{d,t}$ shock, i.e., one in which the import demand shifter and foreign inflation are held constant. Apart from the drop in FX reserves and the increased holdings of dollars, there is very little response in other variables.

Figure 10: Peru



See notes to Figure 7.

5.3.1 The Role of FX Interventions after a US Monetary Tightening

The Central bank of Peru is transparent about its active FX intervention policy (Castillo and Medina (2021); Castillo et al. (2019)).[43] Using our model, we run several counterfactual experiments to quantitatively evaluate the effects of FX interventions. Figure 11 plots the IRFs of our estimated model, *Benchmark,* and a version of the model, *No Intervention,* in which the central bank does essentially no FX interventions ($\theta^{R^*} = 0$ in equation (28)). We can see the effect of FX

[43]See Section E in the Appendix for a graph of the Adler et al. (2024) measure of Peruvian FX intervention, based on data from the Central Bank of Peru's website. The interventions are frequent and large, as a fraction of (lagged) GDP.

interventions in Figure 11 by comparing Benchmark curve with the No Intervention curve.

Central bank interventions are sterilized in that the sale of government dollar assets, F_t^*, are financed by the purchase of an equivalent amount of LCU government bonds, B_t (see equation (30)). The 2,1 panel shows that in the Benchmark version of the model, the central bank reduces its dollar reserves, F_t^*, by around 3% of GDP. The operation is reversed by the end of a year or so, when $R_{d,t}^*$ has returned to its pre-shock level.

Without UIP frictions, FX interventions have zero effect in our model. As explained in section 3.5.3, $\gamma = 0$ implies that households are happy to take the opposite position of a sterilized intervention without the need for any change in market prices. In particular, $F_t^* + D_t^*$, remains unaffected and market clearing in LCU and dollar bond markets is undisturbed.[44] With $\gamma > 0$ then FX interventions have real effects.

In the case with $\gamma > 0$, when the central bank reduces F_t^* in exchange for LCU government debt, households will not increase D_t^* without a decrease in Λ_t, i.e., some combination of a decrease in $R_{d,t}$ and a rise in $R_{d,t}^* + E_t \log S_{t+1} - \log S_t$. The 4,3 panel in Figure 11 shows that Λ_t falls substantially while F_t^* is low, and D_t^* rises (4,2 panel). Households do not fully raise D_t^* by the fall in F_t^* so that $F_t^* + D_t^*$ falls.[45] With the combination of the households and central bank selling dollars on net, it is intuitive that the domestic currency appreciates with the FX intervention (see the first month in panel 1,3). The appreciation helps reduce Λ_t. In addition, it has a negative effect on the price level, so that monetary policy drives $R_{d,t}$ down, also contributing to the fall in Λ_t.

A negative shock to $F_t^* + D_t^*$ has effects via the balance of payments. In particular, it necessarily drives down the current account, according to equation (31). This, in turn, requires net exports to decrease, according to equation (36) (see panels 2,2 and 2,3). The market price that facilitates this move in net exports is the appreciation of the exchange rate.

The initial effect of the FX intervention on GDP is negative. This reflects in part that the FX intervention has a temporary negative impact on consumption, as households substitute towards holding more dollars in response to the increased LCU return on dollars, $R_{d,t}^* + E_t \log S_{t+1} - \log S_t$. It also reflects the fall in net exports. Finally, the impact on investment of the FX intervention is delayed. Over time, investment increases with the FX intervention so that the drop in investment that would occur absent FX intervention (the dashed line in panel 3,1) is muted over time with FX intervention (the solid blue line in panel 3,1). For the financial details about how FX interventions affect investment, including the response of leverage, interest rate spreads, non-performing loans, net worth, bankruptcies and monitoring costs, see section I in the Appendix.

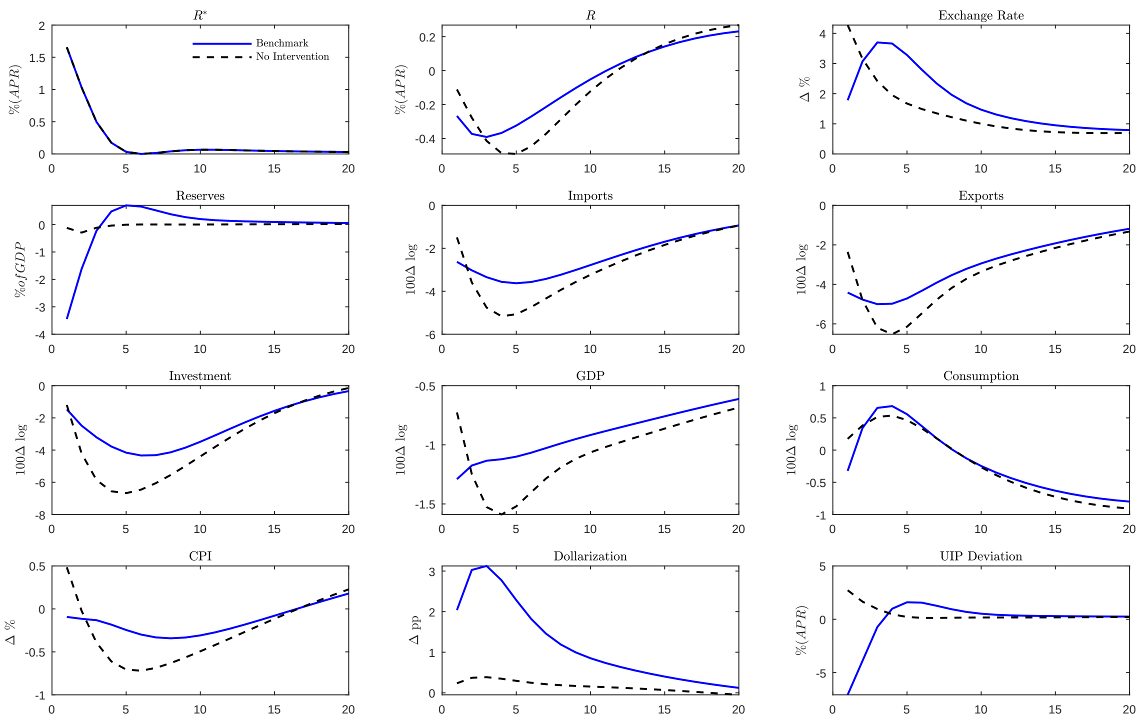
So, initially GDP is hurt by FX intervention and later it is boosted. To reduce the impact on

[44] The LCU and dollar market clearing conditions are given by equations (31) and (32), respectively.

[45] This is qualitatively consistent with the empirical finding in Bayoumi et al. (2015). They argue that when a central bank sells 100 dollars of assets, i.e., reduces F_t^* by 100, the sum of households and the central bank sell an amount of dollars in the range of 24 to 42, i.e., D_t^* rises by 58 to 76 dollars.

GDP to a single number, we compute the cumulative GDP loss, $100 \times \sum_{t=0}^{\infty} \beta^t \Delta \log(GDP_t)$, where $\Delta \log(GDP_t)$ is the log deviation of GDP from its unshocked path. The cumulative loss is 19.75% in the absence of FX intervention and 17.04% with FX intervention. So, given the FX intervention rule that we study, FX interventions reduce 14 percent of the 19.75% GDP loss created by the US monetary tightening. FX intervention by the rule we use only provides modest insulation against a US monetary contraction. We leave it to future work to see how much insulation is desirable, by examining the Ramsey-optimal equilibrium.

Figure 11: FX Interventions in Peru: Macro Variables



Note: the blue line reproduces the IRFs in response to a US monetary tightening from our estimated model (see the red dotted lines in Figure 3.5.3). The dashed line shows what would have happened if $\theta_{R^*} = 0$ in the central bank's FX policy rule, equation (28). The 'UIP deviation' in panel 4,3 corresponds to Λ_t in equation (10).

5.3.2 Noise Trading

Recent research argues that a significant portion of exchange rate volatility is generated by non-fundamental noise trading shocks or UIP shocks (Itskhoki and Mukhin (2021); Eichenbaum et al. (2021)) (see e_t^{Υ} in equation (7)). Figure 12 plots IRFs for two versions of the Peruvian model in response to a shock to the representative household's target share of dollars, Υ_t, in its portfolio. The portfolio target is defined in equation (7) and we set $\gamma_{R^*} = \gamma_{\Theta} = 0$. The shock drives Υ_1 from its steady state value, 0.4, to 0.41, so the shock to e_1^{Υ} is 0.01. The scalar first-order autoregressive process, e_t^{Υ}, has autocorrelation, 0.95. We compare the IRFs of a version of the model economy without FX interventions (*No Intervention*, black dashed line) and a version of the model economy in which the FX intervention rule responds directly to Υ_t:

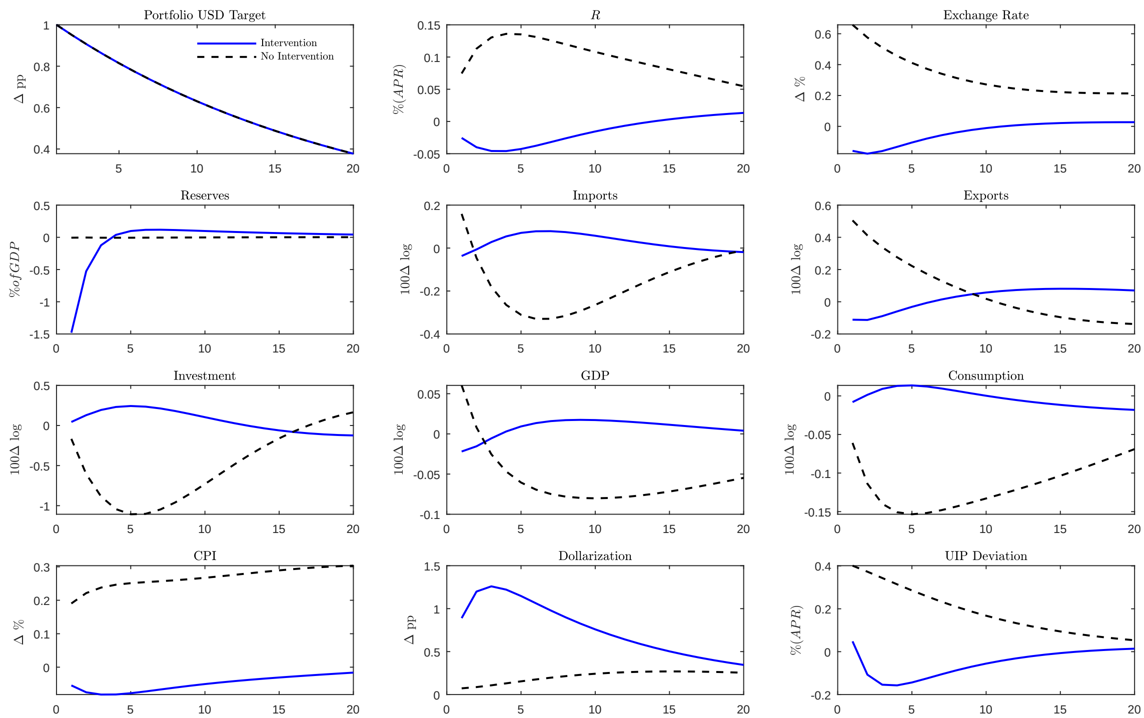
$$\frac{F_t^*}{\overline{F}_t^*} = \left(\frac{F_{t-1}^*}{\overline{F}_{t-1}^*}\right)^{\rho_{fx}} \left(\frac{\Upsilon_t}{\Upsilon}\right)^{-\theta_\Upsilon},$$

where $\theta_\Upsilon = 3$. The IRFs to this version of the economy is called *Intervention* and depicted by the solid, blue line.

The 1,1 panel in Figure 12 displays $100\left(\Upsilon_t - \Upsilon\right)$. The 4,2 panel in Figure 12 reports $100(\Theta_t - \Theta)$. In the No Intervention case the increase in the desire to hold dollars causes a depreciation (see panel 1,3). That in turn inflicts capital losses on entrepreneurs' balance sheets and, with a delay, leads them to cut back on investment. The maximal cut back on investment is a substantial 1 percent. The depreciation also drives up inflation (panel 4,1), so that the monetary authority raises the interest rate (1,2). Households respond by substituting towards domestic assets by raising Θ_t by only a small amount, despite the rise in the target (see 4,2). The small rise in Θ_t relative to Υ_t explains why $\Lambda_t$is positive (see panel 4,3). The rise in the interest rate, together with the fall in GDP, leads to a fall in consumption. Imports fall, both because of the depreciation and the fall in GDP. The depreciation stimulates a rise in exports which is muted by the sticky in dollars export prices.

Now consider the effects of FX intervention, the Intervention case. With the intervention, reserves fall 1.5 percent of GDP (see panel 2,1). Roughly speaking, the FX intervention rule gives households the additional dollars that they want. Note that Λ_t remains close to zero (see panel 4,3) and Θ_t roughly follows the path of Υ_t (panel 4,3). As a result, the FX intervention rule roughly insulates the economy from the noise shock. So, FX intervention can in principle be very effective at handling shocks for the demand for dollars.

Figure 12: UIP Shocks



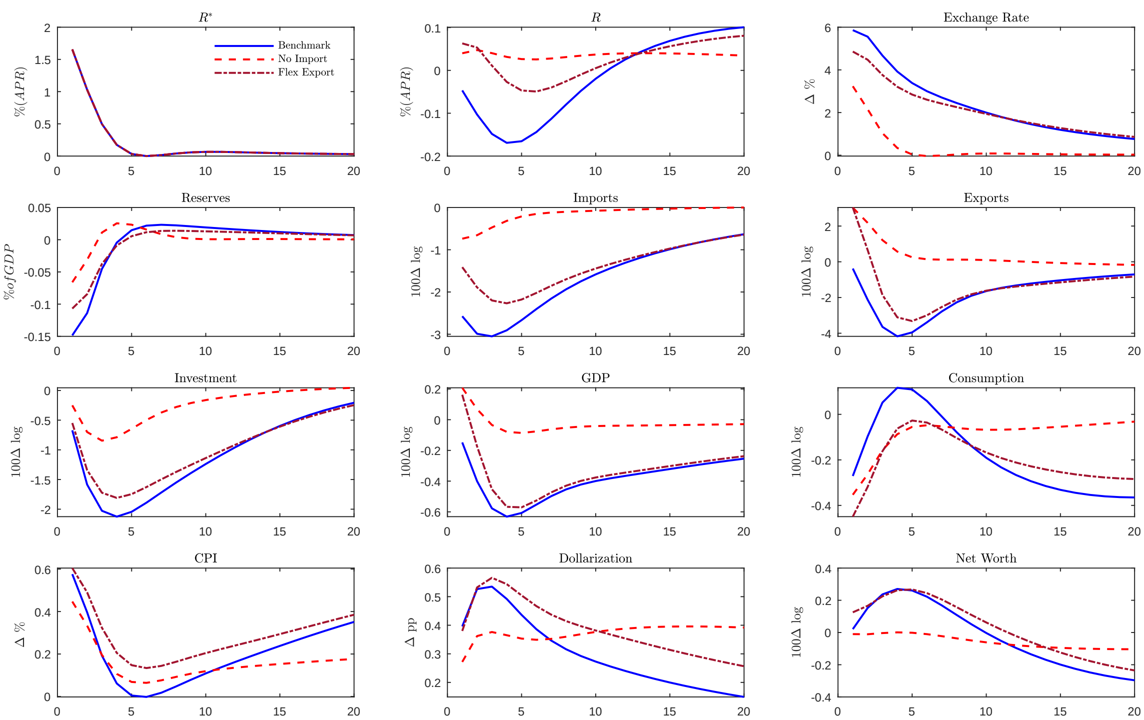
5.4 The Importance of the Trade Channel

The following three figures illustrate how important the trade channel is. For each of the AE, EME and Peru models, we display IRFs like the previous graphs, except that we also include the net worth of entrepreneurs. The following tables display the quantitative impact of removing frictions from each of the AE, the EME and the Peru models. We remove the balance sheet frictions by setting a high value for ϕ so that entrepreneurs have little exposure to dollars and balance sheet effects are small or nil. In the AE, the estimation results selected a value of ϕ very close to 1 so we do not implement this perturbation in that case (see Table 2). In the Peru model we set $\phi = 1$ so entrepreneurs do not borrow in dollars at all. In the case of EMEs for model solution reasons we set $\phi = 0.75$ so credit dollarization is substantially reduced but not eliminated. We also consider the case in which the US monetary tightening does not change the foreign price level or the shifter in export demand (proxied in our SOE models by foreign GDP), 'No Import' (see equations (16) and (15)). This is the case in which the trade channel is essentially shut down.[46] Finally, we consider the case, 'Flex Export', which corresponds to $\theta_x = 0$, i.e, dollar prices in the export sector are set flexibly.

