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 open economy (SOE) models that include standard frictions like balance sheet effects, UIP frictions, sticky-in-dollar export prices, etc. that capture these spillover effects quantitatively. We also include the VAR-estimated import decline that accompanies US monetary tightenings. Using counterfactual experiments, we identify the decline in US imports as the most important mechanism by which a US monetary contraction affects other economies. We also document that Emerging Market Economies (EME) exhibit more pronounced contractions compared with Advanced Economies (AE). Additional counterfactual experiments attribute the limited contraction in AEs primarily to relatively high home bias in AE production. Finally, our findings suggest that FX interventions are relatively ineffective in mitigating the effects of a US monetary contraction that is accompanied by reductions in US imports and inflation. FX interventions are relatively more effective in the face of pure 'noise' shocks in financial markets and in the scenario in which a US monetary policy contraction is not associated with a decline in US imports and inflation.

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Contents

1 Introduction

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 additional 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) and Degasperi et al. (2020)). Another, potentially complementary, view is that the international transmission of monetary shocks operates through the reduction in US imports. We present evidence that this import effect may play a bigger role than the financial frictions.

Recent research on the transmission of monetary shocks considers a variety of factors such as the effects of balance sheet frictions,[4] sticky-in-dollar export prices,[5] deviations from interest rate parity[6], foreign exchange (FX) interventions[7], noise trading in FX markets[8] and other features.[9] In this paper, we incorporate all these features into small open economy (SOE) models, to see which combination best accounts quantitatively for the estimated international transmission of monetary policy shocks for advanced and emerging economies. As noted above, we find that one variable which only recently has entered the relevant literature, US imports, also plays a role in the international transmission of US monetary policy shocks. That US imports decline following a US monetary tightening is also documented by Müller and Verner (2023) using a large panel of countries; this decline is referred to as the "trade channel of monetary policy" by Ozhan (2020). We perform counterfactual experiments with estimated SOE models which suggest that the trade channel may explain most of the global decline in GDP after a monetary contraction. Identifying the exact mechanism by which US imports have such a large effect on the global economy is beyond

[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]see Di Giovanni et al. (2022) and Akinci and Queralto (2023) .

[5]seeGoldberg and Tille (2008) and Gopinath et al. (2020).

[6]see Jiang et al. (2020), Kalemli-Özcan and Varela (2021), Kekre and Lenel (2021), Devereux et al. (2023) and Greenwood et al. (2023).

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

[8]see Eichenbaum et al. (2021), Itskhoki and Mukhin (2023) and Fukui et al. (2023).

[9]see Adrian et al. (2021) and Basu and Gopinath (2024)).

the scope of our paper. The analysis in Di Giovanni and Hale (2022) suggests that the answer may lie with amplification effects associated with the global network of production.

To describe our findings, 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 the benchmark version of the M-F model, expenditure switching in response to exchange rates is a primary factor driving the US and foreign response to a US monetary policy shock.[10] 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 since at least a decade is that a US monetary contraction also has a contractionary impact on the rest of the world, a striking rebuke of the M-F paradigm. A dramatic example of this shift in consensus is the so-called "Taper tantrum" in June 2013, when the language of an FOMC statement led markets 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) suddenly became very concerned about the possibility of 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 tends to lead to a reduction in rest-of-the-world output. However, although we allow for balance sheet and other types of financial frictions in our SOE's, the trade channel appears to be most important. Here, we emphasize that our results are based on post-2000 data, when many regulatory and other reforms have been implemented that appear to moderate the likelihood of financial turbulence.[11]

To evaluate the role of different frictions in the international monetary transmission mechanism we first construct a reduced form, quantitative characterization of that mechanism. Accordingly, the first section of the paper reports the results of a VAR analysis of the effects of the monetary shock measured in Bauer and Swanson (2023a). We begin by displaying the dynamic effects of the shocks on US data and roughly reproduce the results reported by others. However, we also include open economy variables and, as noted above, find that US imports decline substantially in a wake of a US monetary contraction.

We then use VARs to estimate the impact of US monetary contraction on a panel of advanced economies (AE) and a panel of EMEs. In addition, because we have substantial data on Peru, we also study that country separately. Significantly, we find that a US monetary tightening has a

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

[11]Using post-2000 data, Christiano et al. (2021) analyze firm-level datasets from Peru and Armenia which suggest that balance sheet effects may not be very important, even in the face of substantial depreciations (Bleakley and Cowan (2008) reach similar conclusions using 1990s data using firm-level balance sheets from five Latin American countries). In principle, banks may be a source of financial vulnerability because they typically have much higher leverage than firms. However Christiano et al. (2021) show, using financial stability data from the IMF, that regulators around the world have seen to it that currency mismatch in their countries is almost zero in the 2000s.

relatively small negative impact on AE's but a larger impact on the EMEs and Peru. Indeed, the impact of a contractionary US monetary policy shock on GDP in the EMEs and Peru is as big as its impact on US GDP, or even bigger for some of the statistical methods we use.

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 simplify the analysis, we model non-US economies as small open economies that take the US as an exogenous source of US interest rate 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. 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.

Four factors account for the observation that EMEs contract more than AEs after a US monetary tightens. The first factor delivers the outcome that both regions contract after a US rate hike and we call it the *portfolio effect.* This channel reflects that when foreign interest rates rise, people in non-US countries have an incentive to reallocate their portfolios towards dollar assets. The resulting capital outflow gives rise to a reduction in finance available for investment projects in non-US countries, a reduction in demand that, without any other friction, can overwhelm the expenditure switching channel and produce a recession in foreign economies. But, the portfolio effect by itself cannot explain the differential impact on the AEs and EMEs of a US monetary contraction. Indeed, explaining this differential impact is made even more difficult by our finding that the AE monetary authority reduces its policy rate in response to a US tightening and the EMEs tend to raise their policy rates.

Given the differential impact on AE and EME policy rates, the portfolio effect alone would seem to imply more capital outflows from AEs than from EMEs. To explain why the opposite happens, our model incorporates a second type of friction: *interest rate parity frictions* like the ones in Gabaix and Maggiori (2015), Eichenbaum et al. (2021), Gourinchas et al. (2022) and Itskhoki and Mukhin (2023). The implication of this type of friction is that there are non-pecuniary factors that make people in the AE's less inclined than people in EMEs to reallocate their portfolios towards dollars when the dollar return rises. These factors could be the financial frictions discussed in Gabaix and Maggiori (2015) or Itskhoki and Mukhin (2023). Or, they could be the factors like regulations, capital controls or preferred habitat like in Eichenbaum et al. (2021) and Gourinchas et al. (2022). In the case of emerging markets, where Dalgic (2018) shows exchange rates systematically depreciate against the dollar in recessions, the non-pecuniary return on dollars takes the form of business cycle income insurance (see also Christiano et al. (2021)). It could be that the demand for such insurance rises as output falls in the wake of a monetary contraction, leading people to want to hold more dollars. This factor could help explain the greater drop in EME GDP than AE GDP in the wake of a US monetary contraction.

In addition, our model estimation also assigns greater home bias in AE production functions. Home bias alone is very important. When we reduce the home bias in our estimated AE SOEs to the level in the estimated EME SOEs, output in the former drops by about the same as output in the latter.

A combination of the portfolio channel, home bias in the AEs and the interest rate parity frictions allows our SOE models to produce a fall in GDP in non-US countries, with the impact being asymmetrically larger in the EMEs. However, the effects are not quantitatively big enough. So, we introduce a third factor, sticky-in-dollars export pricing, which is motivated by evidence in Gopinath et al. (2020). 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 fourth factor magnifies the impact of a US monetary contraction on EME investment and GDP. That factor is a *balance sheet channel.* The model incorporates costly state verification financial constraints as in Bernanke et al. (1999). In this model capital is owned and operated by 'entrepreneurs' who buy the capital using a combination of their own net worth and loans. We assume that in the EMEs the funding must be partially in dollars. This means that when the exchange rate depreciates after a US contractionary monetary policy shock, entrepreneurs in EMEs experience capital losses that reduce their net worth. The financial frictions in EMEs then become more binding, restricting how much entrepreneurs borrow. With entrepreneurs buying less capital, less capital is produced and investment falls.

The interest parity frictions in our model imply that foreign exchange (FX) interventions have real effects. So, the analysis allows us to say something about how FX policy may buffer an economy from a US monetary tightening. Our VAR analysis suggests that AEs do not do much FX intervention. In the case of the EMEs there is some evidence of FX intervention, but it is not robust across variants of our VAR procedures. So to investigate the role of FX intervention we also look at Peru because its Central Bank is very open about its active FX intervention policy.

After fitting the AE, EME and Peruvian models to the estimated impulse responses we consider the effects of a *pure interest rate US monetary shock.* By this we mean the counterfactual scenario in which the US interest rate is increased, but the impact onto other US variables (including prices and US imports) is zeroed out. We find that with this change, the response of GDP falls by one or two orders of magnitude. That is, most of the contraction in non-US GDP after a US monetary tightening is due to the fall in imports. The financial and other frictions play a role, but they play a smaller role in getting the details right.

Before concluding that the trade channel is the dominant one, we must consider an argument in Bruno and Shin (2021). Their argument suggests that the fall in US imports could actually reflect a financial friction in foreign countries. In that case, the fall in US imports could not fairly be called a channel by which a US monetary tightening contracts the rest of the world economy. Rather, it would be a symptom of the operation of other, financial friction, channels. To understand Bruno and Shin (2021)'s point, suppose (as in our SOEs) that EME exporters must import US goods to produce exports. But, suppose also that EME exporters need to borrow dollars in advance to buy the imported goods. With the exchange rate depreciation those exporters would suffer capital losses on their dollar debts and that might prevent them from borrowing the dollars they need for their imported inputs. In this scenario, the decline in US imports reflects a reduction in the supply of those goods by EME exporters. So which is bringing down imports, demand or supply? We show that an index of the price of imports falls in response to a US monetary tightening. This suggests that the answer is demand: the fall US imports after a US monetary tightening reflects a reduction in demand by US citizens for foreign goods. Thus, our overall conclusion is that the primary channel by which a US monetary tightening is transmitted to the rest of the world is a trade channel.

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 estimation exercises. Section 5 discusses how we use our models to draw inferences about the economic frictions underlying the estimated impulse response functions. Section 6 offers conclusions. An appendix considers robustness of our results to perturbations in the structure of the panel VARs.

2 US and International Impact of a US Monetary Policy Shock

This section reports our VAR analyses of the international impact of US monetary policy shocks, proxied by ε_t^m, taken from Bauer and Swanson (2023b).[12] Subsection 2.1 reports VAR analyses for the US and subsection 2.2 describes the results of our panel data VAR approach for estimating the international impact of US monetary policy shocks.

In the third subsection below, Subsection 2.3, we check the robustness of our results to alternative econometric strategies. This analysis suggests that what is robust in our panel data VAR approach is that after a contractionary US monetary policy shock (1) GDP falls a little in AEs; (2) GDP falls by more in EME's than in the AEs; and (3) EME GDP may even fall by more than US GDP falls.

Our baseline strategy in subsection 2.2 finds that EME GDP falls by as much as three times the

[12]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 in the first step is orthogonalized with respect to information available at the time of the FOMC announcement. For extensive discussion, see Bauer and Swanson (2023b)

fall in US GDP. We redo the calculations in a way that makes no use of VARs at all by doing Jordà (2005)-type regressions (see section B in the Appendix). That analysis also suggests that EME GDP falls by more than US GDP. But, two variations on the panel data VAR approach 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 is reported in subsection 2.3 below and the other is reported in section A.1 in the Appendix.

The robustness analysis is why we view our results as supporting (1), (2) and (3) above, regarding the international impact on GDP.

2.1 US Economy

Here, we do two things with the US data. First, in subsection 2.1.1 we estimate the impulse responses of US data to 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.

When we estimate the SOE models, they take as given how US variables respond to ε_t^m shocks. To this end, we must embed a parsimonious representation of the US VAR into the SOE models. The specific US inputs the SOE models require is the response of three variables - the US interest rate, US inflation and US GDP - to ε_t^m. US inflation is required to help determine the SOE's terms of trade and US GDP is a proxy for an SOE's export demand shifter. The US interest rate is treated as a risk-free return in dollars, available to residents of an SOE for borrowing or lending. 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 will be incorporated into our SOE models.

2.1.1 Nine Variable US VAR

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

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

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).[13]

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 8 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_t^*, the personal consumption expenditures deflator (PCE), Exports, Imports, a trade-weighted measure of the nominal exchange rate[14], the S&P 500 and an index of import prices (see note to Figure 1 for additional details). Our measure of R_t^* is the sum of the 2-year US Treasury bond rate plus the EBP.[15] 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. In the SOE models analyzed below, we treat R_t^* as a short-term default-free interest. In principle we could have used the return on US Treasuries to measure R_t^*. However, we assume that US Treasuries pay less than the return on default free private assets because US Treasuries generate non-pecuniary payoffs (e.g., 'liquidity' or 'convenience').[16] The Fed tightens monetary policy by draining liquidity from the system, thus increasing the non-pecuniary payoff on US Treasuries and raising EBP. 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.[17] Finally, the 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 impulse responses to the ε_t^{mp} are displayed in Figure 1. The dark lines are the mean of the posterior distribution of the impulse responses 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, where the impulse responses overlap with other studies, the results are qualitatively similar.[18] Second, note that the decline in imports is large by

[13]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.

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

[15]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.

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

[17]In the US case, GDP data are only available on a quarterly basis. We use Stock et al. (2010)'s monthly GDP data obtained by multivariate interpolation of the monthly real GDP series. So, our US GDP data are not measured in CPI units.

[18]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

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 one lag in the VAR, we get very similar results. In addition, when we further reduce the system to the three variables, R_t^*, GDP and PCE, we also get similar results for those variables. Fourth, the rise in R^* produces an appreciation of the dollar and a fall in prices, output and equity markets. We also see the first piece of evidence against at least the baseline M-F model, which places expenditure switching at its heart. Under expenditure switching the appreciation of the dollar should lead to substitution away from domestic goods and towards imports. Of course, this is not a major problem for the M-F because the overall decline in purchases in the US, other things the same, pushes imports down, especially if imports are not very substitutable with domestic goods.

The final feature worth noting about the results in Figure 1 is the decline in the price index for imports. This suggests that the fall in imports is driven by demand. It is not predominantly driven by a reduction in the supply of imported goods, triggered by the US monetary contraction. The introduction discusses how this might in principle happen.

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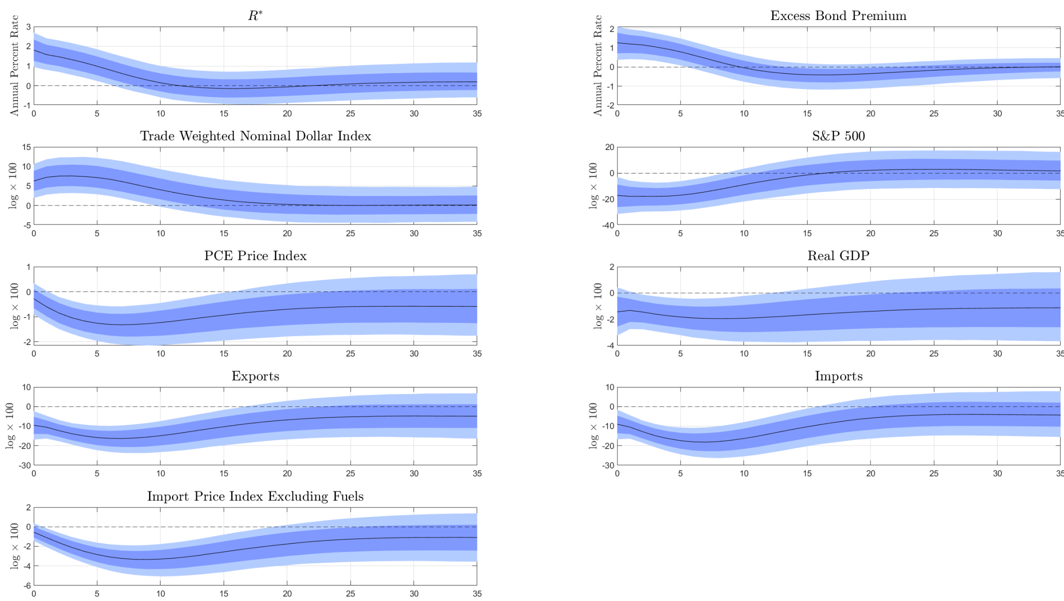
remaining time during the month of the meeting. This strikes us as impossible, especially when the meetings occur at the end of the month. We suspect that the these results reflect that the Bauer and Swanson (2023b) monetary policy shocks are correlated with subsequent revisions in the data. For example, 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 create what Swanson calls a 'look-ahead problem' in the data. Suppose that a contractionary monetary policy shock drives true GDP down in the months after the FOMC meeting. Then, later revisions of the data will adjust the reported GDP numbers down in the month of the monetary contraction. We plan to investigate this hypothesis further. This footnote has benefited from private correspondence with Eric Swanson.

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 mean of the posterior distribution of the impulse responses 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 et al. (2010)'s monthly GDP data obtained by multivariate interpolation of monthly real GDP series.

2.1.2 Three Variable US VAR

We construct a three-variable VAR whose impulse responses to a monetary policy shock match the ones implied by our VAR (see Figure 1). The following three variables are treated as exogenous from the point of view of an SOE:

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

where $\pi_t^f \equiv P_t^f / P_{t-1}^f$ and y_t^f is the transitory component of US GDP, according to our SOE model.[19] 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 terms. We adopt the following time series representation of $\hat{Y}_t$:

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

[19] See equation (13) below.

where D is a 3×1 column vector and ε_t^p denotes the monetary policy shock.

We compute a sequence of n responses from equation (2). We assume $\varepsilon_t^{mp} = 1$ in period $t = 1$ and $\varepsilon_t^{mp} = 0$ for $t > 1$. Also, suppose that $\hat{Y}_0 = 0$, so that the variables are in steady state. 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 n impulse responses, $\left[\hat{Y}_1, ..., \hat{Y}_n\right]$, conditional on D and a specified value of 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 GDP result reflects 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 SOEs are monthly. 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 ξ_t denote the $3n$ monthly impulse responses 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 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, $\left[\hat{\mathcal{Y}}_1, ..., \hat{\mathcal{Y}}_n\right]$, in the two steps described above. Their empirical counterparts are $\left[\xi_1^Q, ..., \xi_n^Q\right]$. We set $D = \xi_1^Q$. Now, we only need A to 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 vector of standard deviations of each element of ξ_j^Q, $j = 1, ..., n$. Then,

$$\min_A \sum_{j=1}^{n} \left(\xi_j^Q - \hat{\mathcal{Y}}_j\right)' \Lambda \left(\xi_j^Q - \hat{\mathcal{Y}}_j\right), \quad \Lambda = \begin{bmatrix} 1/\sigma_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/\sigma_n \end{bmatrix},$$

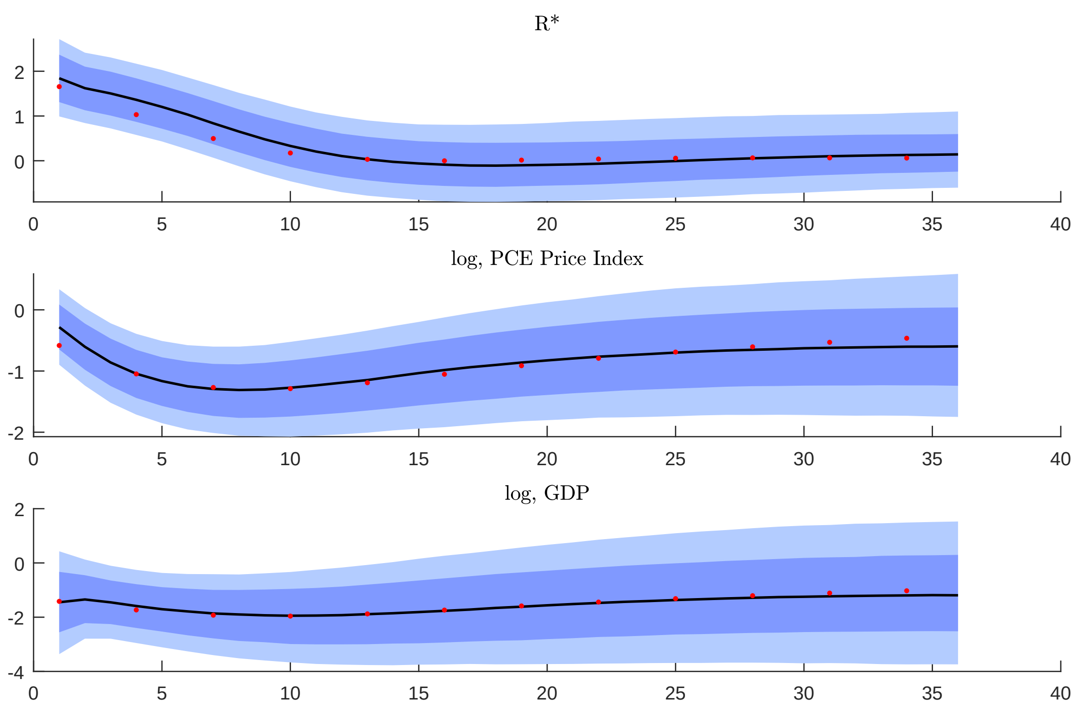
were Λ is a diagonal matrix which downplays hitting VAR impulse responses which are imprecisely measured.

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

$$D = \begin{bmatrix} -0.58 \\ 1.66 \\ -1.42 \end{bmatrix}, \; A = \begin{bmatrix} 0. & -.35 & -.08 \\ 0.87 & 0.98 & 0.06 \\ 0.43 & -0.09 & 0.95 \end{bmatrix},$$

where A has eigenvalues, $0.5 \pm 0.31i$, 0.92. The figure 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. 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.

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



Note: Solid line - impulse responses in Figure 1 with the associated probability intervals in dark and light shade. Dots - impulse responses 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 one EME, 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 model analysis we abstract from the latter form of feedback. Comparing the impulse responses to a US monetary policy shock in the three US variables - the interest rate, inflation and GDP - with the corresponding impulse responses in Figure 1 sheds light on the appropriateness of our no-feedback assumption. We do see differences, but they appear to be quantitatively small.

2.2.1 Panel VAR

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

$$Y_{i,t} = A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + C\varepsilon_t^{mp} + \varepsilon_{i,t}, \tag{3}$$

where

$$Y_{i,t} = \begin{bmatrix} \tilde{Y}_t \\ Y_t^i \end{bmatrix}, \tag{4}$$

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 impulse responses 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).[20]

When we estimate the system in equation (3) 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

[20] 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.

the rebound effect on the US from the foreign impact of US monetary policy shocks is small.

The panel VAR is structured as follows:

$$\begin{bmatrix} Y_{1,t} \\ Y_{2,t} \\ \vdots \\ Y_{N,t} \end{bmatrix} = \begin{bmatrix} A_1 & 0 & \cdots & 0 \\ 0 & A_1 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & 0 & \cdots & A_1 \end{bmatrix} \begin{bmatrix} Y_{1,t-1} \\ Y_{2,t-1} \\ \vdots \\ Y_{N,t-1} \end{bmatrix} + \begin{bmatrix} A_2 & 0 & \cdots & 0 \\ 0 & A_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & 0 & \cdots & A_2 \end{bmatrix} \begin{bmatrix} Y_{1,t-2} \\ Y_{2,t-2} \\ \vdots \\ Y_{N,t-2} \end{bmatrix} + \begin{bmatrix} C \\ C \\ \vdots \\ C \end{bmatrix} \varepsilon_t^{mp} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \vdots \\ \varepsilon_{N,t} \end{bmatrix}, \tag{5}$$

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 (5) as in the case of the US VAR in equation (1). The difference here is the zero restrictions in equation (5) 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 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 impulse responses 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

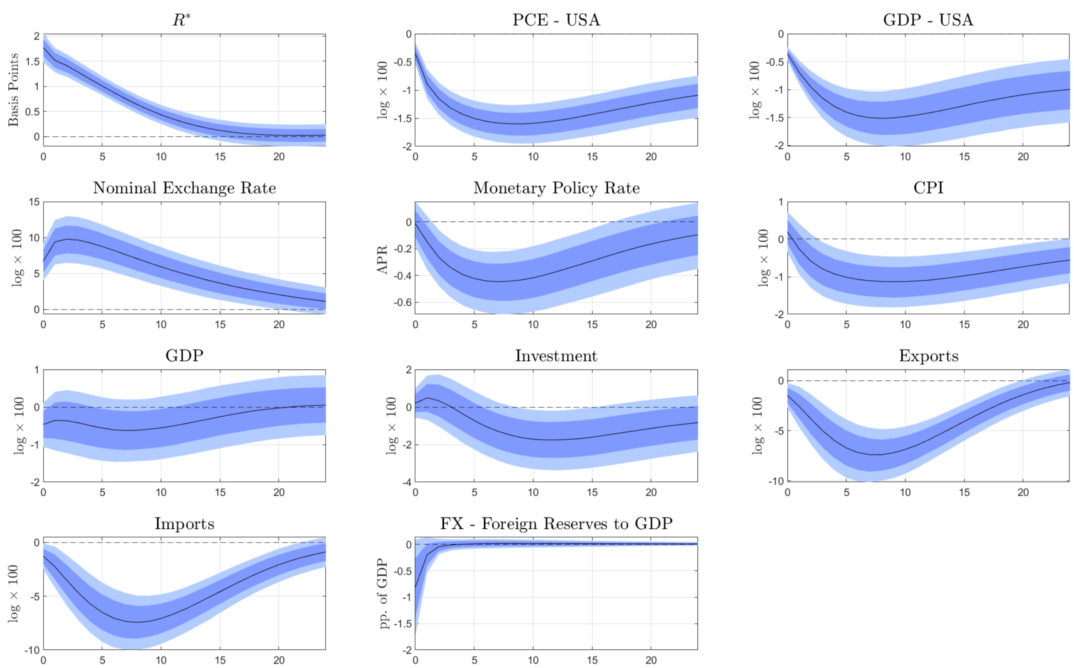
Our AE panel consists of equation (5) $N = 8$ countries: Australia, Canada, UK, Germany, Japan, Korea, Switzerland, and Sweden. Our EME panel has $N = 15$ countries: Brazil, Chile, Colombia, Dominican Republic, Hungary, Indonesia, Mexico, Peru, Philippines, Poland, Russia, Serbia, South Africa, Turkey. 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 US impulse responses 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.[21]

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

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 FX 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 results show a substantial drop in exports, consistent with the fall in US imports. Fifth, the relatively weak fall in GDP may reflect the estimated significant accommodative response by the AE monetary authorities (see R^*).