[46]Movements in domestic dollar export prices could still affect the terms of trade and, hence, exports. But, when the sticky-in-dollar export specification is adopted the terms of trade are hardly affected in the 'No Import' case.

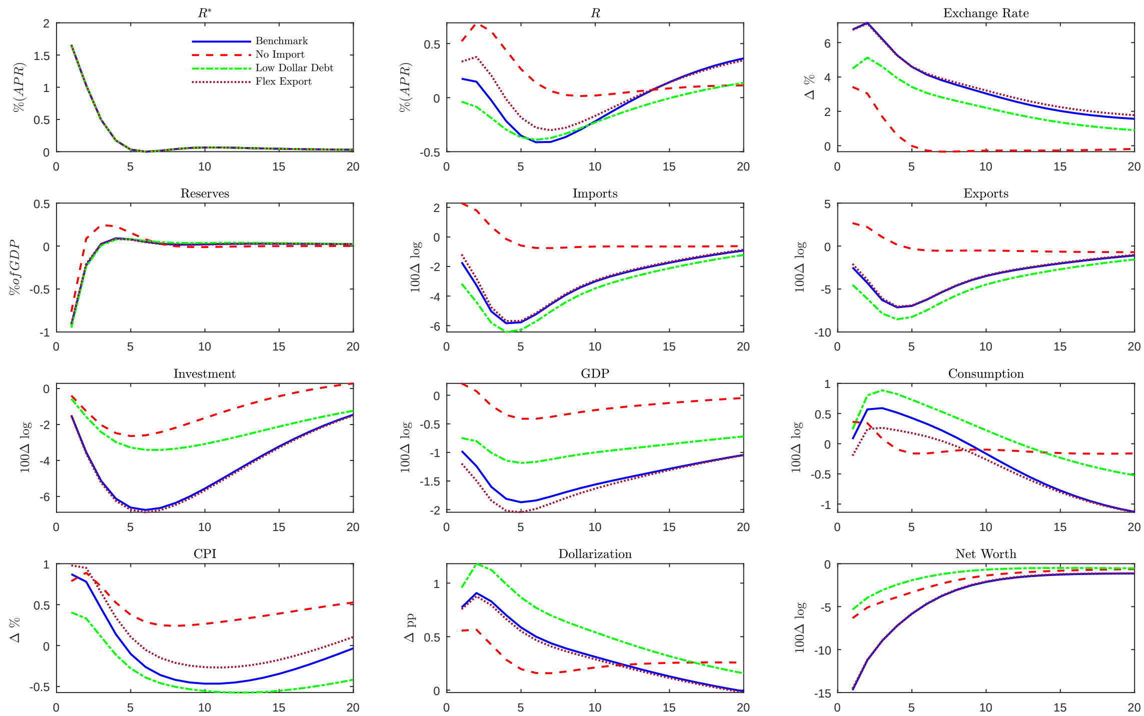
Consider the results for the AE model in Figure 13. The benchmark results are in blue and we see the relatively modest 1/2 percent drop in GDP in the benchmark model (panel 3,2). Note in the same figure that flexible-in-dollar prices cause exports not to change much, and this translates into a very small change in GDP. hardly affect the results for GDP. We do see that exports change very little in panel 2,3, but they don't change much to have a material effect on GDP (see panel 3,2). in in which there are no changes in the foreign price level and foreign demand The key result is that the impact on the impulse response functions of the various frictions is small compared to the impact of US imports. In the baseline results GDP does fall and this brings about a fall in entrepreneurial net worth, primarily via the loss in rental income from capital (not shown). The key thing to note is that when imports are shut down, the rise in R^* has almost no effect on the economy. Imports are the key in the AEs.

Figure 13: AE: Baseline and Baseline Without Two Features



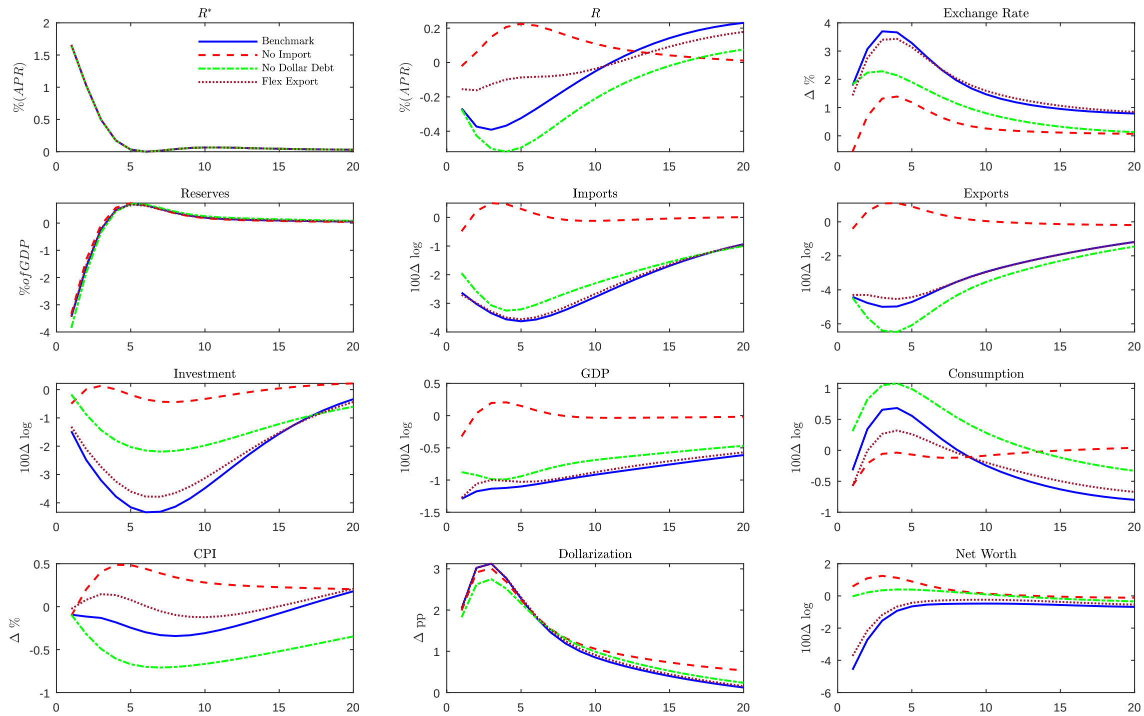
Now consider the EME's in which ϕ is estimated to be in a neighborhood of 1/2. In this case, the depreciation triggered a rise in R^* inflicts capital losses on dollar-indebted entrepreneurs. This shows up in the form of a substantial, protracted fall in their net worth (see panel 4,3). When the balance sheet channel is shut down by setting $\phi = 1$, then the GDP fall is reduced, but not greatly (see the yellow line in panel 3,2), despite the strong investment effect. Apart from reserves, the lines associated with absence of the trade channel are in each case noticeably closest to the zero axis.

Figure 14: EME: Baseline and Baseline Without Three Features



Finally, consider Peru. With two exceptions, the economy without a shift in import demand is the one closest to the zero line. The exceptions are reserves which is no surprise because the FX intervention rule is still in operation. The other exception is also no surprise. Net worth moves least when $\phi = 1$ and the balance sheet constraint is effectively much less important.

Figure 15: Peru: Baseline and Baseline Without Three Features



5.5 UIP Deviations

This section examines the role of the UIP frictions, parameterized by $\gamma, \gamma_{R^*}, \gamma_{\Theta}$, in the international transmission of US monetary shocks. For convenience, we reproduce a variant on our expression for the UIP deviation, Λ_t, in equations (10) and (11):[47]

$$\begin{aligned} \Lambda_t &= R_{d,t} - \overbrace{\left[R^*_{d,t} + E_t \log(S_{t+1}/S_t)\right]}^{\text{expected return on dollar asset in LCU units}}, \\ \Lambda_t &= \gamma \left(\Upsilon_t - \Theta_t\right), \\ \Upsilon_t &= \Upsilon + \gamma_{R^*}\left(R^*_{d,t} - R^*\right) + \gamma_{\Theta}\left(\bar{\Theta}_t - \bar{\Theta}_{t-1}\right) + e^{\Upsilon}_t. \end{aligned} \tag{39}$$

Here, Θ_t denotes the portfolio share of dollars chosen by an individual household, while $\bar{\Theta}_t$ denotes the aggregate share of dollars in all households' portfolios.[48] The first expression in equation (39) defines, to a first order approximation, the UIP deviation, Λ_t, in terms of the return on domestic assets and the return on dollar assets converted into LCU by the expected log change in the exchange rate. The second and third terms are our (reduced form) model of the UIP deviation.

[47] We have expressed equation (10) in a slightly different way, using the approximation, $R_{d,t} \simeq 1 + \log(R_{d,t})$ for $R_{d,t}$ in a sufficiently small neighborhood of $R_{d,t} = 1$. The same approximation was applied in the case of $R^*_{d,t}$.

[48] In equilibrium all households make the same choices.

A baseline in the SOE model literature is the seminal Dornbusch (1976) overshooting narrative, which assumes that UIP holds, i.e., $\gamma = 0$.

In the first section below, we provide two quantitative characterizations of the failure of UIP. The first characterization corresponds to the standard, *delayed overshooting phenomenon*. The second is (we believe) novel and we call it the *excessive overshooting phenomenon*. The two phenomena are puzzles from the point of view of the UIP.

In the second subsection below we do counterfactual simulations of our EME model to demonstrate the important role played by UIP frictions (i.e., the values of $\gamma, \gamma_{R^*}, \gamma_{\Theta}$) in accounting for the two UIP deviations, as well as for the dynamics of aggregate measures of economic activity. We find that the primary role of $\gamma > 0$ is to activate the risk appetite parameter, γ_{R^*}, and the portfolio inertia parameter, γ_{Θ}. Both parameters help to account of the UIP deviations documented in Section 5.5.1, as well as the real effects of a US monetary tightening on investment and GDP. However, γ_{R^*} has a relatively larger impact on aggregate economic activity and γ_{Θ} has a relatively larger impact on the UIP distortions.

5.5.1 Characterization of the Failure of UIP

This subsection examines our VAR evidence, and so the time unit, t, corresponds to months.[49] We consider the case in which $R^*_{d,t}$ and $R_{d,t}$ are one-month, nominally risk free assets. Recall that our empirical measure of $R^*_{d,t}$ pertains to an asset with two-year maturity (see section 2.1.1). At the end of this subsection we explain that our empirical findings hold even more strongly when $R^*_{d,t}$ is measured by a shorter maturity interest rate.

In a slight abuse of notation, let $\Delta_j = R^*_{d,j} - R_{d,j}$ denote the period j response ($j = 1, 2, ...$) in the *dollar premium*, $R^*_{d,t} - R_{d,t}$, to a contractionary US monetary policy shock in period $j = 1$. Similarly, let $\log S_j$ denote the period j response of the log-exchange rate. We make the following assumption:

Assumption 1. $\Delta_j, \log S_j \to 0$, *as* $j \to \infty$ *and that convergence proceeds at a geometric rate.*

By 'proceeds at a geometric rate' we mean that the series eventually evolves like λ^j, for some $\lambda \in (-1, 1)$. Assumption 1 is satisfied in our linearly-approximated SOE model solutions.[50] Our VAR analysis also appears to be consistent with Assumption 1. For example, inspection of the figures for our baseline VARs suggest that $\log S_t$ converges to zero after about two years (for the US, EME, AE and Peruvian economies, see Figures 1, 3, 4 and 5, respectively). We study

[49] Recall from section 2.1.2 that the time unit in the empirical work is monthly and the time unit in the SOE model is quarterly. A detailed discussion of the mapping between quarterly and monthly is discussed in section 2.1.2.

[50] That Assumption 1 holds for the interest rate differential in our SOE models is not surprising. That the log-level of the exchange rate reverts to steady state after a US monetary tightening is a property of our SOE models because of our specification of the monetary policy rule, with $r_S > 0$. For discussion, see sections 3.5 and 4.1. That convergence proceeds at a geometric rate reflects that impulse responses are computed by iterating on a linear difference equation.

$\Delta_j, \log S_j$ in Section J of the Appendix up to period 600 (50 years) and Assumption 1 seems plausible in that zero remains inside the 90 percent probability interval. To save space, the results in the rest of this section and the next are based on our analysis of the EME VARs.

Iterating on the first expression in equation (39) with $\Lambda_t = 0$ for all t, using Assumption 1 and applying the law of iterated expectations, we obtain:

$$\log S_\ell^{UIP} = \sum_{j=0}^{\infty} \Delta_{\ell+j}. \tag{40}$$

Here, $\log S_\ell^{UIP}$ denotes the prediction of the UIP for the ℓ^{th} period response of the log exchange rate in an EME, to a US monetary policy shock, where $\ell = 1, 2, \ldots$. The object on the right of the equality in equation (40) is the sum of the IRFs of the dollar premium into the future. Also, $\ell = 1$ corresponds to the period in which the shock occurs.

Motivated by the above considerations, we use the EME IRFs and equation (40) to compute the IRFs in equation (40) for $\ell = 1, ..., 36$, under the truncation, $\Delta_t = 0$ for $t > 50$.[51] These IRFs appear as the dot-dashed line in Figure 16.[52] The dashed line reports the actual estimated exchange rate IRFs taken from panel 2,1 in Figure 4. For reference, the solid line displays the IRFs of the dollar premium, $R^*_{d,\ell} - R_{d,\ell}$, for the EMEs, for $\ell = 1, ..., 36$.[53]

The UIP puzzle corresponds to the difference between the posterior median of the IRFs for $\log S_j^{UIP}$ (dot-dashed line) and $\log S_j$ (dashed line). The two sets of IRFs differ strikingly, in two ways. First, the shape of the dot-dashed line is different from the hump shape displayed by the actual exchange rate IRF. The graph of $\log S_j^{UIP}$ displays the Dornbusch (1976) overshooting effect, having the property that the maximal effect on the exchange rate occurs in the period of the shock. By contrast, the unrestricted estimate of the exchange rate response, $\log S_j$, displays the well-known delayed overshooting effect, in which the maximal effect occurs a few months later the shock.[54] From the perspective of the UIP the anticipated depreciation of the exchange rate

[51] In the estimated IRFs for the dollar premium, $\Delta_t < 0$ for $50 < t < 100$. So, if we had adopted the different truncation, $\Delta_t = 0$ for $t > 99$, then the graph of $100 \times \log S_\ell^{UIP}$ would have shifted down by 0.65, in a roughly parallel way. Our conclusion regarding delayed overshooting would have been unaffected. Our conclusion regarding excess over shooting would have been even stronger. This is consistent with our overall conclusion, discussed below, that our estimate of $100 \times \log S_\ell^{UIP}$ which utilizes UIP represents an upper bound for what the UIP implies for the exchange rate, given the estimated Δ_t's.

[52] The dot-dashed line does not include posterior probability intervals. If we did incorporate them in a mechanical way, the probability intervals would be very wide because, according to equation (40), $\log S_\ell^{UIP}$ is a function of the IRFs of dollar premia into the indefinite future. At the same time, our VAR implies growing uncertainty into the future, and that uncertainty transmits without any discounting into $\log S_\ell^{UIP}$ for $\ell = 1, ..., 36$. But, we do not have confidence in the VAR's implications for the long-term future, so we decided not to report probability intervals. We explored ways of formalizing our 'distrust' of the long-run implications of the VAR, but decided that developing these approaches is best left for future work.

[53] The IRFs of the dollar premium for this purpose is measured in monthly, percent terms. That is the reason for the '100×' in front of $\log S_{\ell t}^{UIP}$.

[54] For an early demonstration of the phenomenon of delayed overshooting in the wake of a monetary shock, see Eichenbaum and Evans (1995). The delayed overshooting result is somewhat, though not completely, robust. In appendix C we show that our delayed overshooting is robust to the use of Jarociński and Karadi (2020) monetary

on foreign currency after a US monetary tightening is puzzling because $\Lambda_1 < 0$. That is, because foreign currencies are expected to depreciate, anyone holding a foreign asset gets two boosts by selling that asset and buying a dollar asset: first, they get the higher nominal return on the dollar asset and second, they get an additional bonus on the round trip through the foreign exchange rate market. The puzzle, from the perspective of the UIP is:

$$\text{`why do people hold any non-US assets right after a monetary tightening?'} \tag{41}$$

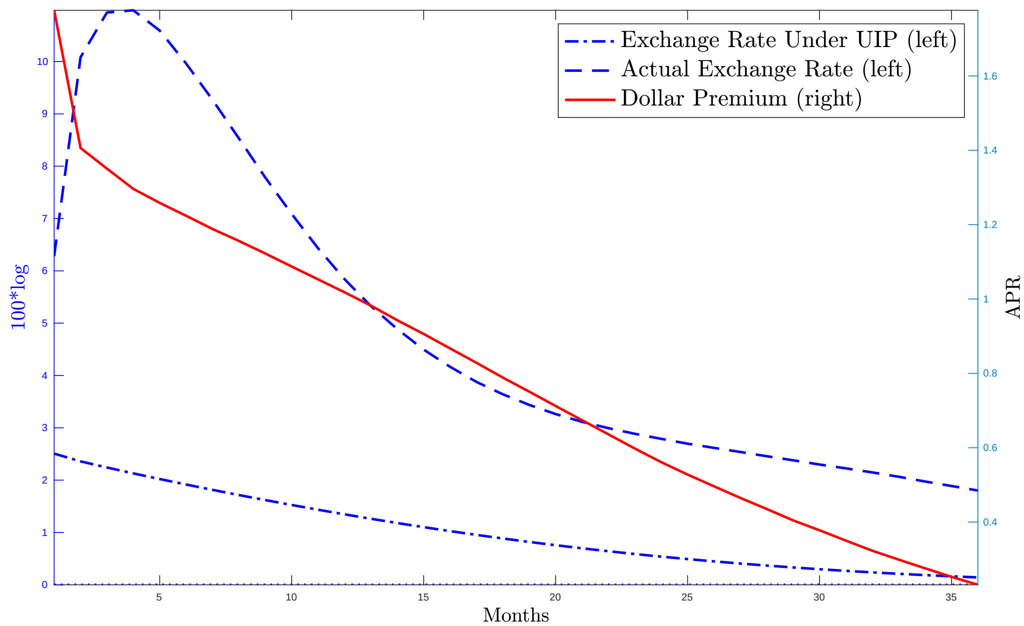
The second puzzle follows from the obvious large difference in the overall *level* of the dashed line, relative to the dot-dashed line predicted by the UIP. This is what we call the excessive exchange rate overshooting effect. The level of the exchange rate is much higher than is justified by the prospective move in the expected dollar premium.

Given that the currency eventually returns to its pre-shock level, the sharp ('excessive') depreciation of the currency must be followed by a bigger appreciation than the one implied by the dot-dashed line, which also converges to zero, but starting from a lower level. Since the appreciation of the currency under UIP (the dot-dashed line) exactly wipes out the advantage of holding dollar assets, the greater appreciation by the actual exchange rate must cause dollar assets to have a lower return than foreign assets, so that $\Lambda_\ell > 0$ after month 3. That is, the expected LCU return on the dollar, $R^*_{d,\ell} + \log S_{\ell+1} - \log S_\ell$, is less than $R_{d,\ell}$ after the first quarter, even though $R^*_{d,\ell} > R_{d,\ell}$. So, the second UIP puzzle is,

$$\begin{aligned} &\text{why does anyone hold any dollar assets a few months after a US contraction,} \\ &\qquad\qquad\qquad\text{when dollar depreciations swamps the dollar premium?} \end{aligned} \tag{42}$$

policy shocks (see also Jarociński (2022)). We examined whether delayed overshooting is robust to doing local projections. The results are reported in Appendix B, but they are too noisy to say whether they support delayed over-shooting or not. Müller et al. (2024) show that delayed overshooting is robust to the use of Romer and Romer (2004) shocks. Degasperi et al. (2020, Figure 2) and Miranda-Agrippino and Ricco (2021, Figure 6) show delayed overshooting in the US trade-weighted exchange rate. Degasperi et al. (2020, Figure 3) also look at the impact of three specific exchange rates, the Euro, the British pound and the Yen. In each of these countries the peak value of the dollar occurs in the period of the US monetary tightening, so overshooting is not delayed in these cases. In our analysis of the country-by-country data underlying Figure 6 we also find, consistent with Degasperi et al. (2020, Figure 3), that there is no delay in the peak response of Japan's exchange rate. Our results for the Euro Area are statistically not significantly different from Degasperi et al. (2020, Figure 3)'s results. According to our point estimates the peak effect of a US monetary tightening on the Euro-dollar exchange rate is technically delayed, but the peak effect on the exchange rate is about the same as the immediate effect. In the case of the UK, our point estimates indicate that the peak effect on the exchange rate is delayed, but determining whether our results are statistically significantly different from Degasperi et al. (2020, Figure 3)'s requires additional analysis. In our analysis of EMEs, we found that only two countries do not display delayed overshooting in their exchange rate after a US monetary tightening. We conclude that on average, across countries, there appears to be a delay in the response of the exchange rate to a US monetary tightening, but there are exceptions.

Figure 16: Exchange Rates and Dollar Premium in EMEs



Notes: The dashed line reproduces the estimated IRF for the EME's exchange rate from the 2,1 panel of Figure (4). The solid line reports the IRFs for $R^*_{d,t} - R_{d,t}$, constructed by subtracting the IRF of $R_{d,t}$ in the panel 2,1 of Figure 4 from the IRF of $R^*_{d,t}$ in the 1,1 panel of the same figure (the dollar monthly premium in the solid line is measured as an annual, percent rate). The dot-dashed line displays $100 \times \log S_j^{UIP}$ computed using equation (40) and the truncation, $\Delta_j = 0$ for $j > 50$. For the purposes of computing $100 \times \log S_j^{UIP}$ the dollar premium is measured at a monthly, percent rate. The dot-dashed line in period j is the sum of the values of the solid line (after division by 12) at horizons $j, j+1, ..., 50$. For additional discussion see the text.

Finally, recall that in our empirical analysis, $R^*_{d,t}$ corresponds to the annualized percent return on two-year US Treasury securities. In the above analysis we interpreted $R^*_{d,t}$ as the annualized percent return on a one-month security. We redid our VARs using shorter term US securities to measure $R^*_{d,t}$. In each case, we found that the premium, Δ_t, was even smaller while there was no impact on the other variables, including the response of the exchange rate to a Bauer and Swanson (2023b) monetary tightening. In light of this result, we interpret the dot-dashed curve in Figure 16 as an upper bound on what the UIP predicts for the exchange rate. Thus, the excessive exchange rate overshooting puzzle may be even bigger than what is suggested in Figure 16. At the same time, the delayed overshooting result does not depend on how we measure $R^*_{d,t}$. We conclude that the two UIP puzzles discussed in this section are not an artifact of our measurement of $R^*_{d,t}$.

5.5.2 Interpreting Delayed and Excess Overshooting

In this section we ask: (1) how does our EME model explain the quantitatively large deviations from UIP? and (2) do the deviations from UIP matter for the international transmission of US monetary policy?

To save space, we make our points by focusing only on the EME case. The AE case is similar (for details, see Appendix section K). For example, the 1,1 panels in Figures 3 and 4 indicate that the exchange rate IRFs in the AEs and EMEs are very similar. Each follows a hump-shaped pattern with a high peak. The magnitude of the interest rate differentials, $R^*_{d,t} - R_{d,t}$, are not very different between AEs and EMEs, relative to the magnitude of the exchange rate depreciations and appreciations.

Because we work with our SOE model in this section, t now corresponds to quarters.

Our estimation procedure assigns values to the parameters, $\gamma, \gamma_{R^*}, \gamma_\Theta$, to enable the SOE to broadly match the IRFs described section 5.5.1. Figure 17 displays the estimated EME model IRFs (solid, blue line, *Benchmark*). Note from panel 1,3 that we obtain one period (quarter) delayed overshooting in that model. This matches the VAR evidence of a three month delay. The 3,3 panel of the figure shows that $\Lambda_1 < 0$ in the estimated model. In that model people continue to hold at least some local assets, i.e., $\Theta_1 < 1$, so $\Lambda_1 < 0$ contradicts household optimization under UIP. People do shift their portfolios somewhat towards dollars (panel 4,2) after a US monetary tightening, but with $\Lambda_1 < 0$ and $\Theta_1 < 1$ people walk away from a higher expected return by not increasing Θ_1 even more.[55] So, the model embeds an answer to the puzzle stated in equation (41).

According to panel 3,3, $\Lambda_1 < 0$ and $\Lambda_t > 0$ for $t = 2, ...$ This matches what we found in the analysis of the VAR above. That is, after one quarter has passed the currency begins to appreciate so much that the LCU return on the dollar, $R^*_{d,t} + E_t [\log S_{t+1} - \log S_t]$, is less than the return on $R_{d,t}$ even though $R^*_{d,t} - R_{d,t} > 0$. Yet, according to the solid, blue line, people continue to hold a relatively high share of dollars (panel 4,2). So, the model also embeds an answer to the puzzle stated in equation (42).

We now discuss the role of γ, γ_Θ and γ_{R^*} in answering our two questions.

The Role of γ The version of the model with $\gamma > 0$ and $\gamma_{R^*} = \gamma_\Theta = 0$ in principle offers a reduced-form explanation for how $\Lambda_1 < 0$ can be part of an equilibrium. As people increase their holdings of dollar assets when $R^*_{d,t} - R_{d,t}$ jumps after a US monetary tightening, they exceed their target dollar share in assets, Υ_1. On the margin they suffer non-pecuniary costs holding dollars and this is why they are willing to forego the additional pecuniary gains they can expect by raising Θ_t even more. Also, with $\gamma > 0$ the desire to back out of dollars after the first period puts people below target, eventually making $\Lambda_t > 0$. With a positive non-pecuniary return on dollars they do not mind forfeiting the extra returns they could get if they reduced Θ_t faster.

For the most part, the qualitative effects of $\gamma > 0$ move the model towards the data. On thing that the model misses on with only γ is the delayed over shooting (see 1,3). At a quantitative level it misses everything. It misses the excess overshooting in the level of the exchange rate. Investment and GDP fall relatively little.

When $\gamma = 0$, the model performs very badly (see the dotted line). Delayed overshooting is

[55] In principle, aversion to exchange rate uncertainty could prevent people from maximizing expected return on their portfolio. But, it is well known that with preferences of the kind we use, risk aversion plays very little role. Indeed, with our linearization method we abstract from risk aversion altogether.

gone and the level of the exchange rate rises only a little, similar dot-dashed curve in Figure 16. The model also performs poorly with real variables. The drop in investment and GDP is cut in half and are now quite modest.

The Role γ_{R^*}. The risk appetite parameter, $\gamma_{R^*} > 0$, has the consequence that a rise in R_d^* leads to an increase in the target share of dollars. We can see the effect of increasing the value of this parameter from $\gamma_{R^*} = 0$ (dot-dashed line) with $\gamma_{R^*} > 0$ (dashed line). The US monetary tightening only lasts for about a year, but still has longer term effects. The immediate effect is to increase share of dollars in people's portfolio which in turn raises the exchange rate sharply, though only temporarily. So, γ_{R^*} does not help with delayed overshooting. It also only helps a little to raise the overall level of the exchange rate as excessive overshooting calls for. Finally, γ_{R^*} also does not help much with the pattern of UIP deviations in the 4,3 panel.

Where the parameter, γ_{R^*}, appears to have a big impact is on economic activity. For example, note that the dashed line roughly coincides with the solid lines in the 3,1 and 3,2 panels. In particular, with a delay investment falls in response to the sharp depreciation in the exchange rate (panel 1,3). The sharp depreciation that $\gamma_{R^*} > 0$ produces, has the consequence that entrepreneurs experience substantial capital losses. Investment adjustment costs prevent an immediate response of investment as entrepreneurs sustain spending for a while, by substituting loans for their lost net worth. However, eventually investment falls as much as it does with all the UIP frictions, helping to drag down GDP. Investment stays low for a while because it takes time for net worth to recover. The delayed and dragged out effects on investment of an exchange rate depreciation is discussed in detail in Section I in the Appendix. That discussion reviews the dynamics of interest rate premia on risky borrowers, the non-performing loan rate, leverage and issues relevant to the transmission of exchange rate shocks to investment, via financial markets.