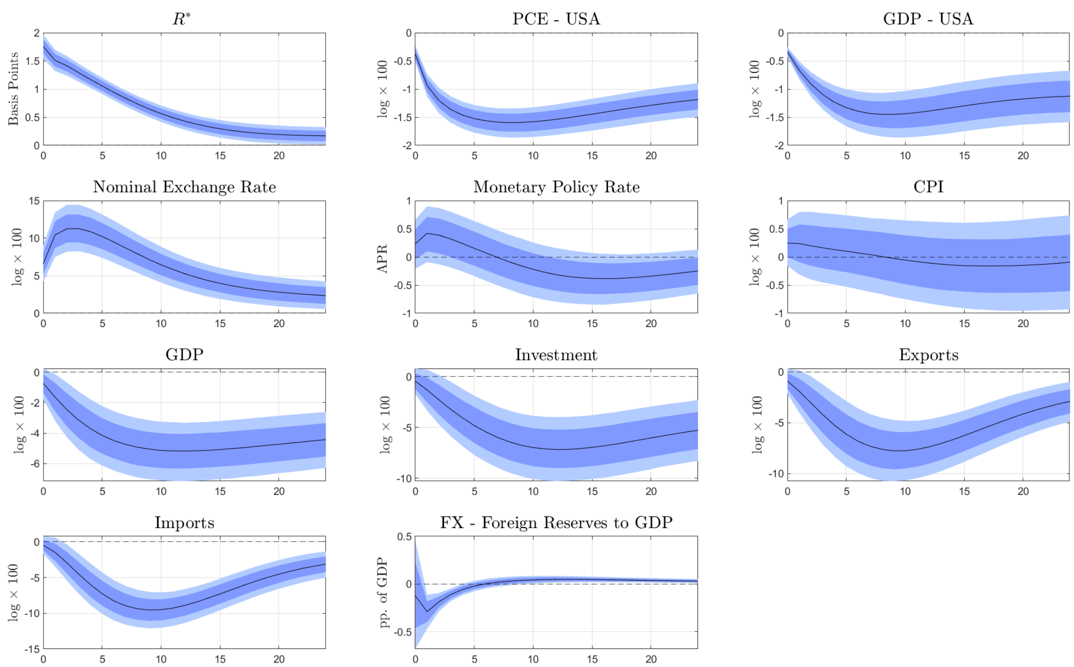
Figure 3: Response to Contractionary US Monetary Policy Shock, Advanced Economies



Note: Impulses from the panel VAR estimation for the AE countries: includes Australia, Canada, UK, Germany, Japan, Korea, 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.

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. 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 LCU policy rate while, as noted above, the latter reduce that rate. Fourth, by comparing Figures 3 and 4 we can see that the LCU expected return on the dollar 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 corresponds 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.[22] 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



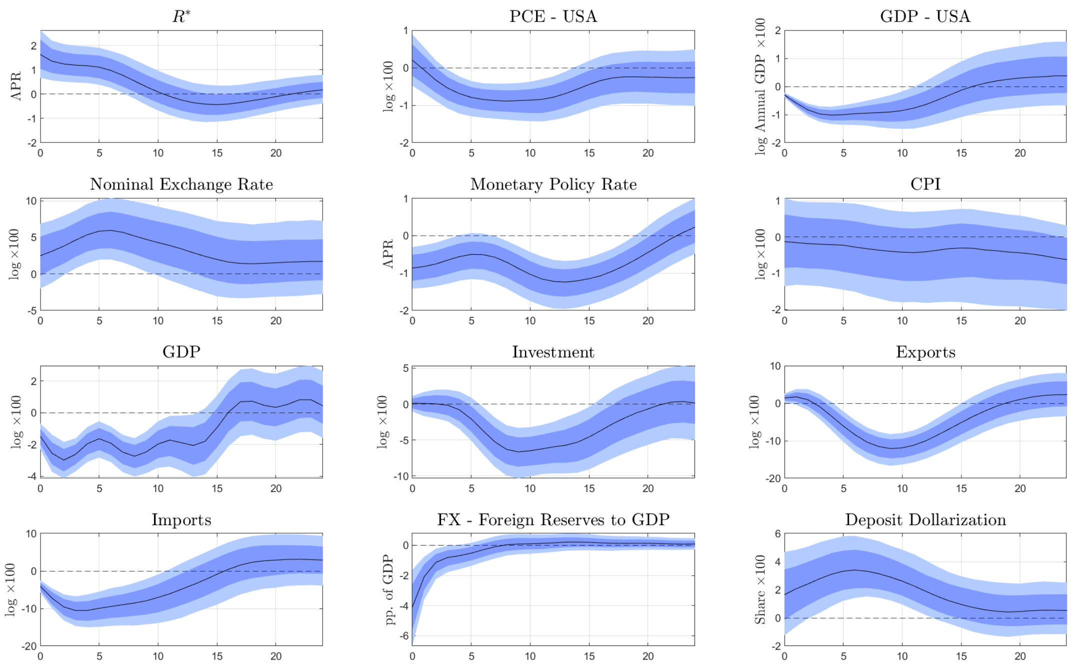
Notes: response to a unit shock in ε_t^m in panel VAR results for emerging market economies, Brazil, Chile, Colombia, Dominican Republic, Hungary, Indonesia, Mexico, Peru, Philippines, Poland, Russia, Serbia, South Africa, Turkey. Solid lines correspond to the mode of the Bayesian posterior, dark shaded 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.

We also report results for estimating equation (3) 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 22 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 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

[22] See footnote **??** for a discussion about how to recover the interest rate premia from impulse responses.

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 impulse responses by approximately 7.

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



Note: Response to unit shock in ε_t^m in equation (3) 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.

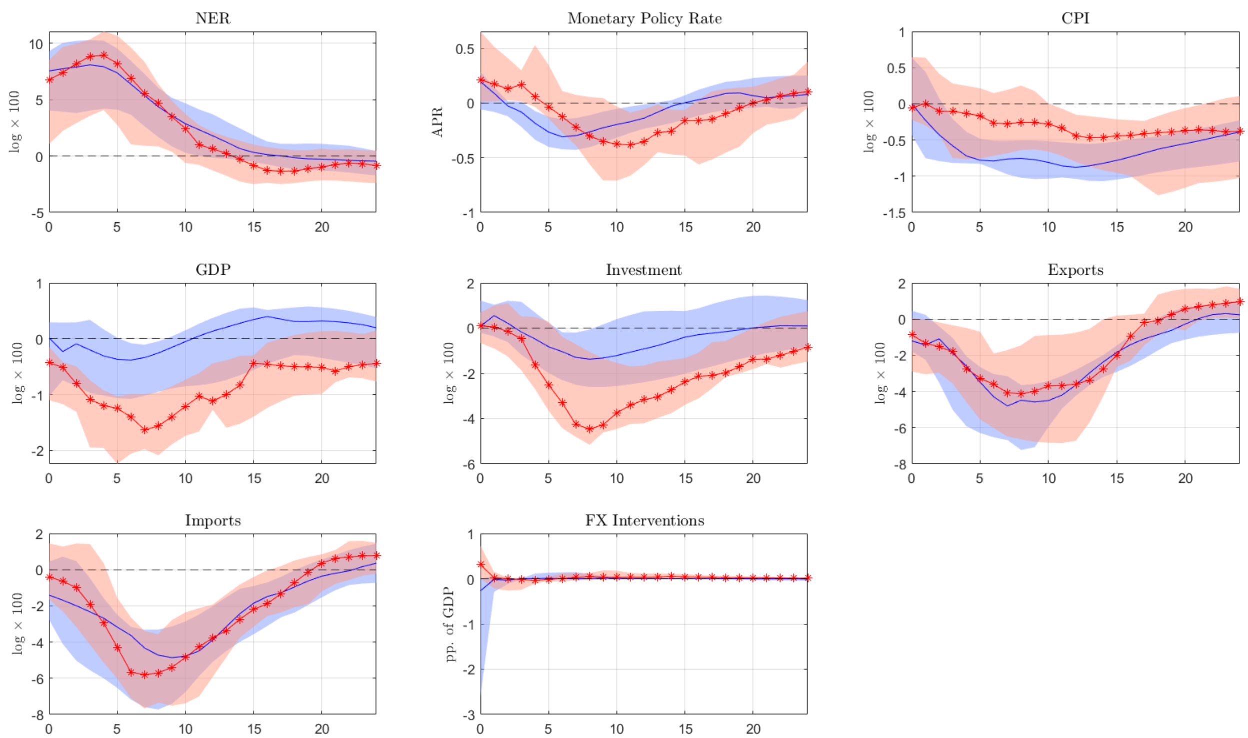
2.3 Country by Country Impulse Responses

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 (4) 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 (3) separately for each country, i, in our sample. In addition, we delete the first three equations in equation (3), so that no covariance assumption is violated in the VAR.

We compute impulse response functions for each country in our data set, except the US. We then group them by whether the country is an EME or an AE. The responses to a US monetary tightening are displayed in Figure 6. The blue lines indicate the average, across countries in the

AEs, of the mean response at each horizon. The blue shaded area presents the interquartile range of mean 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 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: Impulse responses over 24 months to a US monetary tightening shock as measured in Bauer and Swanson (2023b). We estimate a version of equation (3) separately for each country, i. The version of equation (3) 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 mean under the posterior distribution, of the impulse responses. The line in the above figure with red stars (solid blue line) is the cross-country average of the mean 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.

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. (2011) 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. In particular,

$$\Theta_t \equiv \frac{S_t D_t^*}{S_t D_t^* + D_t}, \quad h_t\left(\Theta_t\right) = \frac{\gamma}{2}\left(\Theta_t - \Upsilon_t\right)^2, \; \Upsilon_t = \Upsilon + \exp\left(\gamma_R\left(R_t^* - R^*\right)\right) + e_t^{\Upsilon} \tag{6}$$

where Υ is the value of the portfolio share in nonstochastic steady state. The object, e_t^{Υ}, is a 'noise' shock to the household's target, with a first order autoregressive representation. Also, $\gamma_R > 0$ captures the idea that when R_t^* is high people prefer dollar assets, perhaps because of a decrease in 'risk appetite', or 'flight to safety'. The variable, D_t^* denotes the household's end-of-period t holdings of dollar assets which pay R_t^* gross interest in dollars in period $t+1$. The variables, S_t and D_t denote the number of local currency units (LCU) per dollar and D_t denotes the end-of-period t holdings of LCU domestic assets which pay R_t gross interest in LCU in period $t+1$. The household's flow budget constraint is:

$$S_t D_t^* + D_t + P_t^c C_t + E_t Q_{t,t+1} a_{t,t+1} = S_t R_{d,t-1}^* D_{t-1}^* + R_{d,t-1} D_{t-1} + W_t \ell_t + \Pi_t - T_t + a_{t-1,t} \tag{7}$$

The terms on the left and right of the equality correspond to the household's period t purchases and receipts in LCU. Here, 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 $t+1$.[23] 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.

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

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

nonstochastic steady state,

$$E_t \log\left(S_{t+1}\right) - \log\left(S_t\right) + \log\left(R_{d,t}^*\right) + \Lambda_t = \log\left(R_{d,t}\right) \tag{8}$$

where,

$$\Lambda_t = \gamma\left(\Upsilon_t - \Theta_t\right).$$

The object on the left of the equality in (8) is the total return on holding dollar assets, in LCU. The part with the exchange rate corresponds to the return on the round trip through the exchange market. The next term is the dollar return. Finally, 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. Uncovered interest parity (UIP) corresponds to $\gamma = 0$ and is violated in the impulse response functions presented above. For example, the initial response of the exchange rate in all cases presented has an inverse 'U' shape. The rise in the exchange rate corresponds to a negative The object, Λ_t, is often referred to as the domestic interest rate premium.

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:

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}, \varepsilon > 1. \tag{9}$$

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

$$Y_{i,t} = \tilde{K}_{i,t}^{\alpha}\left(A_t \ell_{i,t}\right)^{1-\alpha}, \ 0 < 1 < \alpha. \tag{10}$$

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:

$$P_{i,t} = \begin{cases} \tilde{P}_t & \text{with probability } 1-\theta \\ P_{i,t-1} & \text{with probability } \theta \end{cases}. \tag{11}$$

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 (10) and (11), 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

The demand for exports, X_t, is given by:

$$X_t = \left(\frac{P_t^X}{P_t^f}\right)^{-\eta_f} \left(Y_t^f\right)^{\gamma_f} \tag{12}$$

where P_t^X / P_t^f denotes the terms of trade, and $\eta_f > 0$ denotes the elasticity of demand. We model foreign output, Y_t^f, as the product of a permanent component, $\mathcal{Z}_t$, and a transitory component, y_t^f, as follows:

$$Y_t^f = y_t^f \mathcal{Z}_t. \tag{13}$$

The monetary shock affects Y_t^f through 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 impulse responses to monetary shocks, we can abstract from those other shocks.[24] We assume that $\mathcal{Z}_t$ grows at its steady state rate, which we denote by Δa.