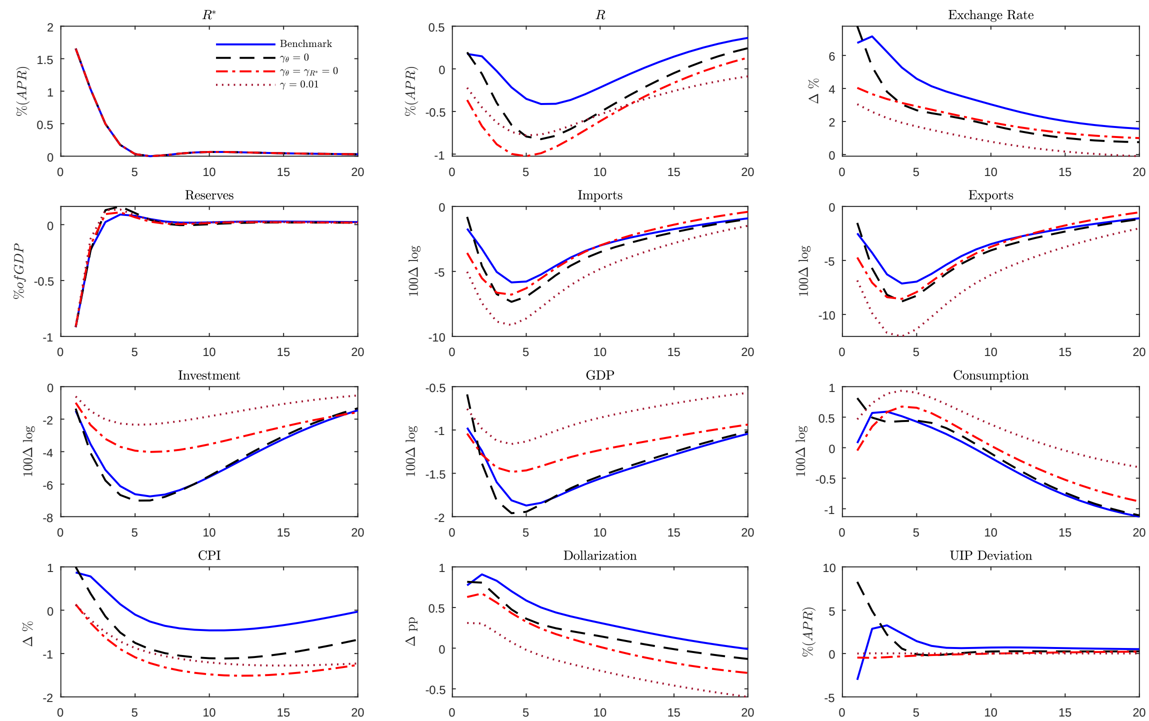
It is interesting to note that γ_{R^*} only affects the pure interest rate effect, and not the pure price level effect or the pure trade effect. In the previous section we showed that the pure interest rate effect is small, and most of the impact of a US monetary contraction operates via the pure trade effect. So, how can γ_{R^*} be 'important' if it operates via a relatively unimportant channel? As it turns out, essentially the whole of the pure interest rate effect is due to $\gamma_{R^*} > 0$. For more details, see Section G in the Appendix.

The Role of γ_Θ As its name suggests, the portfolio inertia parameter, $\gamma_\Theta < 0$, acts like a portfolio adjustment cost. The impact of the value of that parameter can be assessed by comparing the dashed line in Figure 16 with the solid blue line. The parameter, γ_Θ has a significant impact on the UIP distortions. For example, panel 4,3 shows that that parameter allows the model to replicate the substantial switch between $\Lambda_1 < 0$ and $\Lambda_\ell > 0$ for $\ell > 1$. As people increase Θ_1, $\gamma_\Theta < 0$ reduces their incentive to raise Θ_1 by reducing the target share, Υ_1. This helps to make Λ_1 more negative than otherwise (see panel 4,3). The parameter also allows the model to produce the delayed overshooting phenomenon (panel 1,3). The basic story about why people seem to leave money on the table by not acquiring more dollars in the quarter of a contractionary US monetary policy contraction is that various factors sour them on dollars. Our model does not take a stand on the micro-foundations of these factors, which could be a combination of habits in portfolio shares, regulatory rigidities, or something else.[56]

Eventually, people begin to reduce the share of their portfolios held in dollars (see panel 4,2). However, $\gamma_\Theta < 0$ works to slow the fall in the share of dollars as $\bar{\Theta}_t - \bar{\Theta}_{t-1} < 0$ because the parameter now has the effect of raising the target share of dollars. This suggests that $\gamma_\Theta < 0$ also helps with the puzzle in equation (42). The reason people do not get out of dollars faster is that there are portfolio adjustment costs. The fact that people continue holding dollars with $\gamma_\Theta < 0$ places upward pressure on the exchange rate at horizons, $\ell > 1$. Thus the parameter also helps the model to accommodate excess portfolio overshooting.

[56] In Gabaix and Maggiori (2015) people fear moving into dollars too much because they lack trust in the financial institutions they must deal with (see also Aoki et al. (2016)). In Itskhoki and Mukhin (2023) people are limited in how many dollars they can acquire because it is assumed that financial institutions must hold all the currency risk, and that the people that manage those institutions are much more risk averse to currency volatility than the representative household. We think of our reduced form modified UIP model as potentially encompassing the micro foundations in Gabaix and Maggiori (2015) or Itskhoki and Mukhin (2023). For other reduced form approaches to UIP deviations analogous to the approach taken here, see Schmitt-Grohé and Uribe (2003), Christiano et al. (2011b) and Eichenbaum et al. (2021). A different approach to delayed overshooting is described in Ilut (2012) and considers alternatives to rational expectations. Ilut (2012) explains how ambiguity aversion makes people hesitant to acquire dollar assets because of a concern that that the dollar may not appreciate after all.

Figure 17: The Impact of Portfolio Friction Parameters



Notes: response to a US monetary tightening under different parameterizations of the model. The baseline parameterization corresponds to the version of the model with parameters set as in section 17. The horizontal axis is measured in quarters, consistent with the observations in section 2.1.2. The monetary tightening shock occurs in period 1.

5.6 Out of Sample Model Evaluation

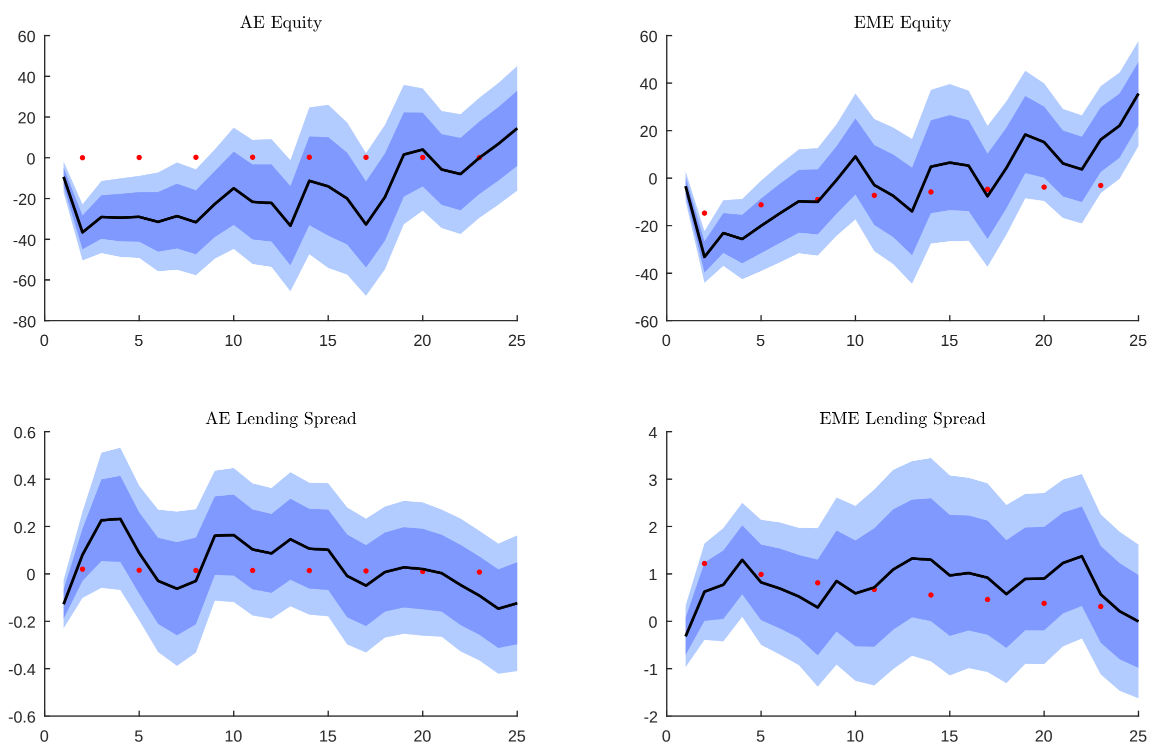
Our small open economy model includes a rich array of financial frictions. For example, the credit market has implications for the interest rate spread for risky entrepreneurial borrowers (see Section 3.4). These implications were not used in the estimation of the model and provide us with a type of out-of-sample test for our model. The solid lines in Figure 18 displays estimates of the response of Equity and Lending Spreads in AE and EME data. The dark and light blue areas represent 68 and 90 percent confidence intervals, respectively. In each case, the empirical estimates are produced using the local projection method used elsewhere in our analysis. In particular, the left and right-hand variables in these projections correspond to averages across the AE and EME countries for which we have data (for details, see Appendix B).

We limited ourselves to the subset of our countries for which monthly data on equity and lending spreads are available from the IMF database, IFS. In the case of our measure of equity, for the AEs we have data on Canada, Japan and UK. In the case of spreads, we have data for Australia, Canada, Japan, Norway, Sweden, Switzerland and the UK. Turning to the EMEs, we have data on equity from Brazil, Chile, Hungary, Mexico, Philippines, Poland, Russia, South Africa and Thailand. We have data on EME spreads for Brazil, Chile, Colombia, Dominican Republic, Hungary, Indonesia, Mexico, Peru, Philippines, Russia, Serbia, South Africa and Thailand.

Comparing the solid and dotted lines, we see that the model is roughly consistent with the empirical IRFs. The model misses somewhat in the case of AE's. The reason is that in that case ϕ is estimated to be close to unity. Even though the exchange rate response to an $R^*_{d,t}$ shock is substantial, it has little impact on entrepreneurs when they have no dollar debt. This is why our model implies that equity and the interest rate spread hardly respond to an $R^*_{d,t}$ shock in the AEs. Zero response in the interest rate spread is consistent with our empirical IRF for the AEs. However, zero response in equity lies outside the confidence intervals for the first three quarters in the AE IRF. Because we estimate ϕ to be substantially less than unity for the EMEs, exchange rate movements have a substantial impact on interest rate spreads and equity in the EMEs. The model responses closely mirror the corresponding empirical estimates.

Given that equity and interest rate spreads played no role in model estimation, we regard these results as providing support for our SOE models.

Figure 18: Estimated Model Implications for Equity and Spreads



Notes: (1) the empirical equity data correspond to 100 times the log of an equity index reported in the IFS database. The empirical spread data are measured at an annual rate in decimal terms and are also obtained from the IFS; (2) solid lines indicate point estimates by local projects discussed in the text; (3) dark and light shaded areas correspond to 68 and 90 percent confidence intervals; (4) equity data in the model are 100 times the log of entrepreneurial net worth, N_t (see equations (18) and (26)); (5) dotted lines correspond to IRFs from our estimated models; (6) the date t spread variable in the model is measured by $E_t\left[Z_{t+1} - R_{t+1}\right]$, where Z_{t+1} denotes the LCU interest paid by risky entrepreneurs in period $t+1$, for one unit of LCU borrowed in period t from a bank. Also, $R_{t+1} = R_{d,t}\phi + s_{t+1}\left(1-\phi\right)R^*_{d,t}$ denotes the LCU interest rate paid by risk-free banks in period $t+1$ on one unit of LCU borrowed in period t (as indicated in equation (22), banks are assumed to be required to borrow a share, ϕ, in local currency and $1-\phi$ in foreign currency). For additional discussion of entrepreneurs in the model, see 3.4.

6 Conclusion

We document that non-US countries contract after a US monetary tightening, with EMEs contracting more than AEs. In fact, the contraction in EME output is at least as big, maybe bigger, than the contraction in US output. In our analysis, bigger balance sheet frictions in the EMEs account for their greater sensitivity to US monetary shocks.

Our key novel finding concerns the role of US imports in the international transmission of US monetary shocks. We find that the primary channel by which non-US economies contract after a US monetary tightening operates through a fall in US demand for imports induced by the US monetary tightening. We reach this conclusion by doing counterfactual simulations using small open economy models that we fit to the data.

Our analysis confirms much of the modern literature which focuses on a wide range of financial and other frictions. Violations of uncovered interest rate parity are big (we believe they are bigger than previously reported) and these violations play an important role in the international propagation of US monetary policy shocks. Balance sheet effects appear to play an important role in Emerging Market economies.

We do not examine the details of how a fall in US imports propagates through the global trading network to impact on the non-US countries we study. The role of the global trading network is an exciting area of research.

We also ask whether a country can use FX interventions to shield itself from US monetary policy actions, while it pursues its own inflation and output objectives using, say, an interest rate targeting rule. We study a standard FX intervention rule and find that that rule only marginally insulates a representative EME economy from US monetary shocks. It has been argued that there are other shocks, sometimes they are called noise shocks or portfolio share shocks, that play an important role in exchange rate dynamics (see Itskhoki and Mukhin (2021); Eichenbaum et al. (2021)). We find that FX interventions can be very useful at smoothing out the effects of these shocks.

The argument regarding FX interventions resembles the case made by Poole (1970) for dealing with money demand shocks. Suppose a noise shock hits people and they suddenly want to hold a larger fraction of their financial portfolio in the form of cash. It might be welfare improving for the monetary authority to give people the cash they want in exchange for assets and thereby prevent financial market prices from affecting the rest of the economy. Similarly, if there is a positive shock to the fraction of their financial portfolio that people want to hold in the form of dollars (a ‘noise shock’), then the central bank can enter the market and sell people the dollars they want in exchange for local currency assets, without the rest of the economy being disturbed by a significant jump in interest rates or the exchange rate. In our simulations a version of the FX intervention rule that we work with does insulate the economy against noise shocks in the exchange rate market.

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A Robustness Treatment of US Data in Panel VARs

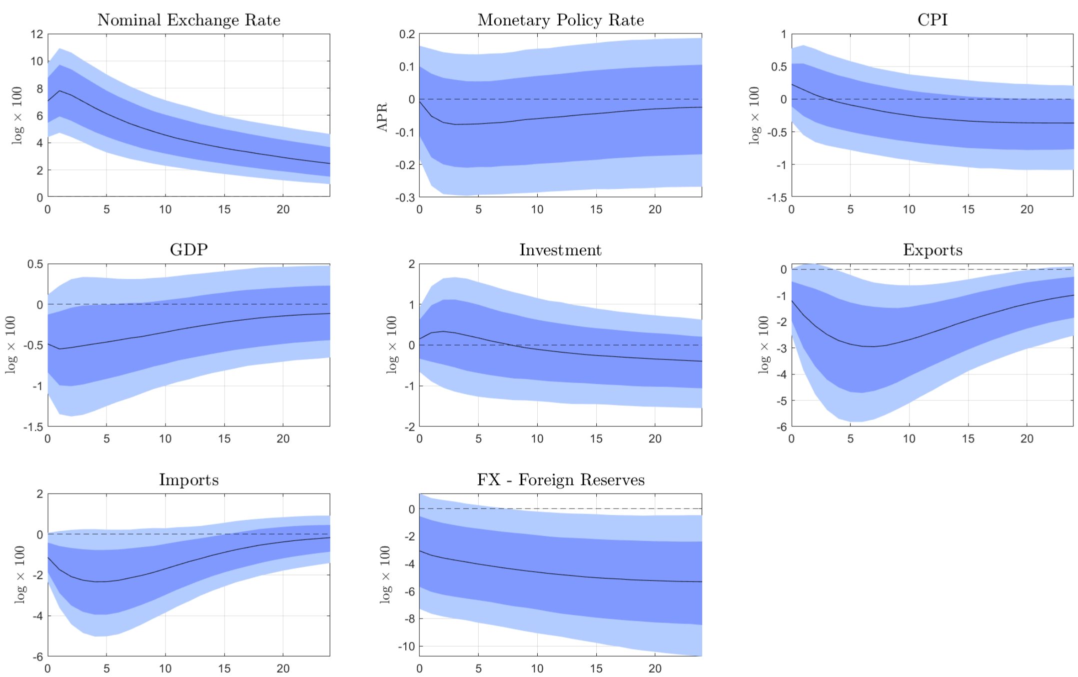
Here, we report the results of two robustness checks on the results reported in Figures 3 and 4.

A.1 Dropping US VAR From Country-level Data in Panel Regressions

We reestimate impulse response functions using a version of country-level equation (4) in which the three equations containing the US variables in $\tilde{Y}_t$ are deleted. Two lags of those variables are left as exogenous right hand variables in the country-level equations. The resulting panel VAR (i.e., equation (6)) zeros out any possible feedback from foreign economies to the US after a US monetary policy shock. Unlike the panel data VARs in section 2.2 the panel data VARs here cannot generate IRFs for US data, so none are presented.

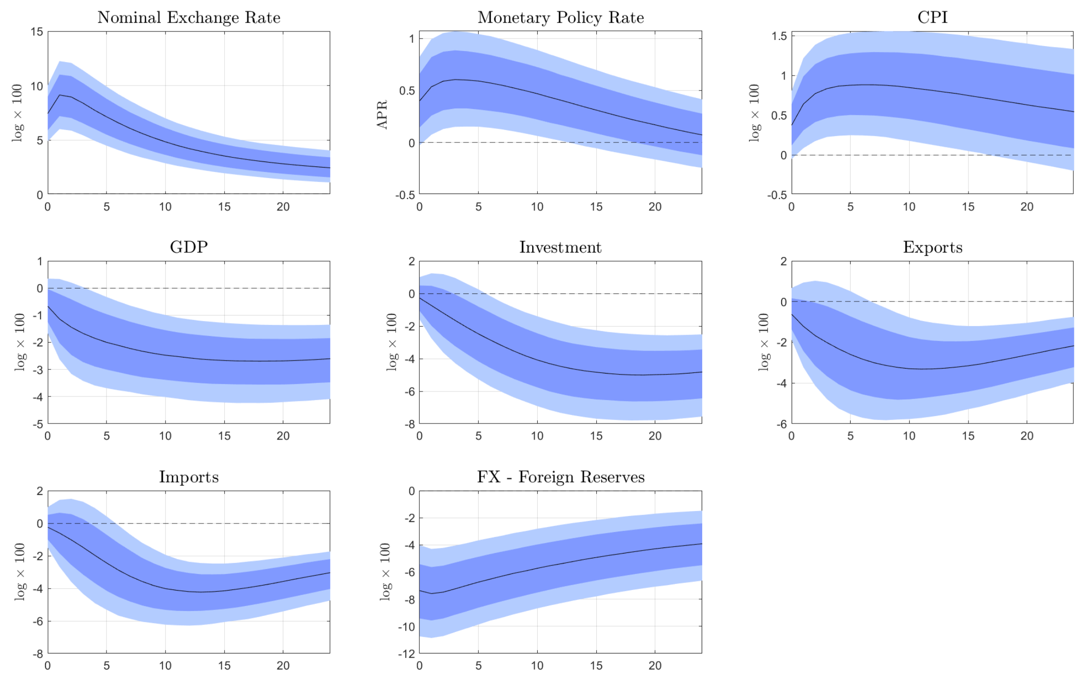
We redo the estimation of the perturbed version of equation (6) for AEs and EMEs. The resulting IRFs are reported in Figures 19 and 20, respectively.

Figure 19: Response to Contractionary US Monetary Policy Shock, Advanced Economies



Note: IRFs from a perturbed version of the panel VAR estimation for the AE countries reported in Figure 3. The perturbation deletes country-level equations where the US data are left-hand variables. Lagged US data remain in the remaining country-level equations. Because the US data are treated as an exogenous process, the system does not generate IRFs in US variables, unlike in Figure 3.

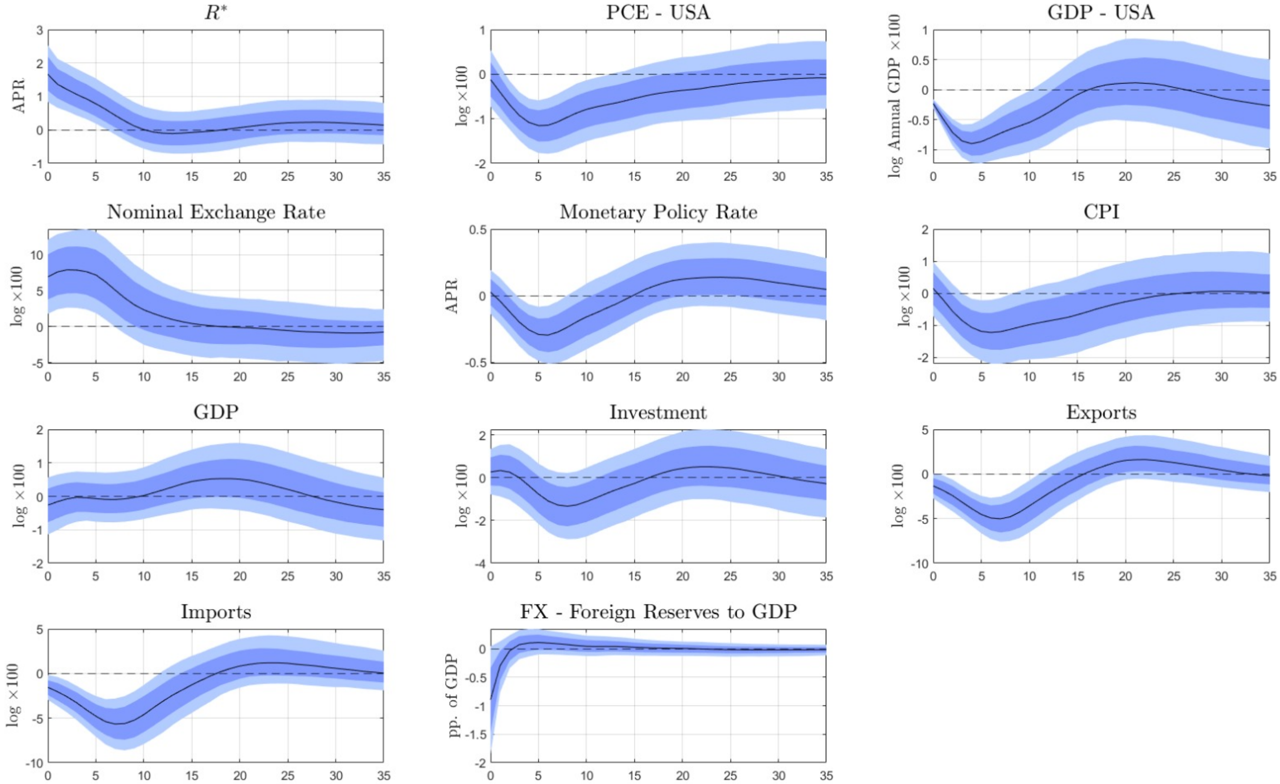
Figure 20: Response to Contractionary US Monetary Policy Shock, Emerging Market Economies



Note: IRFs are for EMEs. See notes to Figure 19 and text.

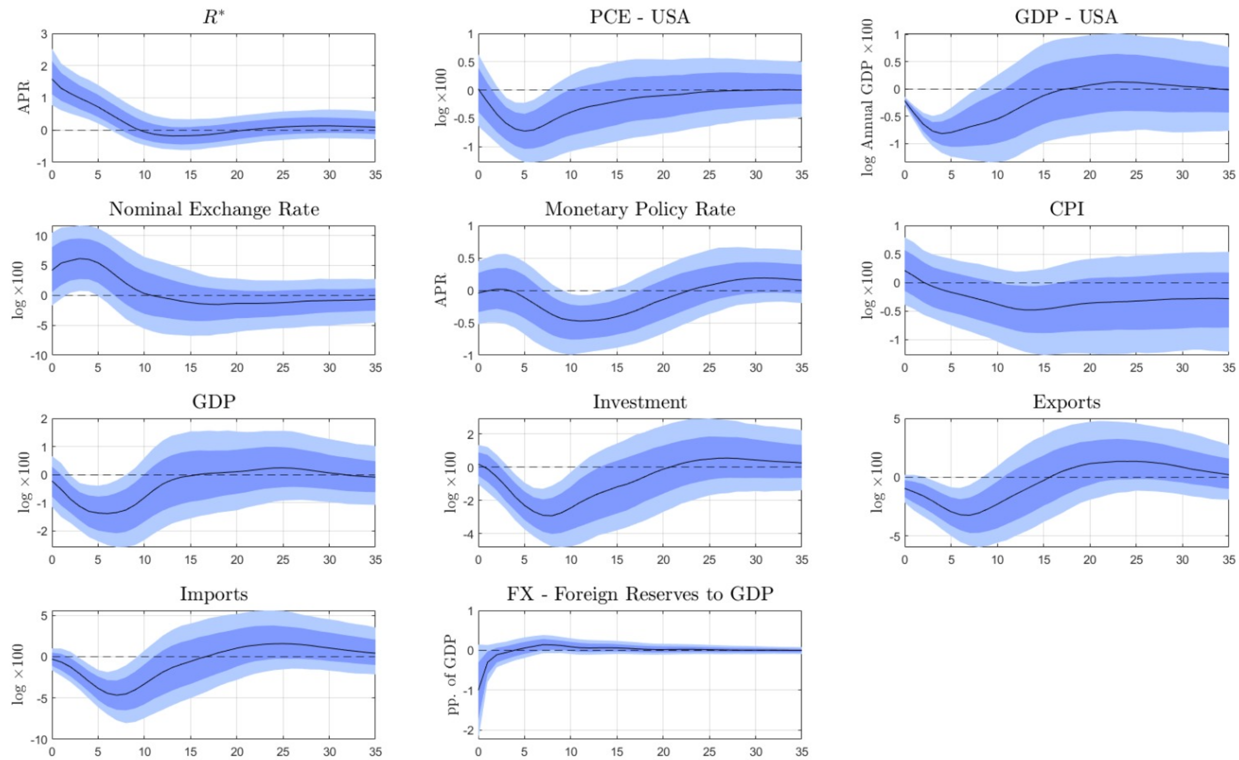
A.2 Panel Regressions Using Cross Country Averages

Figure 21: Response to Contractionary US Monetary Policy Shock, Advanced Economies



Note: IRFs are for AEs.

Figure 22: Response to Contractionary US Monetary Policy Shock, EMEs



Note: IRFs are for EMEs.

B Robustness of Results to Local Projections

We perform regressions similar to what is proposed in Jordà (2005). Consider the following equation:

$$y_{t+h} = \beta_y^h \varepsilon_t^m + \beta_{y,1}^h \varepsilon_{t-1}^m + \beta_{y,2}^h \varepsilon_{t-2}^m + \sum_y \sum_{j=1}^{2} J_{y,j}^h Y_{t-j} + u_t^{y,h}, \tag{43}$$

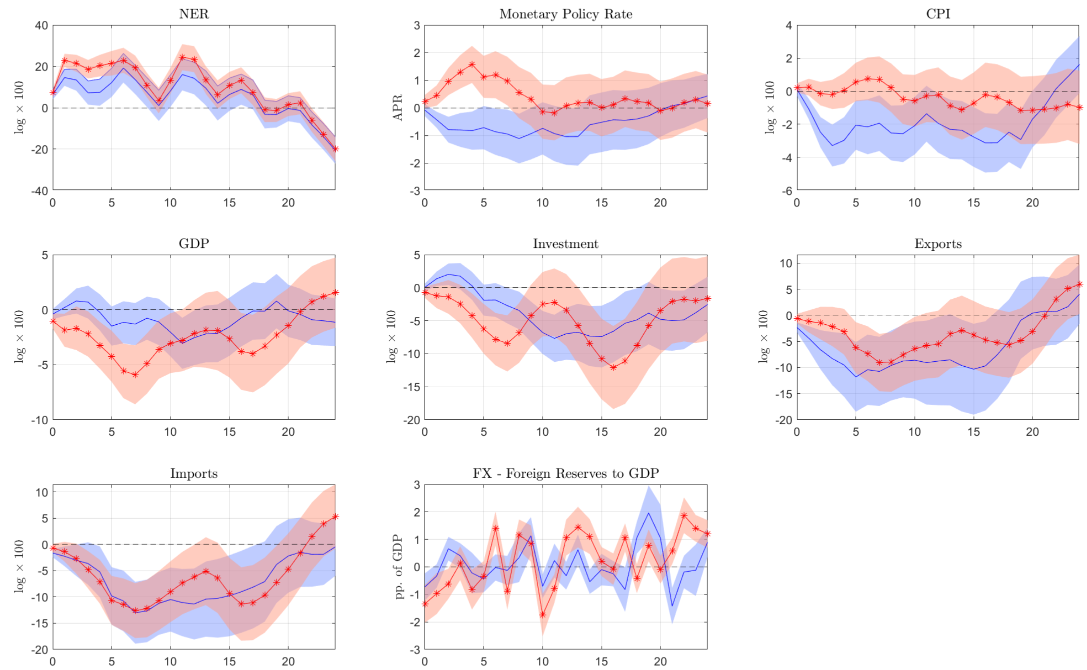
for $h = 0, ..., 24$. We perform these regressions separately for the AEs and the EMEs.[57] In the case of the AEs y_{t+h} is variable y at lead $t+h$, where y refers one of the 8 non-US variables in Y_t. The variables, y, are indicated in Figure 23. Also, Y_t in equation (43) corresponds to the average of $Y_{i,t}$ in equation (5) over the i's in the AEs. Similarly, for the case of the EMEs. Equation (43) corresponds to 25×8 least squares regressions, 25 regressions for each of the 8 non-US elements of Y.

The values of β_y^h are displayed in Figure 23. Not surprisingly the results are somewhat more noisy than what we find in our panel VARs (see Figures 3 and 4). However, the results are qualitatively the same. Output falls more in the EMEs than in the AEs. Indeed, the results are consistent with the baseline results in the text, in which EME output falls substantially more than

[57] To avoid clutter, our notation in equation (5) does not distinguish whether we are working with the AEs or the EMEs.

US output after a US monetary tightening. Monetary policy is accommodative in the AEs and restrictive in the EMEs. Importantly, exports fall significantly in both the AEs and the EMEs.

Figure 23: Response to Contractionary US Monetary Policy Shock, AEs and EMEs



Note: Starred red lines (shaded areas) represent the point estimates of β_y^h (two-standard deviation intervals) corresponding to EMEs. Solid blue lines and shaded areas corresponds to AEs. Standard deviations correspond to Newey-West robust standard errors. See text for further discussion.

C Robustness to Jarociński and Karadi Shocks

We also considered the monetary policy shocks computed in Jarociński and Karadi (2020). The analog of Figure 3, done using the monetary shock measure of Jarociński and Karadi (2020), appears in Figure 24. Similarly, the analog of Figure 4 for the EMEs appears in Figure 25. Finally, the analog of Figure 5 for Peru appears in 26.

Broadly, the effects of a US monetary tightening on AEs and EMEs are similar. Consider the AEs first. According to the Jarociński and Karadi (2020) monetary shock measure, (1) AE GDP falls, though by a bigger percent than the fall in US GDP implied by the Bauer and Swanson (2023b) shock (compare Figures 24 and 3); (2) as in the analysis in the text, the fall in EME GDP is substantially larger than the drop in AE GDP; (3) exports fall by a larger amount (in percent terms) than GDP in AEs and EMEs.