The domestic production function for exports is

$$X_t = \left[\gamma_X^{\frac{1}{\eta_x}} \left(X_{d,t}\right)^{\frac{\eta_x - 1}{\eta_x}} + \left(1 - \gamma_X\right)^{\frac{1}{\eta_X}} \left(X_{m,t}\right)^{\frac{\eta_X - 1}{\eta_X}}\right]^{\frac{\eta_X}{\eta_X - 1}}, \tag{14}$$

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) 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 (9):

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

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 (11), with probability of not changing its price, θ^X.[25]

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

[25] 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.

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).[26] 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, 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. (2011). 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

[26] 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).

(2018) 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 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:

$$N_t + \overline{B}_t^e = P_t^k K_t, \tag{15}$$

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 $var\left(\log \omega\right) = \sigma^2$. 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 $t+1$:

$$\begin{aligned} K_t \omega r_{t+1} + (1-\delta)\,\omega K_t P_{t+1}^k = {} & K_t P_t^k \omega \left[\frac{r_{t+1} + (1-\delta)\, P_{t+1}^k}{P_t^k}\right] \\ = {} & K_t P_t^k \omega R_{t+1}^k, \end{aligned} \tag{16}$$

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,

$$\bar{\omega}_{t+1} = \frac{Z_{t+1}\overline{B}_t^e}{P_t^k K_t R_{t+1}^k}. \tag{17}$$

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:

$$E_t \upsilon_{t+1} \int_{\overline{\omega}_{t+1}}^{\infty} \left[P_t^k K_t \omega R_{t+1}^k - Z_{t+1} \overline{B}_t^e \right] dF(\omega), \tag{18}$$

where υ_{t+1} denotes the marginal utility value of a unit of LCU to the household.

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:

$$B_t^{LCU} = \phi \overline{B}_t^e,\ S_t B_t^{\$} = (1-\phi) \overline{B}_t^e, \tag{19}$$

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:

$$\begin{aligned} A_{t,t+1} = & \left[1 - F(\overline{\omega}_{t+1})\right] \overline{B}_t^e Z_{t+1} + (1-\mu) G(\overline{\omega}_{t+1}) P_t^k K_t R_{t+1}^k \\ & - R_{d,t} \phi \overline{B}_t^e - s_{t+1} (1-\phi) \overline{B}_t^e R_{d,t}^*, \end{aligned} \tag{20}$$

where $s_{t+1} \equiv S_{t+1}/S_t$ denotes the rate of depreciation and

$$G(\overline{\omega}_{t+1}) = \int_0^{\overline{\omega}_{t+1}} \omega dF(\overline{\omega}_{t+1}). \tag{21}$$

The first term after the equality in equation (20) corresponds to payments by the $1 - F(\overline{\omega}_{t+1})$ 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 $\mu G(\overline{\omega}_{t+1}) P_t^k K_t R_{t+1}^k$. Under the assumption of free entry, the ex ante value of banking must be zero:

$$E_t \upsilon_{t+1} A_{t,t+1} = 0. \tag{22}$$

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' in one period $t+1$ continuation state, $A_{t,t+1} < 0$, and a surplus in another period $t+1$ state, $A_{t,t+1} > 0$. Household optimality in the Arrow securities market requires only that the prices, $Q_{t,t+1}$, equal υ_{t+1} in equation (22). With prices set in that way, households are willing to take a position opposite to the bank so that each Arrow security market clears. Moreover, the value of trades over all the Arrow securities markets must be zero, according the the free entry conditions, equation (22).

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 (22). So, the equilibrium contract is the one that solves the problem in equation (18) subject to equation (22). 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 (16)). 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 (16)). 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^k_{t+1} 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^k_{t+1} 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 (20). 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 (19)). 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, $P^k_{t-1}K_{t-1}R^k_t$. Here, $\Gamma : [0,\infty] \to [0,1]$ and $\Gamma(\overline{\omega}_t)$ is increasing in $\overline{\omega}_t$. Note from equation (17) 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^e_t. 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 $W^e_t = 0$ 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:

$$N_t = \gamma^e \left[1-\Gamma(\overline{\omega}_t)\right] P^k_{t-1}K_{t-1}R^k_t + W^e_t. \tag{23}$$

where W^e_t denotes a transfer of net worth from households to entrepreneurs. The period t transfer to households from entrepreneurs is $(1-\gamma^e)\left[1-\Gamma(\overline{\omega}_t)\right] P^k_{t-1}K_{t-1}R^k_t - W^e_t$ and this term is part of Π_t in the household's budget constraint, equation (7).

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

3.5 Government Policy

We assume that the local government purchases domestic homogeneous goods:

$$G_t = g\mathcal{Z}_t \tag{24}$$

where $\mathcal{Z}_t$ denotes the same trend term that appears in equation (13).

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

$$\log\left(\frac{R_t}{R}\right) = \rho_R \log\left(\frac{R_{t-1}}{R}\right) + (1-\rho_R)\left[r_\pi \log\left(\frac{\pi_t^c}{\pi^c}\right) + r_y \log\left(\frac{y_t}{y}\right) + r_S \log\left(\widetilde{S}_t\right)\right] + \epsilon_{R,t}.$$

Here, $\pi_t^c = P_t^c / P_{t-1}^c$ denotes consumer price index inflation (CPI), y_t denotes Y_t/A_t, where Y_t denotes aggregate homogeneous good output.[27] We include y_t 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. In practice, r_S is very small, so that the exchange rate in the model is a near-unit root. We indicate the nonstochatic steady state of a time series variable by deleting its time subscript.

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):

$$\frac{F_t^*}{\overline{F}_t^*} = \left(\frac{F_{t-1}^*}{\overline{F}_{t-1}^*}\right)^{\rho_{fx}} \left(\frac{R_t^* - 1}{R^* - 1}\right)^{-\theta_{R^*}}, \tag{25}$$

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:

$$\overline{F}_t^* = \left(\upsilon^{cb}\right)^{1-\vartheta} \left[R_{t-1}^* B_{t-1}^{\$} + \overbrace{P_t^m \left(I_{m,t} + C_{m,t}\right)/S_t}^{\text{imports in units of dollars}}\right]^{1-\vartheta} \left(\overline{F}_{t-1}^*\right)^{\vartheta} \tag{26}$$

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.

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

[27] 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.

'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:

$$D_t = B_t^{LCU} + B_t. \tag{27}$$

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

$$D_t^* + F_t^* + F_t^o = B_t^{\$}. \tag{28}$$

We also have clearing in the Arrow securities markets:

$$A_{t,t+1} = a_{t,t+1}, \tag{29}$$

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:

$$Y_t = I_{d,t} + C_{d,t} + X_t^{d,*} + g\mathcal{Z}_t + \overbrace{\frac{\mu G\left(\overline{\omega}_t\right) P_{t-1}^k K_{t-1} R_t^k}{P_t}}^{\text{homog goods for monitoring by banks}}, \tag{30}$$

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 (24)). 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, $G\left(\overline{\omega}_t\right)$, is defined in equation (21).

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:

$$P_t^x X_t - P_t^m\left(C_{m,t} + I_{m,t} + X_{m,t}\right) = F_t^* - R_{t-1}^* F_{t-1}^* + D_t^* - R_{t-1}^* D_{t-1}^* - B_t^{\$} + B_{t-1}^{\$} R_{t-1}^* \tag{31}$$

Let $R_t^* = 1 + r_t^*$, so that the current account, CA_t, is:

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

Then, we have that (31) can be written as follows:

$$CA_t = F_t^* + D_t^* - B_t^{\$} - \left(F_{t-1}^* + D_{t-1}^* - B_{t-1}^{\$}\right), \tag{32}$$

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 28, the expression on the right of the equality in equation (32) 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

$$GDP_t = \frac{P_t Y_t - \mu G\left(\overline{\omega}_t\right) P^k_{t-1} K_{t-1} R^k_t}{P^c_t}. \tag{33}$$

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 (30)), which is not part of GDP. That is why monitoring costs are subtracted in the numerator of equation (33).

4 Parameter Estimation

To estimate the model parameters we use a Bayesian version of the 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 the procedure using the code in version 6 of Dynare (see Adjemian et al. (2024)). We follow Jarocinski and Karadi (2020) who also do an impulse-response matching exercise to estimate a small open economy model. They use impulse responses calculated at a monthly frequency and they specify their model period to be one quarter. So, the estimation involves varying the values of the parameters of a quarterly model to match the implied quarterly impulses constructed from the monthly VAR analysis. This is the procedure that we follow.

We set key parameters of the model using IRF matching using data from the AEs and Peru [estimation results for the EMEs are expected to look like those for Peru]. For foreign income (Y_t^f) and foreign inflation (π_t^f) we use US GDP and inflation respectively. For R_t^* we use US risk free rates plus the excess bond premium. For estimation we apply [additional description in revision, plus more discussion of parameter values, many of which were discussed in the introduction, but not all] The balance sheet parameter, ϕ, is not reported in the two tables below. Motivated by the results in the 4×2 panel in Figure 3, we set $\phi = 1$ (100% local currency borrowing) in the case of the AEs. Motivated by the observations about Peru in Castillo and Medina (2021), we set $\phi = 0.5$ in the EMEs and Peru. Table 1 includes parameters for a simple three variable representation of the US. The results there are based on parameter

Table 1: Estimated Model Parameters

Variable	Description	Peru	EME	AE
γ	Portfolio Adjustment	2.70	1.84	4.68
γ_R	Portfolio Demand Shifter	0.91	28.42	27.90
κ	Investment Adjustment	3.14	6.92	3.03
θ_{R*}	FX Intervention Coefficient	0.36	0.34	0.00
ρ^{FX}	FX Intervention Persistence	0.71	0.89	0.00
η_c	Consumption Elasticity of Substitution	1.43	1.16	0.78
η_x	Export elasticity of Substitution	1.49	1.82	1.40
ν_i	Investment Elasticity of Substitution	1.20	0.81	0.25
η^f	Price Elasticity of Exports	2.04	5.17	2.62
γ_f	Export Demand Shifter	2.67	5.71	4.50
θ^x	Export Calvo Stickiness	0.79	0.89	0.82
$1-\omega_c$	Home Bias, Consumption	0.53	0.54	0.93
γ_I	Home Bias, Investment	0.29	0.29	0.49
γ_x	Home Bias, Exports	0.42	0.41	0.61
γ_f	Export Demand Shifter	2.67	5.71	4.50
ρ_R	MP Persistence	0.86	0.95	0.89
$1-\phi$	Credit Dollarization	0.50	0.56	0.01
$\bar{\Upsilon}$	Steady State Deposit Dollarization	0.40	0.40	0.05
$\frac{F^*}{4\times GDP}$	Steady State Reserves/GDP	0.30	0.15	0.05

Table 2: 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
ϵ	Elasticity of Subsititution, intermediate goods	6.00
θ	Calvo Parameter, intermediate goods	0.75
ϵ^x	Elasticity of Subsititution, export goods	6.00

5 Fit of the Models and Counterfactual Experiments

Here, we simulate the SOE models' response to a US monetary tightening, accompanied by the drop in US imports and inflation estimated in Section 2. We show that, with one exception, when the model parameters are set as in Tables 1 and 2, the SOE's implied responses to a US monetary policy shock roughly match the VAR-based estimates. The exception is the EMEs, which require additional work. The first three sections present results for AEs, EMEs and Peru. In each case, we also display the response of the economies to a pure interest rate shock, one in which R_t^* follows its estimated path (first panel in Figure 2) after a US monetary policy shock but US GDP growth and inflation are kept at their steady state values. In the case of the AEs, we also show how output would fall roughly as much as in the EMEs if home bias were decreased to the EME levels.

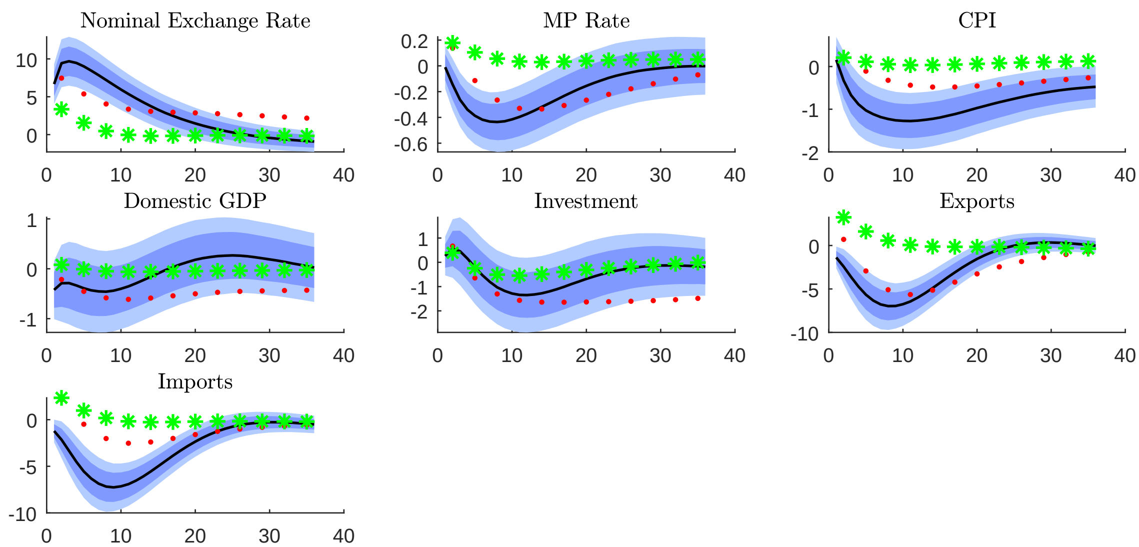
Subsection 5.4 performs additional counterfactual computations. We evaluate the relative contribution to the SOE impulse response functions of financial frictions, UIP frictions, sticky-in-dollar pricing and US imports on the response to a US monetary tightening. We show that the trade channel of a monetary shock plays a bigger role than the balance sheet channel, the UIP frictions and the sticky-in-dollars export prices.

5.1 Advanced Economies

The solid lines in Figure 7 display the mean impulse responses and probability intervals for AEs presented in Figure 3. In addition, the dots display the impulse responses to a monetary tightening implied by the estimated model for the AEs. The time unit on the horizontal axis is months, and the quarterly data from the model are displayed for the third month in each quarter. The stars present the model responses to a pure R^* rise. The latter leaves the impulse response in R^* unchanged at its estimated value in Figure 1, but zeros out the responses in GDP (hence, the US demand for imports) and US inflation.

First, note that, with some exceptions, the model reproduces the solid black line reasonably well. The exceptions are the CPI and imports, which rise a bit above the 90 percent probability band for a few periods. The key thing to note is that the yellow stars are almost flat at zero. We found that difference between the dotted and starred line is nearly entirely due to shutting down the movement in the shifter in the demand for exports. Put differently, nearly all of the response of the AE model to a monetary tightening is due to the drop in US imports, according to our estimated model.

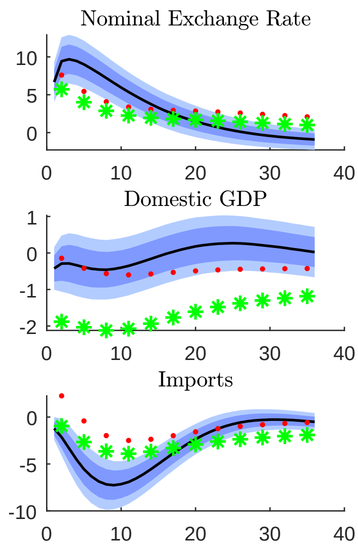
Figure 7: AE - VAR IRFs, SOE IRFs and SOE Responses to Pure R^* Shock



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) dots correspond to impulse responses 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.

Note that the estimated home bias parameters in Table 2 are substantially higher for the AEs than for the EMEs and Peru. The stars in Figure 8 show how the AEs would respond to a US monetary tightening if home bias in their consumption, investment and export sectors were set to their estimated values in the EMEs. Note that the very small drop in GDP in the model (see the dots) drops to nearly two percent in the first year, before reverting to trend. This is certainly a smaller drop than the roughly 5 percent drop implied by our panel data VAR and by the Jordà (2005)-type regressions in Section B. However, the drop is roughly what is implied by our country-by-country analysis in Section 2.3 and by a variant of our panel data VAR reported in section A.2 in the Appendix.

Figure 8: Impact of High Home Bias in Advanced Economies



Notes: see notes (1)-(3) in Figure 4. Stars in figure correspond to IRFs of estimated model in which the home bias parameters in consumption, investment and imports are set to their values in the AE model (see Table 1).

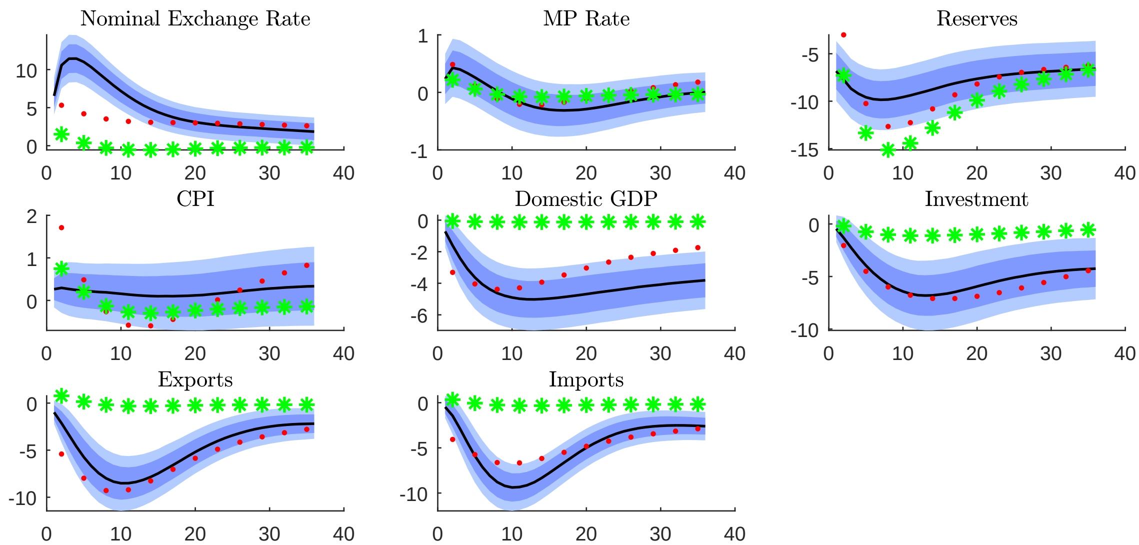
5.2 Emerging Market Economies

Our results for emerging market economies are displayed in Figure 9. Table 1 lists the estimated parameters for the EME model. The fit of the model is not as good as in the case of the AEs.[28] Note that the model reproduces the fact that EME GDP and investment fall substantially more than the corresponding data in the AEs. Notably, with two exceptions the yellow stars are all flat. The exceptions are R_t^*, which roughly matches the corresponding path in Figure 1 and Central Bank reserves. The latter fall more substantially than they do in the data. (Except with the first few observations, the dots are obscured by the stars, so that dots and stars coincide after 14 periods.)

Now consider the stars, which indicate the response to a pure R_t^* shock. With the exception of R_t^* and reserves, all responses are essentially flat at zero. As in the AE case, the primary reason for the drop in output after a US monetary tightening is the drop in US imports. A rise in R_t^* unaccompanied by a drop in imports would have very little impact on the EMEs, according to this analysis.

[28]The emerging market economy model is still being worked on.

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



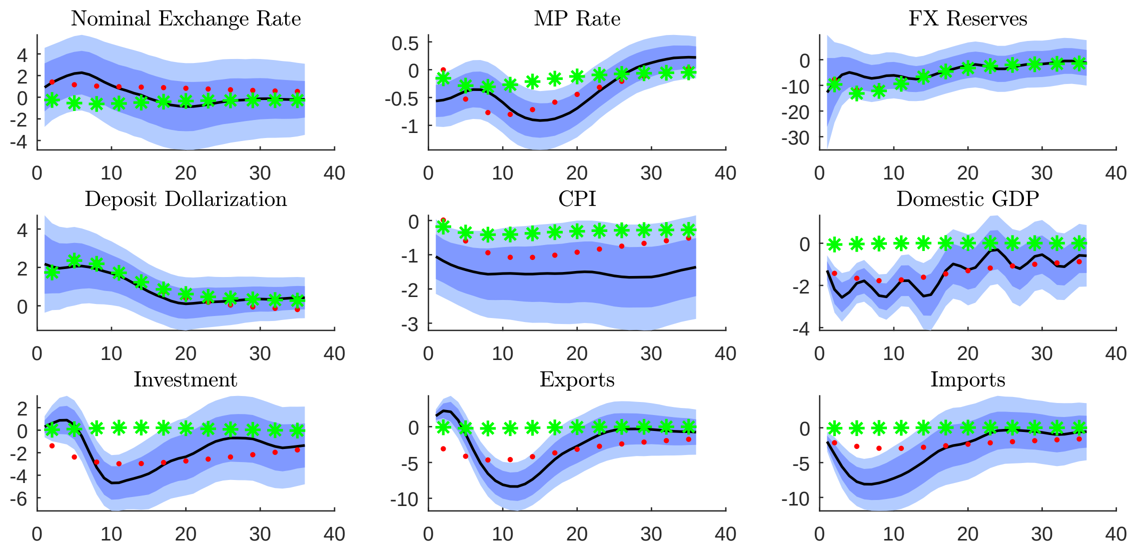
See notes to Figure 7.

5.3 Peru

Table 1 lists estimated parameters for the Peru model. In Figure 10, the dark solid line indicates the mean estimated responses from the VAR analysis, and the shaded areas represent 68 and 90 percent probability intervals. The dots correspond to the impulse responses in the estimated model. The match between model impulses and data impulses is reasonably good. The rise in R_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_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_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 known for its transparent and active FX intervention policy (Castillo and Medina (2021); Castillo et al. (2019)). Using our model, we run several counterfactual experiments to quantitatively evaluate the effectiveness of FX interventions. Figure 11 plots the impulse responses of our estimated model ('Benchmark') and a version of the model ('No Intervention') in which the central bank does not do FX intervention ($\theta^{R^*} = 0$ in equation (25)). FX intervention moderates the exchange rate depreciation (see Panel 1,3) and the resulting small reduction in inflation (Panel 3,1) leads the CB to reduce the interest rate by a small amount. The impacts of the FX intervention on GDP and Consumption are virtual nil (Panels 3,2 and 3,3).

We display additional variables in Figure 11 which illustrate how an FX operation works in the economy. The 2,1 panel shows that the FX operation reduces the Central Bank's holdings of reserves, F_t^*, by around 10% in the first year, relative to the No Intervention alternative. The intervention is sterilized, so that the central bank uses the proceeds of the sale in F_t^* to purchase local currency, and use that to purchase LCU domestic government debt.[29] The domestic households partially take the opposite position. In particular, they buy some of the dollar assets in exchange for the domestic government debt sold by the Central Bank. Panel 4,2 in the figure shows

[29] The model has lump sum taxes so the quantity of government debt *per se* in the economy is not important.

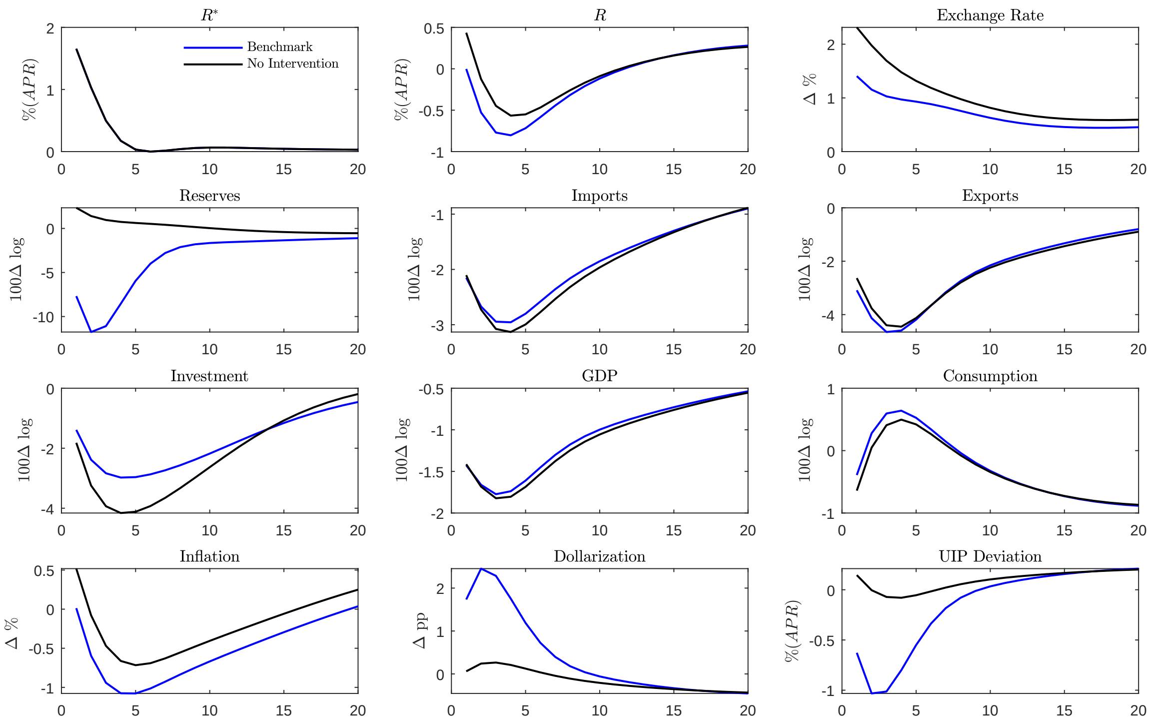
that deposit dollarization, Θ_t in equation (6), rises substantially. If γ, the weight on the household's deposit dollarization target, were 0, then the households would fully take the opposite position relative to the government. This is because the central bank transfers gains and losses on its FX portfolio in lump sum form to the household, so it does not care about the currency composition of the financial assets in its own possession. When $\gamma > 0$ the household cares specifically about the share of dollars in its personal portfolio and so it does not completely undo the central bank's intervention. In this case, when the central bank sells dollars, the combination of the household and central bank sell dollars on net.[30] This is one way to understand why the exchange appreciates with an FX intervention. The relative exchange appreciation roughly eliminates the decline in investment (see panel 3,1) because it reduces entrepreneurs' capital losses due to exchange rate depreciation (see discussion in Section 25).