Turning to the results for Peru, we see that the results in the text based on Bauer and Swanson (2023a) are similar when we use the Jarociński and Karadi (2020).

Figure 24: Response to Contractionary US Monetary Policy Shock, Advanced Economies, JK

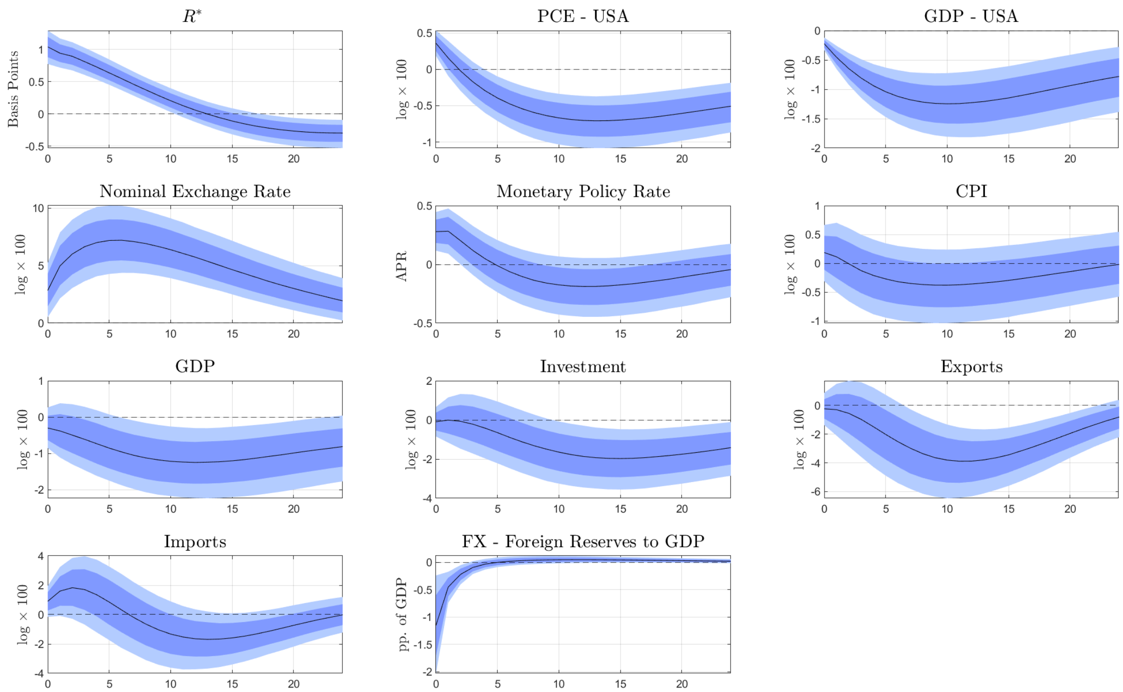


Figure 25: Response to Contractionary US Monetary Policy Shock, Emerging Markets, JK

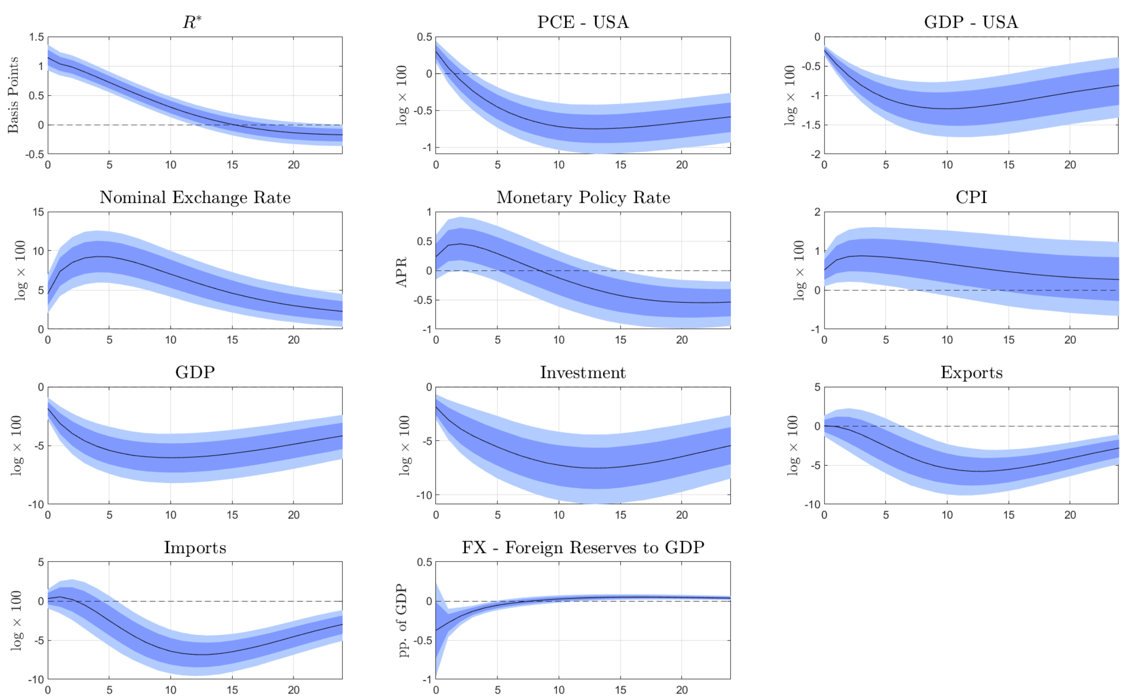
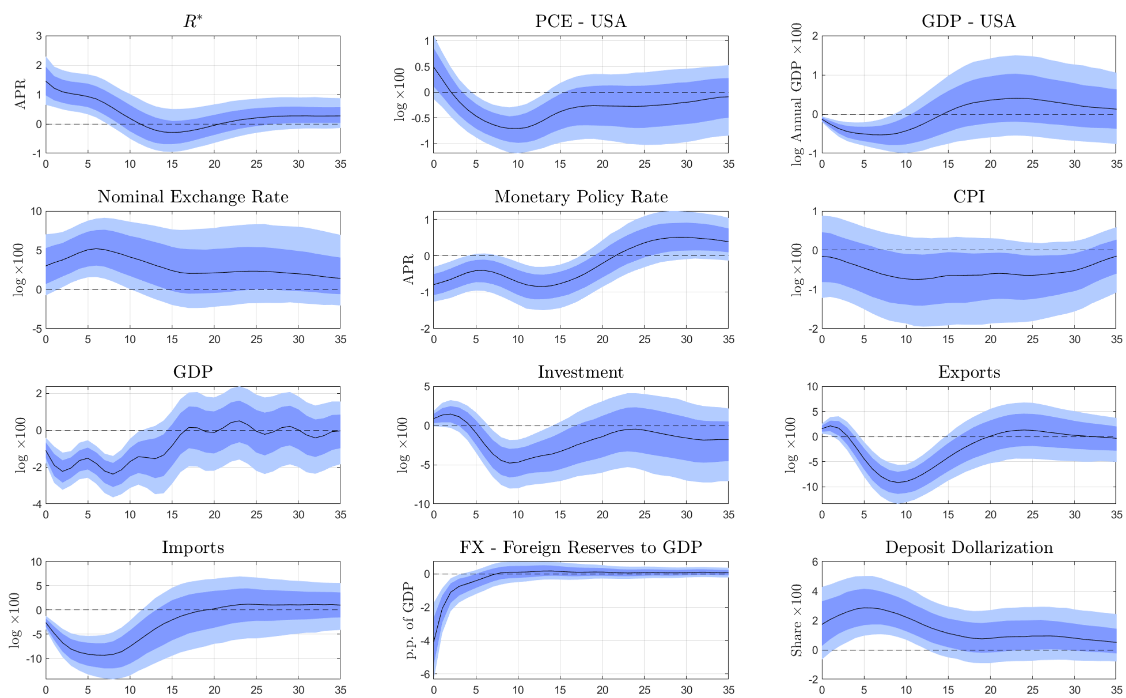


Figure 26: Response to Contractionary US Monetary Policy Shock, Peru, JK



D Prior and Posteriors for Model Parameters

This appendix reports priors and posteriors associated with our approximate Bayesian estimation approach. Because the estimation involved adjusting priors to target various steady state and other features, the results are not as straightforward to interpret as they are normally.

Table 4: AE Estimation

Parameter	Description	Prior Distribution	Prior Mean	Prior Std Dev	Posterior Mean	Posterior Std Dev
γ	Target Portfolio Cost	Normal	4.00	1.00	3.20	1.00
γ_R	Risk Appetite	Normal	200.00	75.00	44.78	13.57
γ_θ	Portfolio Inertia	Normal	-50.00	10.00	-47.77	10.67
κ	Investment Adjustment	Normal	3.00	1.00	1.78	0.91
ρ_R	MP Persistence	Normal	0.80	0.15	0.91	0.03
η_c	Consumption Elasticity of Substitution	Normal	2.50	0.30	1.53	0.37
η_x	Export elasticity of Substitution	Normal	2.50	0.50	1.18	0.55
ν_i	Investment Elasticity of Substitution	Normal	1.80	0.10	1.73	0.10
η^f	Price Elasticity of Exports	Normal	2.00	0.20	2.67	0.19
γ_f	Export Demand Shifter	Normal	6.00	0.50	3.86	0.75
θ^x	Export Calvo Stickiness	Beta	0.80	0.05	0.80	0.02
$1-\omega_c$	Home Bias, Consumption	Normal	0.85	0.02	0.90	0.02
γ_I	Home Bias, Investment	Normal	0.70	0.05	0.78	0.08
γ_x	Home Bias, Exports	Normal	0.70	0.05	0.77	0.05
ρ_R	MP Persistence	Normal	0.80	0.15	0.91	0.03

Table 5: EME Estimation

Parameter	Description	Prior Distribution	Prior Mean	Prior Std Dev	Posterior Mean	Posterior Std Dev
γ	Target Portfolio Cost	Normal	2.00	0.20	1.78	0.23
γ_R	Risk Appetite	Normal	70.00	10.00	29.46	8.46
γ_θ	Portfolio Inertia	Normal	-60.00	15.00	-19.47	7.97
κ	Investment Adjustment	Normal	5.00	1.50	5.85	1.17
θ_{R*}	FX Intervention Coefficient	Normal	0.50	0.15	0.16	0.02
ρ^{FX}	FX Intervention Persistence	Beta	0.85	0.10	0.21	0.06
η_c	Consumption Elasticity of Substitution	Normal	0.50	0.10	0.41	0.11
η_x	Export elasticity of Substitution	Normal	1.00	0.12	0.70	0.14
ν_i	Investment Elasticity of Substitution	Normal	1.20	0.30	0.91	0.15
η^f	Price Elasticity of Exports	Normal	1.50	0.10	1.53	0.10
γ_f	Export Demand Shifter	Normal	6.00	2.00	5.67	0.38
θ^x	Export Calvo Stickiness	Beta	0.80	0.10	0.80	0.07
$1-\omega_c$	Home Bias, Consumption	Normal	0.75	0.10	0.98	0.01
γ_I	Home Bias, Investment	Normal	0.60	0.10	0.71	0.11
γ_x	Home Bias, Exports	Normal	0.60	0.10	0.44	0.08
ρ_R	MP Persistence	Normal	0.85	0.15	0.82	0.05
$1-\phi$	Credit Dollarization	Normal	0.60	0.05	0.45	0.05
$\bar{\Upsilon}$	Steady State Deposit Dollarization	Normal	0.40	0.10	0.47	0.05
$\frac{F^*}{4\times GDP}$	Steady State Reserves/GDP	Normal	0.15	0.01	0.15	0.01

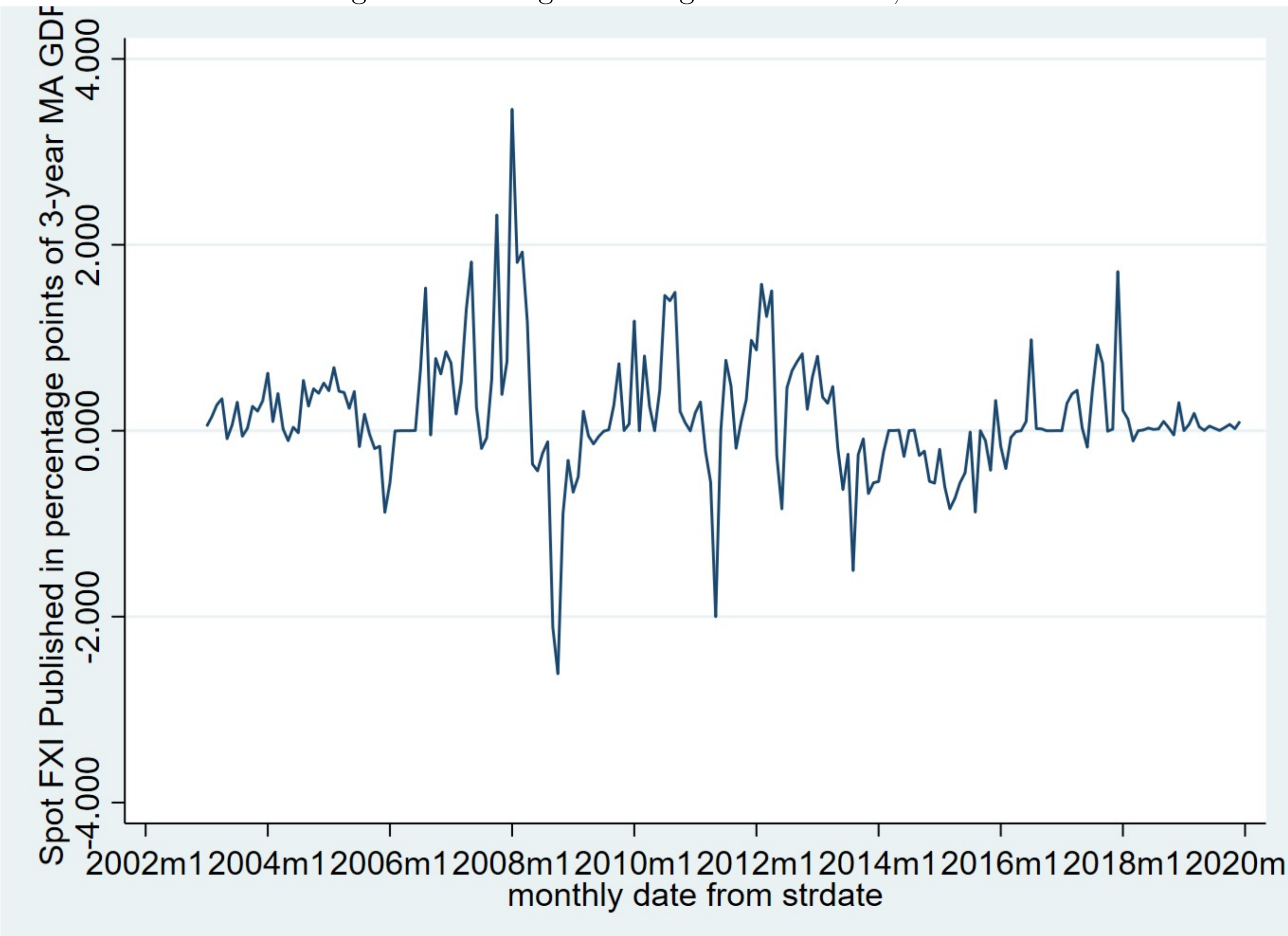
Table 6: Peru Estimation

Parameter	Description	Prior Distribution	Prior Mean	Prior Std Dev	Posterior Mean	Posterior Std Dev
γ	Target Portfolio Cost	Normal	2.50	0.50	2.56	0.50
γ_R	Risk Appetite	Normal	30.00	10.00	22.46	7.59
κ	Investment Adjustment	Normal	3.00	1.00	3.16	0.81
θ_{R*}	FX Intervention Coefficient	Normal	0.50	0.05	0.42	0.04
ρ^{FX}	FX Intervention Persistence	Beta	0.80	0.10	0.78	0.05
η_c	Consumption Elasticity of Substitution	Normal	1.20	0.60	0.94	0.60
η_x	Export elasticity of Substitution	Normal	1.50	0.30	1.58	0.30
ν_i	Investment Elasticity of Substitution	Normal	1.20	0.20	1.17	0.20
η^f	Price Elasticity of Exports	Normal	2.00	0.20	2.11	0.20
γ_f	Export Demand Shifter	Normal	5.50	0.50	4.02	0.36
θ^x	Export Calvo Stickiness	Beta	0.80	0.05	0.77	0.04
$1-\omega_c$	Home Bias, Consumption	Normal	0.70	0.05	0.83	0.07
γ_I	Home Bias, Investment	Normal	0.30	0.10	0.21	0.11
γ_x	Home Bias, Exports	Normal	0.50	0.10	0.51	0.10
ρ_R	MP Persistence	Normal	0.80	0.15	0.88	0.04

E Foreign Exchange Interventions in Peru

Data in the following figure are taken from Adler et al. (2024). Note that FX interventions in Peru are substantial.