Note that the appreciation associated with the FX intervention (blue line) stimulates exports, though by a very small amount (panel 2,3) because export prices are sticky in dollars in the model. Imports go up slightly more than exports.

Finally, note the variable, 'UIP deviation', which corresponds to Λ_t in equation (8). In panel 4,3, we see that with FX intervention (blue line) the non-pecuniary return to holding dollars, Λ_t, turns negative. This reflects the fact (see the 4,1 panel) that when the government sells dollar assets, households buy them. They are induced to do so because $R_{d,t}$ is lower (see panel 1,2) due to the lower level of inflation associated with the smaller depreciation.

[30]See Bayoumi et al. (2015), who argue that when a central bank sells one 100 dollars of assets, the sum of households and the central bank sell an amount of dollars in the range of 24 to 42.

Figure 11: FX Interventions in Peru

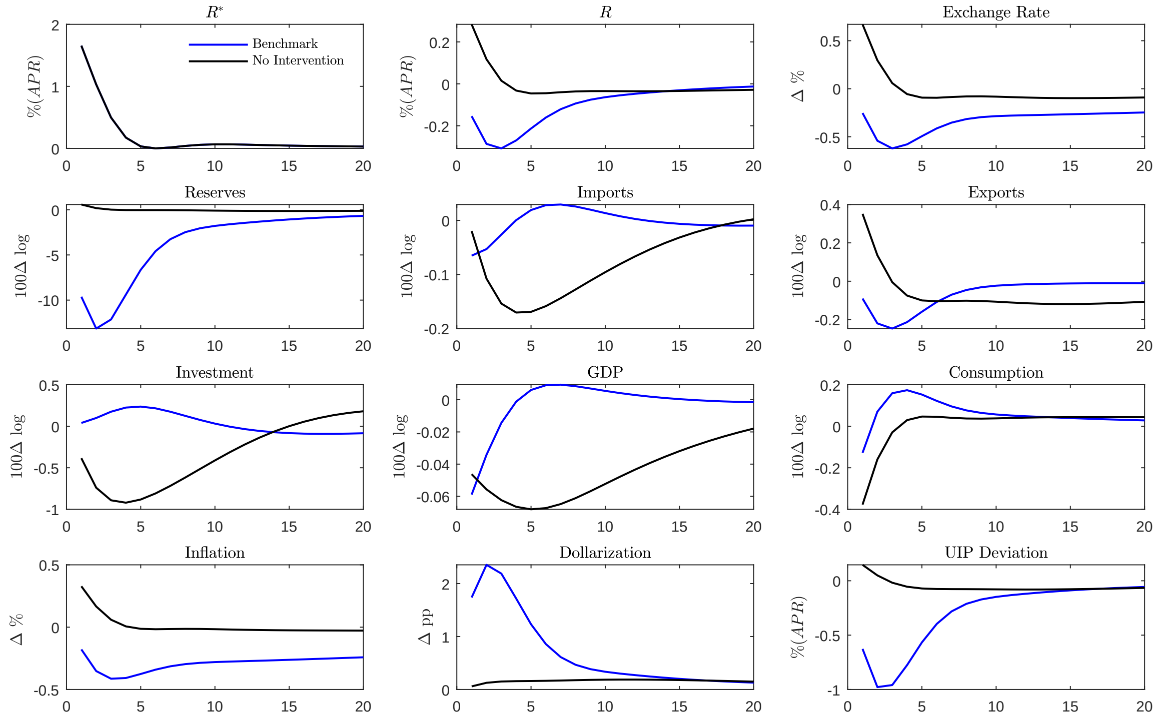


5.3.2 The Role of FX Interventions after a Pure Rise in R^*

We now consider the impact of a monetary tightening on Peru, when the import demand and foreign prices are held constant. The previous subsection suggested that FX intervention has little effect after a US monetary tightening. We now consider the role of FX intervention in response to a pure rise in R_t^*. The results are reported in Figure 12. The 'Benchmark' responses correspond to the response of the estimated model to a pure interest rate shock and correspond to the starred lines in Figure 10. The 'No intervention' responses correspond to what would happen in response to a pure R_t^* shock when the central bank does not do FX intervention.

The economics of the FX intervention corresponds to the discussion above. The key thing to note is that the interventions do smooth out GDP after a few periods. They also smooth the response of consumption and investment. At the same time, there is little to smooth here (note the scale on the axes).

Figure 12: Pure Interest Rate Shock, with and without FX Interventions



5.3.3 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 (6)). Figure 13 plots the effectiveness of FX interventions against a positive shock to households' target share of dollars, Υ_t, in its portfolio. The shock drives the target from its steady state value, $\Theta = 0.4$, to 0.42, so the shock to e_t^{Υ} is 0.02. We compare an economy without FX interventions with an economy which FX interventions respond to the noise trading shock. We replace the FX intervention rule, equation (25), with

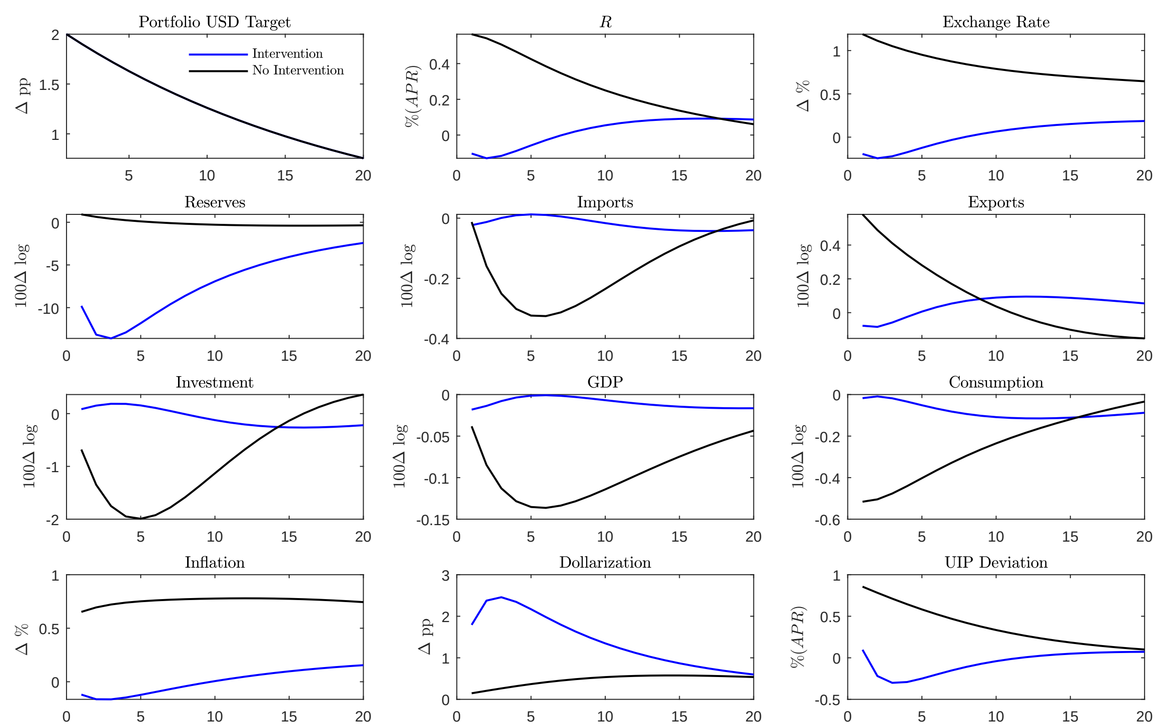
$$\frac{F_t^*}{\overline{F}_t^*} = \left(\frac{F_{t-1}^*}{\overline{F}_{t-1}^*}\right)^{\rho_{fx}} \left(\frac{\Upsilon_t}{\Upsilon}\right)^{-\theta_{\Upsilon}},$$

and $\theta_{\Upsilon} = 3$. The autocorellation of the e_t^{Υ} is 0.95. The 1,1 panel in Figure 13 displays $100\left(\Upsilon_t - \Upsilon\right)$. The 4,1 panel in Figure 13 reports $100(\Theta_t - \Theta)$. In the absence of intervention 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 leads them to cut back on investment. The cut back is a substantial 2 percent. The depreciation also drives up inflation (panel 4,1), so that the monetary authority raises the interest rate (1,2). This is why the rise in Θ_t is smaller than the rise in the target and why Λ_t turns positive (see panel 4,3). The rise in the interest rate, together with the fall in GDP, leads to a fall in consumption.

With the intervention, reserves fall 10 percent (see panel 2,1). Imports fall, both because of the depreciation and the fall in GDP. The depreciation leads to a rise in exports which is muted by the sticky in dollars export prices.

Now consider the effects of FX intervention. Roughly speaking, the FX intervention gives households the dollars that they want. Note that Λ_t remains close to zero. As a result, the economy is roughly insulated from the noise shock. So, FX intervention seems to can be effective at handling shocks to the demand for dollars.

Figure 13: UIP Shocks

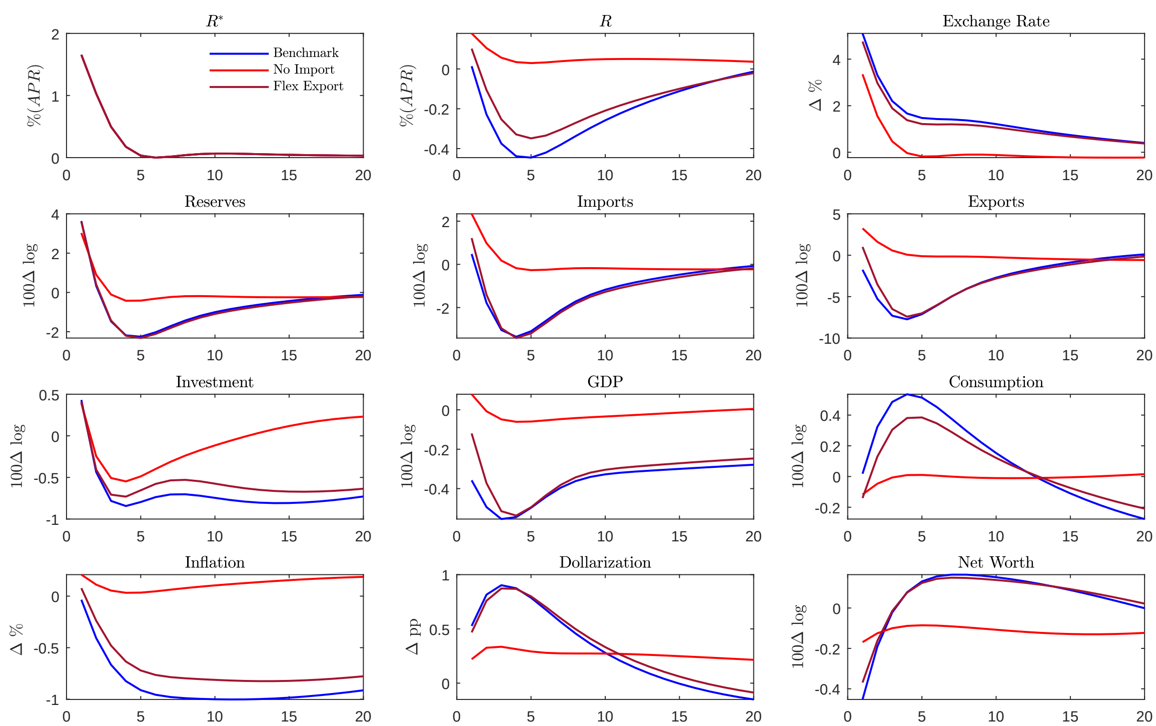


5.4 The Importance of the Trade Channel

The following three figures illustrate how important the trade channel is. For each of the AE, EME and Peru models, we display impulse responses 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 $\phi = 1$, so that entrepreneurs do not borrow in dollars. In this case, the balance sheet effects are practically 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 1). 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 (12) and (13)). This is the case in which the trade channel is essentially shut down.[31] Finally, we consider the case, 'Flex Export', which corresponds to $\theta_x = 0$, i.e, dollar prices in the export sector are set flexibly.

Consider the results for the AE model in Figure 14. 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.