Figure 27: Foreign Exchange Interventions, Peru



Note: Data obtained from replication files associated with Adler et al. (2024). Data represent FX purchases and sales (when negative), in US dollars as a percent of a 3-year moving average of Peruvian GDP measured in dollars.

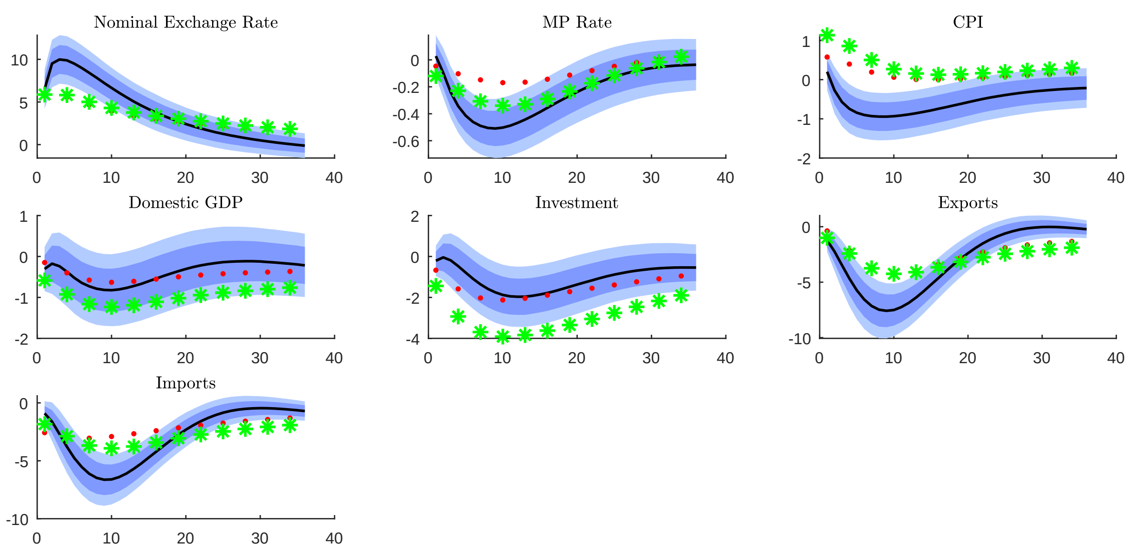
F Home Bias in Advanced Economies

In section 5.1 we showed that the AE model can account for the evidence that GDP falls by a smaller amount in AEs than in EMEs, after a US monetary tightening. At the same time, the AE model has the shortcoming that it implies a counterfactually small share of trade in GDP (see Table 3). In fact, our sample suggests that AEs are about as open as EMEs. We were concerned about the hypothesis that the success of the AE model in matching the relatively small decline in AE GDP reflects its counterfactual implication for the share of trade in GDP. After all, if the AEs were in financial and goods market autarky, then *nothing* would happen to AE GDP if the US tightened monetary policy. To check this hypothesis we perturbed the home bias AE parameters, $1-\omega_c, \gamma_i, \gamma_x$ by setting their values to 0.75 times their estimate for the EMEs, so that $1-\omega_c = 0.735(.90), \gamma_i = 0.53\,(.78)\,, \gamma_x = .33(.77)$. The numbers in parentheses correspond to the baseline estimated home bias parameters for the AE model reported in Table 2. We recomputed the numbers in the AE column of Table 3 and found that they are essentially unchanged, except,

$X/GDP = M/GDP = 0.58$. So, the fraction of trade in GDP in the model with the perturbed home bias parameters is higher than what that fraction is in the baseline estimated model.

Figure 28 displays the impulse responses of the AE model at the original (red dots) and perturbed (yellow stars) parameter values. The red dots and empirical responses are taken from Figure 7. Notably, the fall in output under the perturbed values of the parameters is only a little bigger than it is in the estimated model. So, low value of the home bias parameters in the estimated AE model are not the reason the model is successful at explaining the relatively small drop in GDP after a US monetary tightening. Specifically, home bias parameters themselves do not explain the difference between AE and EME response. We can see why the estimation procedure does not like the perturbed parameter values. The smaller home bias increases passthrough from the exchange rate into inflation and magnifies the drop in investment.

Figure 28: Impact of Low Home Bias in Advanced Economies

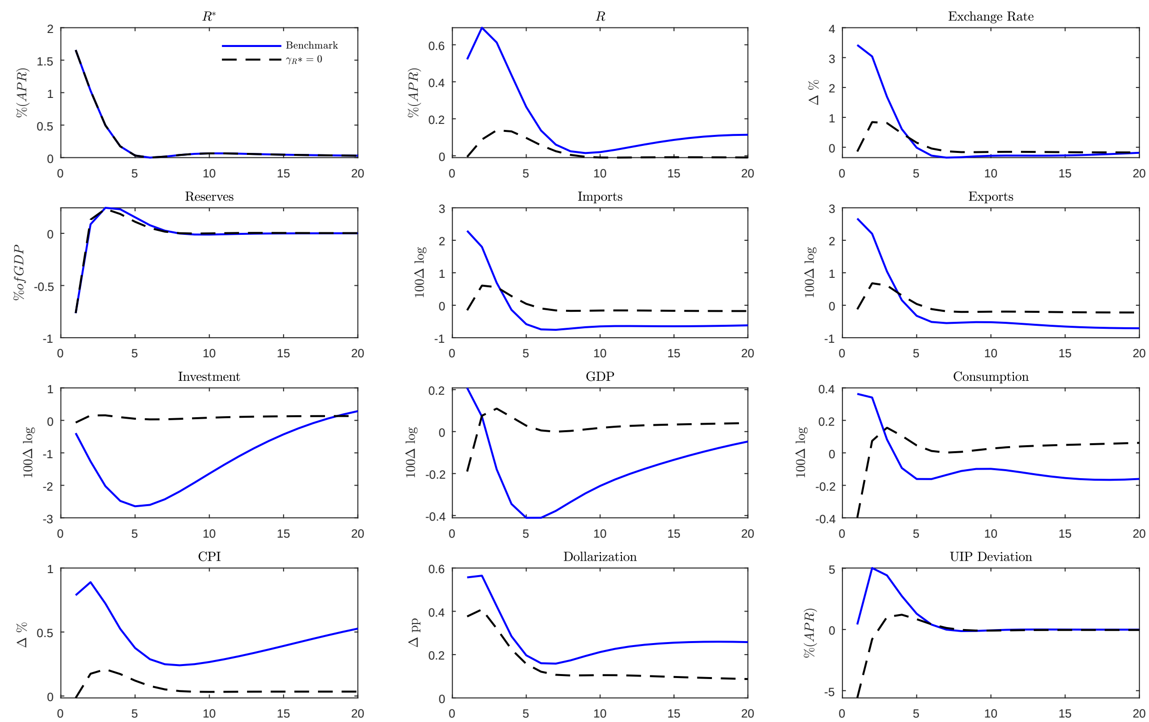


Notes: see notes (1)-(3) in Figure 7. The starred lines in the figure correspond to IRFs of estimated model in which the home bias parameters in consumption, investment and imports are set to the values indicated in the text associated with this figure.

G The Pure R_d^* Shock and γ_{R^*}

In the paper we explain that the γ_{R^*} parameter, which controls the impact of $R_{d,t}^*$ on the household's dollar share target, Υ_t, is substantial. At the same time, we report that the pure interest rate effect is 'small'. Yet γ_{R^*} obviously operates only via the pure interest rate effect and not via the other two effects. Figure 29 shows that most of the pure interest rate effect is due to $\gamma_{R^*} > 0$.

Figure 29: Impact on Transmission of PureR_d^* Shock of γ_{R^*}

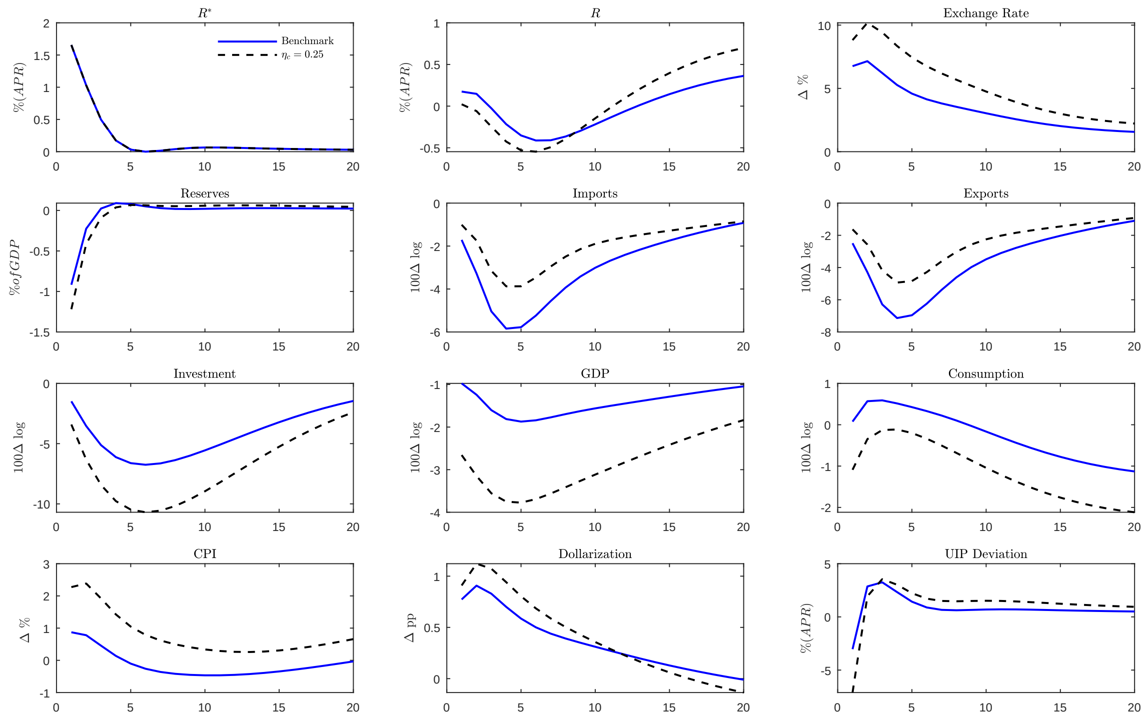


Notes: see notes (1)-(3) in Figure 7. The starred lines in the figure correspond to IRFs of estimated model in which the home bias parameters in consumption, investment and imports are set to the values indicated in the text associated with this figure.

H Consumption and the Elasticity of Substitution

In Figure 30 we display the IRFs of the EME model under our baseline parameterization of the elasticity of substitution, $\eta_c = .41$, and under a lower elasticity of substitution, $\eta_c = 0.25$. As expected, consumption now drops. In effect the lack of substitutability means that the price of consumption goods is higher which the exchange rate change. In fact the exchange depreciates by even more with the change. We can see why the estimation did not 'like' a lower value of η_c. While that moves the exchange rate response in the direction of the data at the same time it moves investment too far down and the CPI too far up.

Figure 30: Impact of Reducing Elasticity of Substitution In Production of Consumption Goods

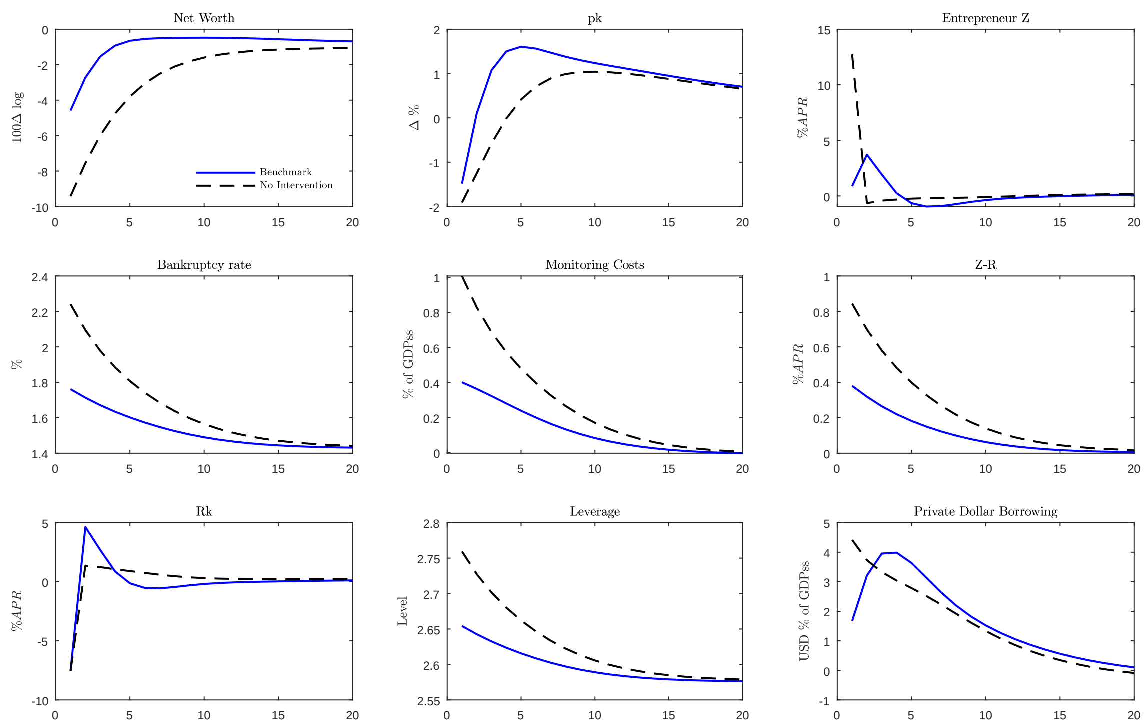


Notes: see notes (1)-(3) in Figure 7. The starred lines in the figure correspond to IRFs of estimated model in which the home bias parameters in consumption, investment and imports are set to the values indicated in the text associated with this figure.