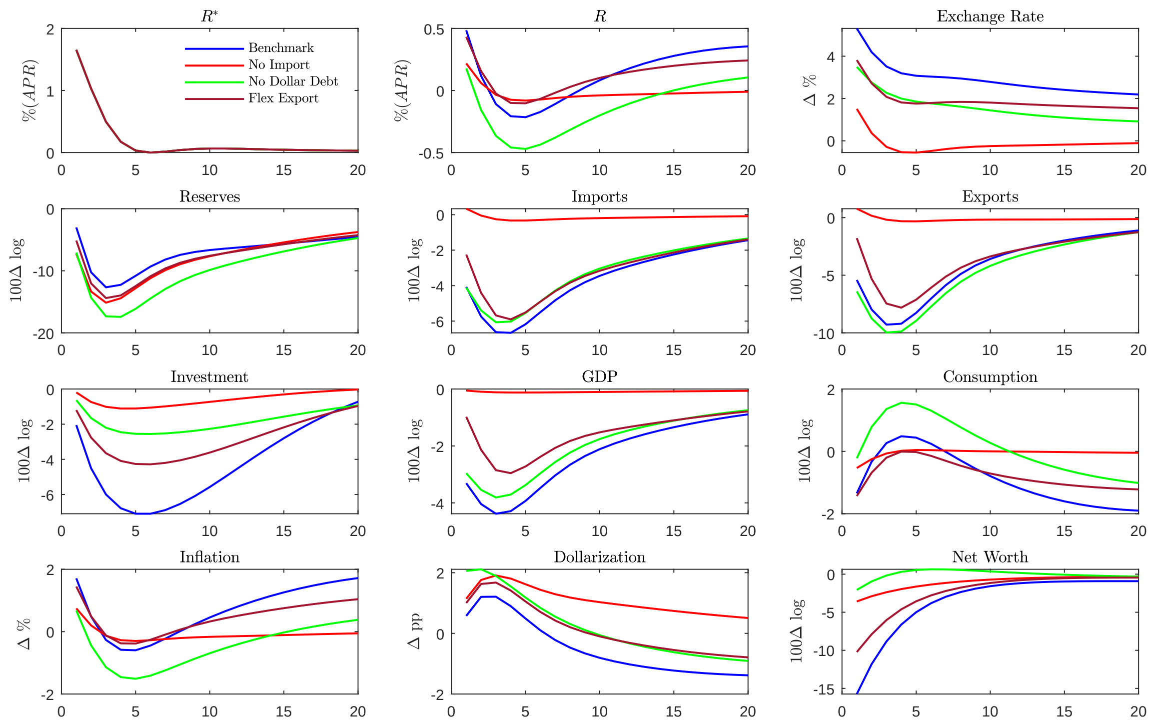
Figure 14: AE: Baseline and Baseline Without Two Features



[31] 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.

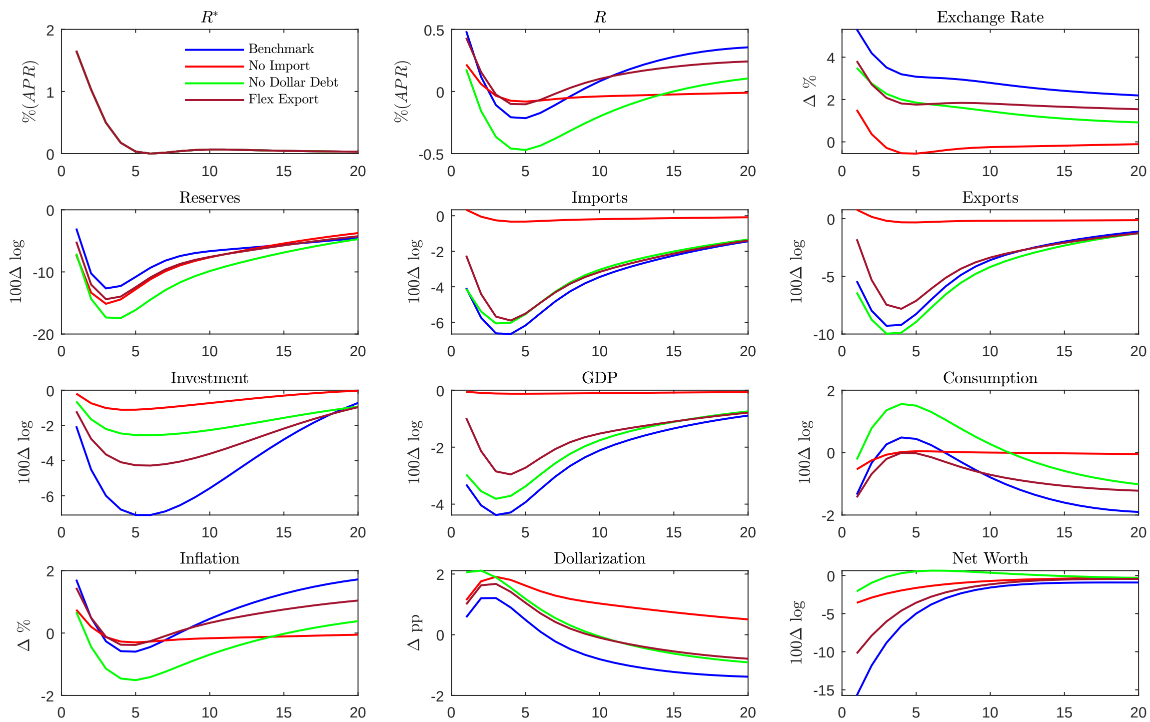
Now consider the EME's in which ϕ is estimated to be in a neighborhood of $1/2$. In this case, the depreciation triggered a rise in R^* inflicts capital losses on dollar-indebted entrepreneurs. This shows up in the form of a substantial, protracted fall in their net worth (see panel 4,3). When the balance 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 15: 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 16: Peru: Baseline and Baseline Without Three Features



6 Conclusion

Using impulse responses functions (IRFs) from VAR analysis, we document that non-US countries contract after a US monetary tightening. Also, EMEs contract more than AEs do. In fact, the contraction in EME output is at least as big, if not more so, as the contraction in US output. By performing counterfactual experiments on non-US small open economies fit to the IRFs, we find that a key channel by which non-US economies contract operates through a fall in US imports, what is referred to as the trade channel by Ozhan (2020). 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.

Our analysis suggests a perspective on the international transmission of US monetary policy in which greater weight is placed on trade. Financial considerations remain important, but the role of trade may be underestimated.

Actually, the findings on the importance of the trade channel may shed light on an intriguing puzzle. Starting in 2022 the US has raised the federal funds rate by an amount that is unprecedented in the past 30 years. Although EMEs typically experience a slowdown, or even crisis, when the US raises rates, no such slowdown has occurred (yet) in response to the recent US rate hike. According to our analysis this observation can at least in part be explained by the fact that the rate hike did not produce a contraction in the US economy or in US imports.[32] So, the answer to the missing contraction puzzle in the EMEs may lie in the answer to the puzzle of why the US economy itself appears not to have slowed down in response to the recent US rate hikes. The latter puzzle is beyond the scope of this paper.

[32]In fact, real imports declined somewhat between Q2 2022 and Q2 2023. But, the peak appears to be related to Covid because after Q2 2023 real imports appear to be on their pre-Covid trend line. These data were obtained from the online database, FRED, produced by the Federal Reserve Bank of St. Louis. The mnemonic of the variable we looked at is IMPGSC1.

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A Robustness Treatment of US Data in Panel VARs

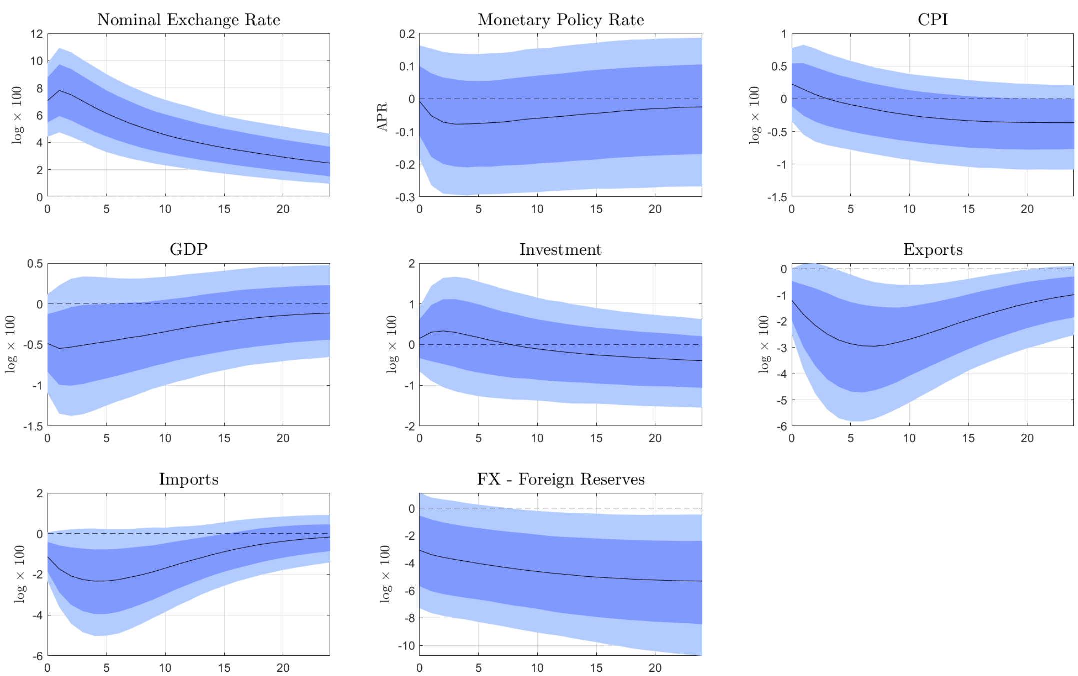
Here, we report the results of two robustness checks on the results reported in Figures 3 and 4.

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

We reestimate impulse response functions using a version of country-level equation (3) 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 (5)) 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 impulse responses for US data, so none are presented.

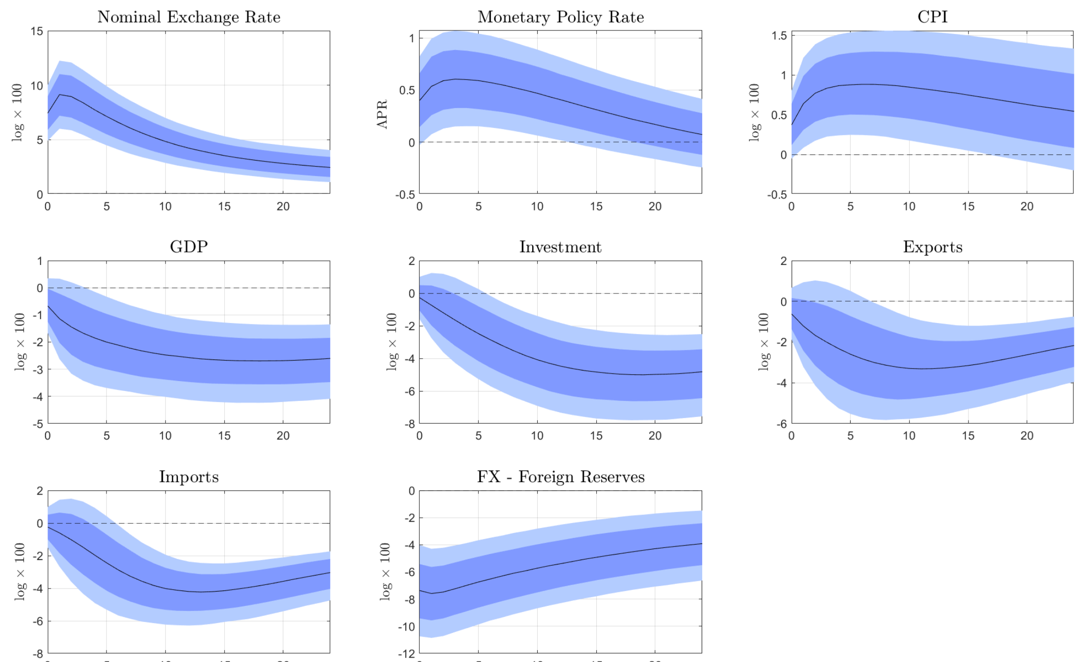
We redo the estimation of the perturbed version of equation (5) for AEs and EMEs. The resulting impulse responses are reported in Figures 17 and 18, respectively.

Figure 17: Response to Contractionary US Monetary Policy Shock, Advanced Economies



Note: Impulse responses 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 impulse responses in US variables, unlike in Figure 3.

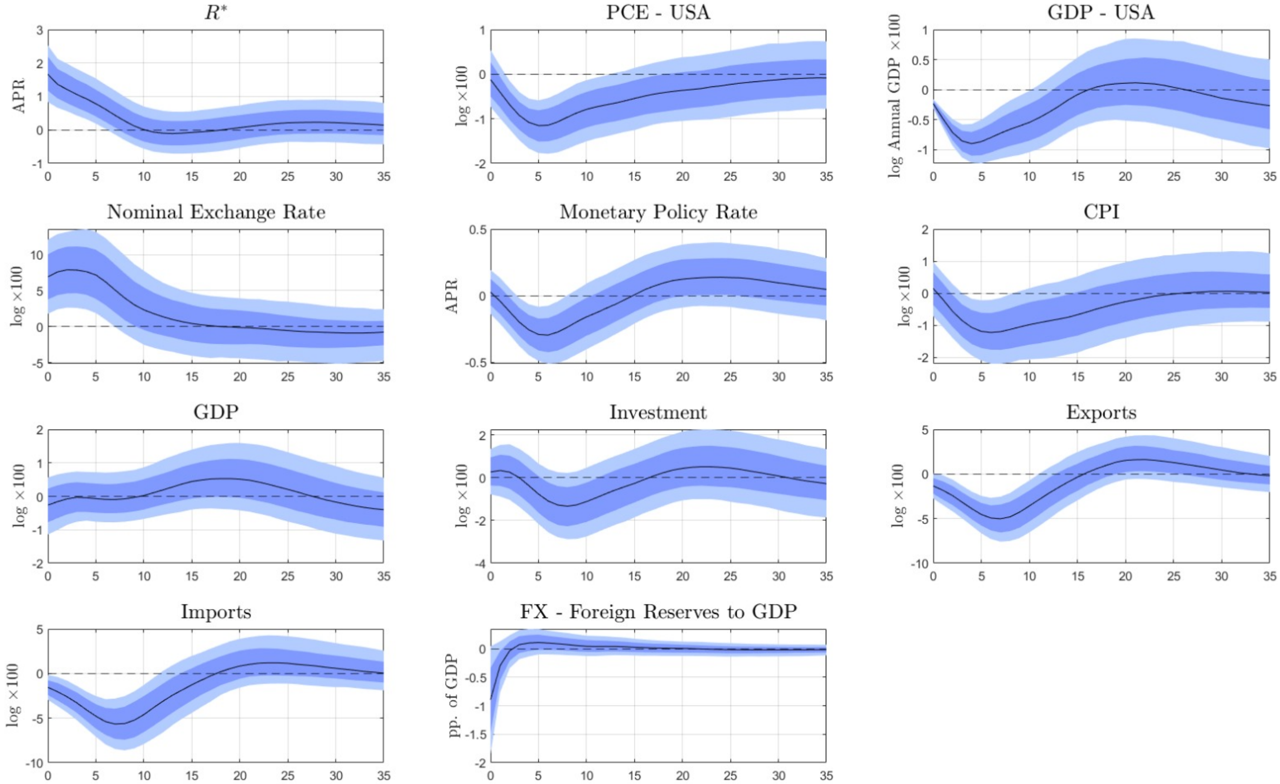
Figure 18: Response to Contractionary US Monetary Policy Shock, Emerging Market Economies



Note: Impulse responses are for EMEs. See notes to Figure 17 and text.

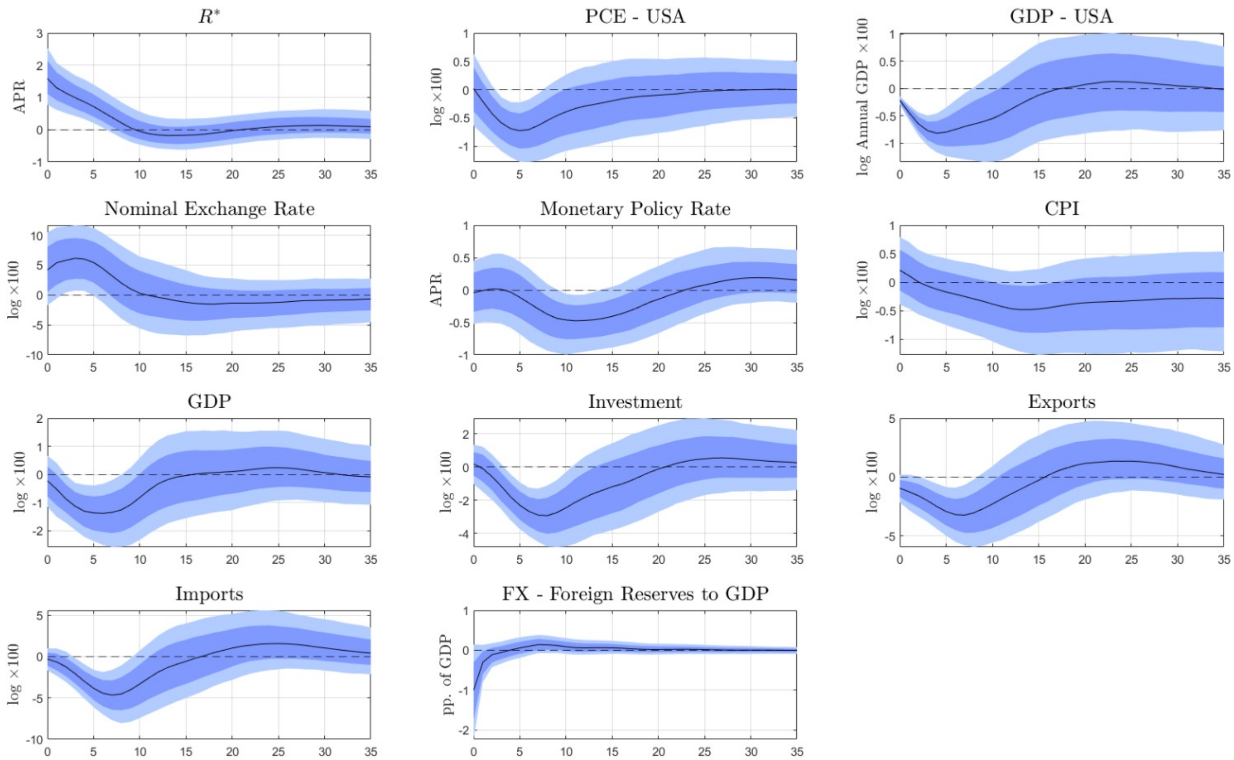
A.2 Panel Regressions Using Cross Country Averages

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



Note: Impulse responses are for AEs.

Figure 20: Response to Contractionary US Monetary Policy Shock, EMEs



Note: Impulse responses are for EMEs.

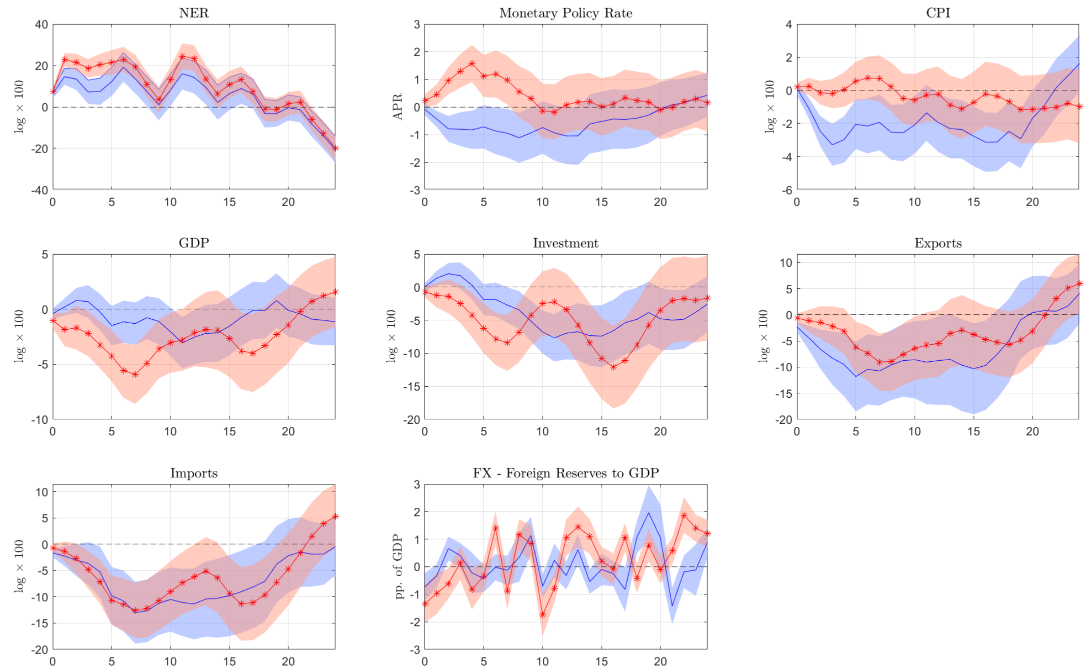
B Robustness of Results to Doing Jorda Regressions

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

$$y_{t+h} = \beta_y^h \varepsilon_t^m + \beta_{y,1}^h \varepsilon_{t-1}^m + \beta_{y,2}^h \varepsilon_{t-2}^m + \sum_y \sum_{j=1}^{2} J_{y,j}^h Y_{t-j} + u_t^{y,h}, \tag{34}$$

for $h = 0, ..., 24$. Here, Y_t denotes the average of $Y_{i,t}$ in equation (4) over all i. Also, y_{t+h} is variable y at lead $t+h$, where y_t denotes one of the variables in Y_t. The first summation in equation (34) adds over all y in Y. The second adds over $j = 1, 2$. Equation (34) corresponds to 25×11 least squares regressions, including the 11 elements of Y. These regressions were performed for AE and EME countries. The values of β_y^h are displayed in Figure 21. 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. Monetary policy is accommodative in the AEs and restrictive in the EMEs. Finally, prices fall more in the AEs than in the EMEs.

Figure 21: Response to Contractionary US Monetary Policy Shock, AEs and EMEs

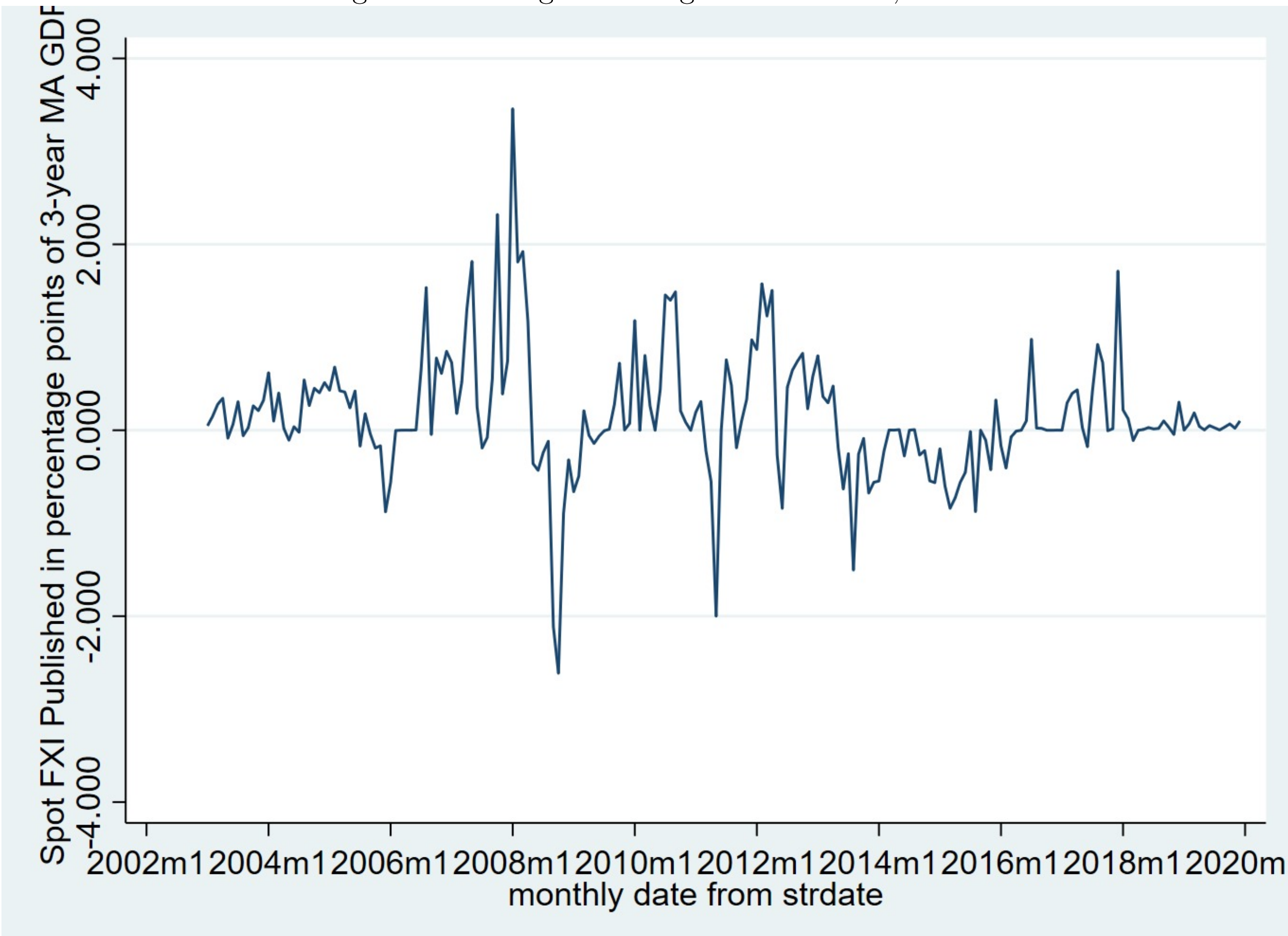


Note: Starred red lines (shaded areas) represent the point estimates of β_y^h (two-standard deviation intervals) corresponding to EMEs. Solid blue lines and shaded ares corresponds to AEs. Standard deviations correspond to Newey-West robust standard errors. See text for further discussion.

C 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 22: 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.