I Impact of FX Intervention on Financial Variables in Peru Model

Here we consider the impact on financial markets of the FX intervention considered in the Peru model in section 5.3.1 in the text. The text examines the impact of FX intervention on the transmission of a US monetary tightening to the main macroeconomic variables in Peru (see Figure 11). To understand the impact on financial variables associated with investment, consider Figure 31. Consider the response of entrepreneurial net worth of entrepreneurs, in panel 1,1. The relatively big exchange rate depreciation that occurs in the absence of an FX intervention (see Figure 11) produces a nearly 10 percent drop in net worth. As discussed in the text, FX intervention moderates the sharp initial depreciation that occurs in the absence of intervention. Panel 1,1 shows that by reducing the initial depreciation, FX intervention cuts the initial decline in entrepreneurial net worth by more than one-half. The reason for the big fall in net worth in the absence of FX intervention is partly the very large jump in interest paid by entrepreneurs. The latter is due to the jump in the exchange rate (see dashed line in panel 1,3) and the fact that part of entrepreneurial debt is financed in dollars. In addition, the fall in the price of capital causes the realized rate of return on capital to plunge in the period of the shock (panel 3,1). Note that the impact of the drop in net worth on borrowing and, hence, investment is initially mitigated by a rise in leverage (see panel 3,2 and the initial increase in private borrowing in panel 3,3). The reason for the increase in leverage is that the drop in the price of capital creates the expectation that that price will rise over time (panel 1,2), increasing the capital gains component of the expected rate of return on capital, R_t^k (see equation (19)). Other things the same, a higher expected rate of return on capital leads to higher leverage in the in equilibrium loan contracts.

Figure 31: FX Interventions in Peru: Financial Variables



Notes: financial variables corresponding to the IRFs in Figure 11. 'Net Worth' corresponds to N_t in equation (18); 'pk' corresponds to the price of capital, P_t^k, in section 3.6, scaled by the price of homogeneous goods; 'Entrepreneur Z' refers to the period t realized interest rate, Z_t, paid by the entrepreneur on debt undertaken in period $t-1$; 'Bankruptcy rate' is the time t realized value of $F(\overline{\omega}_t)$, the fraction of non-performing entrepreneurs (see section 3.4.2); 'Monitoring costs' is the realized time t resources, $\mu G(\overline{\omega}_t)$, devoted by banks to recovering funds from non-performing entrepreneur borrowers (see equation (24)); '$Z-R$' denotes the interest rate spread, $E_t[Z_{t+1}-R_{t+1}]$, between what entrepreneurs expect to pay on a loan taken in period t and what the bank expects to pay to fund that loan; 'Rk' corresponds to the period t rate of return on capital, R_t^k, defined in equation (19); 'Leverage' denotes the leverage of entrepreneurs, defined as total assets divided by net worth, $P_t^k K_t/N_t$.

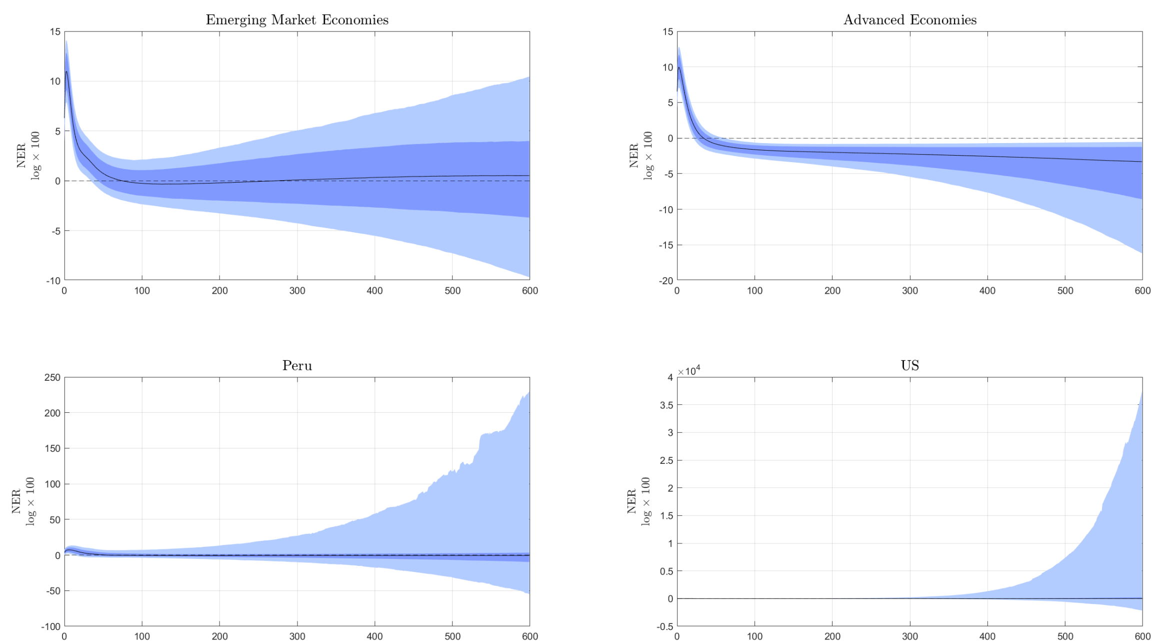
J The Long-run Impact of a US Policy Shock on Exchange Rate and Dollar Premium

The two sets of figures in this section document the appropriateness of the assumptions underlying the representation of the log-level of the exchange rate in section 5.5.1 of the text. We actually only use assumptions in the case of the EMEs. However, the long-horizon IRFs and shows that the assumptions also apply to the US and Peruvian VARss. We report a small amount of evidence against the assumption in the case of the AEs.

J.1 Long-Horizon IRFs for log Exchange Rate

Figure 32 displays the 600 month (50 year) impulse responses in the log-level of the exchange rate. The dark and light shaded areas correspond to 68 and 90 percent probability intervals. Note that in the case of EMEs, the US and Peru, a long run zero response lies within the probability intervals. In the case of the AEs, the upper bound of the probabilities intervals lies below zero. This suggests that there is a permanent depreciation in the AE exchange rates after a US monetary tightening.

Figure 32: Long Run Impact on Level of Nominal Exchange Rate After a US Monetary Tightening

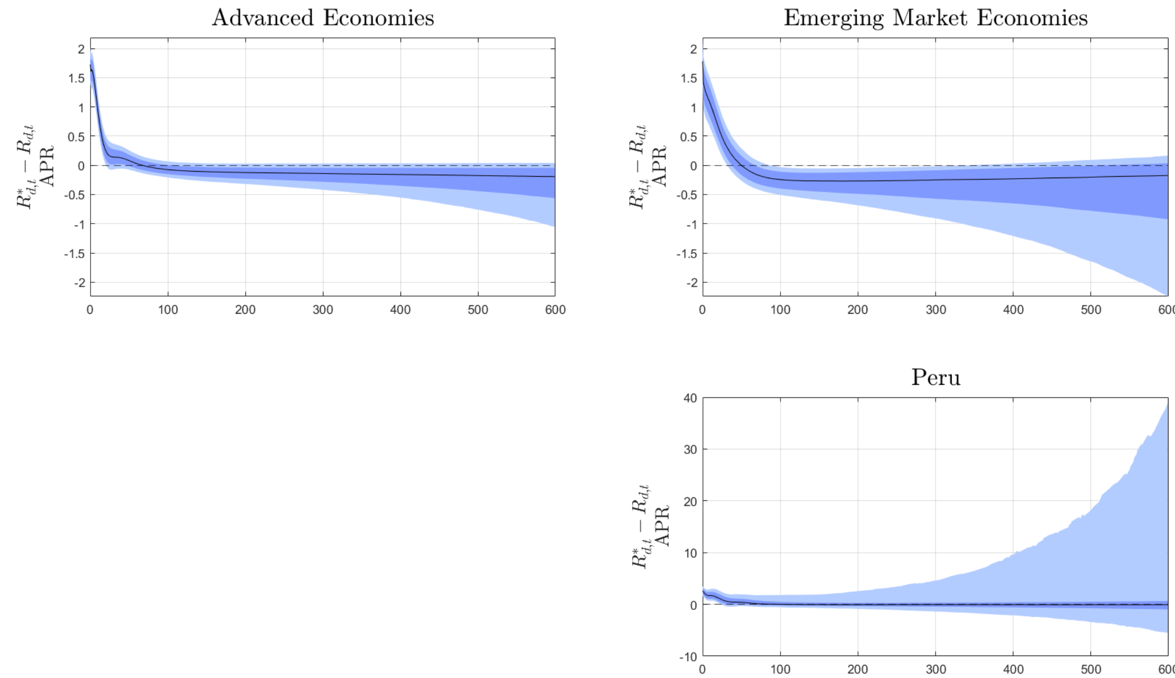


Notes: 600 period IRFs of the log level of nominal exchange rate to a Bauer and Swanson (2023b) monetary tightening for different VAR's in Section 2 of the manuscript. Panel 1,1: IRF from EME VAR underlying Figure 4; Panel 1,2 IRF from AE VAR underlying Figure 3; Panel 2,1: IRF from Peru VAR underlying Figure 5; Panel 2,2: IRF from US VAR underlying Figure 1.

J.2 Long-Horizon IRFs for Dollar Premium

Figure 33 shows that the long-run response of the dollar premium to a US monetary policy shock includes zero in probability intervals. The modal response is eventually a small negative number in the case of AEs and EMEs.

Figure 33: Long Run Impact of US Monetary Tightening on Dollar Premium

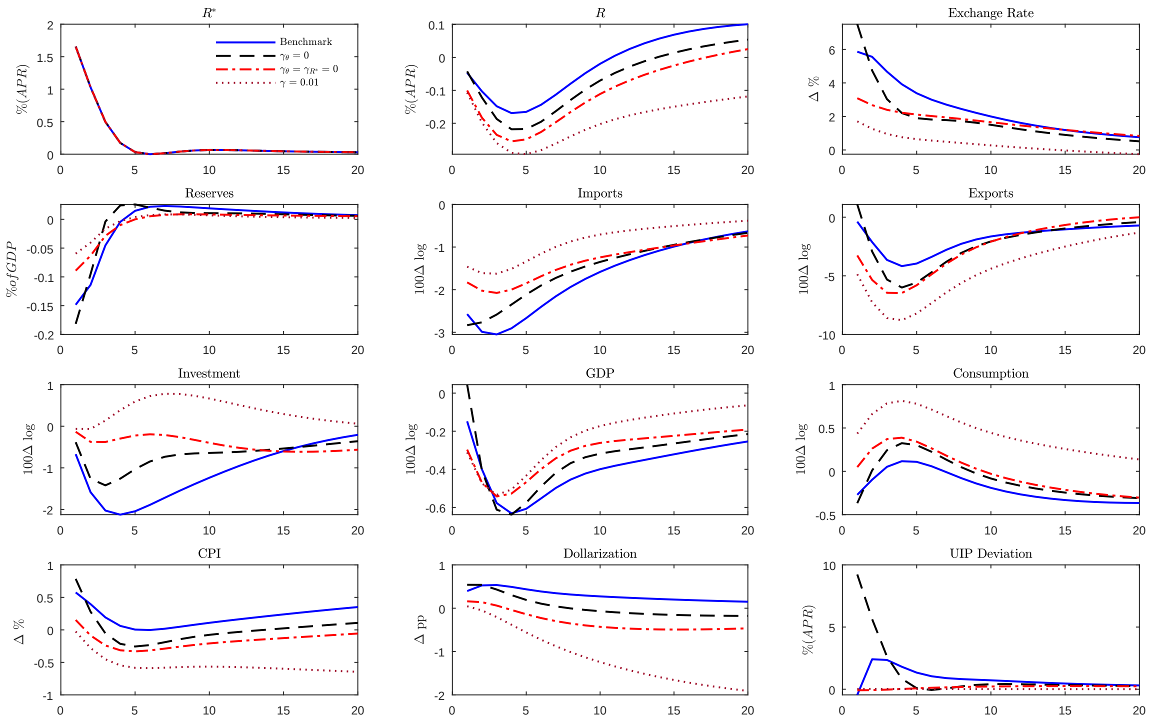


Notes: 600 period IRFs of the dollar premium, $R^*_{d,t} - R_{d,t}$, to a Bauer and Swanson (2023b) monetary tightening for different VAR's in Section 2 of the manuscript. Panel 1,1: IRF from AE VAR underlying Figure 3; Panel 1,2 IRF from EME VAR underlying Figure 4; Panel 2,2: IRF from Peruvian VAR underlying Figure 1.

K Excessive Overshooting in the AE Model

Figure 34 displays the impact of the UIP frictions on the transmission of a US monetary tightening to AE economies. The figure is the analog of Figure 17 in the text, which displays the impact in the EME model. The dotted line in the figure shows the response when UIP frictions are turned off. The solid line shows what happens in the estimated version of the model, with the parameter values reported in section 4 of the text. In the latter, the UIP frictions double the percentage point drop in GDP after a monetary tightening. In the AE model the UIP frictions increase the percentage point drop by only about 15 percent. The discussion in the text suggests that the primary reason that UIP frictions play a smaller role in the transmission of US monetary shocks to AEs is their balance sheets are less vulnerable to exchange rate shocks, modeled here as reflecting a high value ofϕ, the fraction of loans to risky entrepreneurs that are financed in local currency units.

Figure 34: The Impact of Portfolio Friction Parameters



Notes: response to a US monetary tightening under different parameterizations of the model. The baseline parameterization corresponds to the version of the model with parameters set as in section 34. The horizontal axis is measured in quarters, consistent with the observations in section 2.1.2. The monetary tightening shock occurs in period 1.

L Impact of Export Demand Parameters on the Results

Here, we explore the impact on IRFs of the two parameters of export demand: γ_f, controls the elasticity of the demand shifter with respect to the transitory component of US GDP and η_f, is the elasticity of demand with respect to the terms of trade, p^x. In section 4.2 we provide intuition for why η_f plays a small role in our results and why γ_f plays a large role.[58] The results in Figure 35 support this intuition. The figure displays (solid blue line) the IRFs for the EME model at its estimated parameter values (see Table 2). Where the variables overlap, the solid blue line coincides with the red dots in Figure 9. The dashed line shows the IRFs when the value of γ_f is cut roughly in half, by setting it to unity. The dot-dashed line shows the IRFs η_f is also changed by raising it from roughly 4 to $\eta_f = 8$.

Consider first the dashed line. Note that the maximal drop in GDP in the baseline model is nearly 2 percent and that the smaller value of γ_f reduces the drop in GDP to a maximum of only 0.5 percent. Reducing the value of γ_f has a substantial effect on GDP by reducing the magnitude of the drop in the export demand shifter. In effect, the move from the blue line to the

[58] For the demand shifter, see equation (16)).

dashed line can be interpreted as the effect of a positive shift in the demand for exports. This increases employment and GDP, as well as the price level. This in turn leads to an increase in the interest rate, which results in an appreciation of the currency. Via the balance sheet effect, this improves the net worth position of entrepreneurs (not shown) and thereby allows them to expanding borrowing. This in turn leads to an increase in investment, which, together with the response of exports, pushes up GDP. The impact on consumption is mixed: the rise in the interest rate, pushes consumption and the rise in GDP pushes consumption up because of the wealth effect. In sum, changing the magnitude of γ_f has a significant impact on model properties.

Turning to γ_f, note from Figure 9 that the dot-dashed and dashed lines are similar. This means that doubling the value of η_f has relatively little impact on the economy. This is not surprising because the US price level moves relatively little, while EME export prices are sticky, so that the terms of trade do not change much.

Figure 35: EME's, Perturbing Parameters of Export Demand