Global Spillover Effects of US Uncertainty[*]

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Abstract

We study spillover effects of fluctuations in US uncertainty. Using monthly panel data from fifteen major emerging market economies (EMEs), we show that an unanticipated rise in US stock market uncertainty has negative effects on their stock prices and exchange rate, increases long-term interest rate spreads, and leads to capital outflows. These negative financial effects transmit to the real economy as a drop in output, a rise in consumer prices, and a rise in net exports from these countries. The negative effects on output, exchange rates, and stock prices are weaker, but the effects on capital flows and trade flows stronger, for South American countries compared to other EMEs. We present a small open economy (SOE) model that can account for our empirical findings. A negative external shock that increases the interest rate spread faced by the SOE produces responses of macroeconomic and financial variables that are consistent with our estimated responses. The model also provides a possible explanation for the heterogeneity in macroeconomic and financial responses across countries based on the differential response of the monetary policy instrument to the increase in interest rate spread.

Keywords: US Uncertainty; Emerging Market Economies; Spillovers; Small Open Economy Model; Panel VAR; Capital Flows; Interest Rate Spread; Monetary Policy Response

JEL Classification: C33; E44; E52; E58; F32; F41

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1 Introduction

What are the international spillover effects of fluctuations in US uncertainty? In particular, given the recent integration of emerging market economies (EMEs) to world financial markets, how does US financial uncertainty transmit to the financial and macroeconomic sectors of these countries? If these spillovers are non-trivial, how can EMEs best cope with them? Specifically, does this cross-border transmission depend on the monetary policy stance of the EMEs?

These issues have gotten increased attention recently. Policy makers in EMEs and professional forecasters often cite fluctuations in US and global uncertainty as a major reason for revising their economic forecasts downward as well as for volatility in capital flows.[1] More importantly, US uncertainty fluctuations could have more serious policy implications for EMEs than those just emanating from simple negative spillover effects on output. For instance, in a recent paper, Rey (2013) highlights how uncertainty fluctuations in US financial markets, as measured by the Chicago Board of Options Exchange (CBOE) VIX index, tend to drive a global financial cycle and thereby, affect global asset prices and financial flows to EMEs significantly. Based on her empirical results, Rey (2013) argues that for EMEs the traditional open-economy policy "trilemma" might have morphed into a "dilemma": these countries cannot have both independent monetary policy and perfect capital mobility, even with flexible exchange rates. They thus might need to use capital controls in order to be able to pursue appropriate monetary policy for domestic stabilization goals. In fact, even the role and effectiveness of traditional monetary policy in EMEs in mitigating macroeconomic and financial impact of fluctuations in US uncertainty is not fully understood.

We contribute to this topic on two main fronts. First, we measure empirically and study theoretically the spillover effects on EMEs of fluctuations in US financial uncertainty. Second, we study, again both empirically and theoretically, heterogeneity across countries in both the transmission of this shock as well as the monetary policy response.[2] Our results provide strong evidence that a rise in uncertainty in US financial markets has substantial financial and macroeconomic spillover effects abroad. Moreover, we find that the nature of monetary policy response by EMEs can affect the transmission of the US uncertainty shock.

Specifically, we estimate a monthly panel VAR for the following important fifteen EMEs: Chile, Colombia, Brazil, India, Indonesia, Malaysia, Mexico, Peru, Philippines, Russia, South Africa, South Korea, Taiwan, Thailand, and Turkey.[3] The panel VAR includes an unanticipated component of US financial market uncer-

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[1] For example, the Bank of Korea has been keeping its policy interest rate low recently in part due to concerns on global financial market volatility :

> [The Monetary Policy Board of the Bank of Korea] ... judges that the possibilities exist of [the global economy] being affected by heightened international financial market volatility due for example to a shift in the US Federal Reserve's monetary policy, and by the weakening of economic growth in emerging market countries. ... in view of external economic conditions judges the uncertainties surrounding the growth path [of the local economy] to be high. (Monetary Policy Decision, December 2015, The Bank of Korea)

As another example, the Governor of South African Reserve Bank in a speech titled "Challenges to South African Monetary Policy in a World of Volatile Capital Flows" mentions:

> Part of the underlying volatility arises from the fact that .. these flows .. have followed changes in global market sentiment. The continued uncertainties in the global economy ... have contributed to periodic bouts of risk aversion, often resulting in a flight to so-called safe havens, despite the fact that the underlying fundamentals in the emerging markets have not changed. The problem ... is one of ... excessively volatile portfolio flows, which respond to the vagaries of global risk aversion. (Address to the Swiss Chamber Southern Africa, May 2012)

[2] We use the CBOE VIX index, which is implied US stock market uncertainty, as the baseline proxy of US financial uncertainty since it is the most widely used indicator in the literature. In an extension, we also use the US financial uncertainty measure estimated by Ludvigson, Ma, and Ng (2015).

[3] We choose these countries following classification of emerging economies by the IMF and Morgan Stanley. We exclude countries that suffered from major economic crises during our sample period, such as Argentina and Venezuela, or are in the Euro zone (and hence might get affected very differently because of monetary policy/exchange rate regime), as well as countries

tainty as a regressor so that the spillover effects on the EMEs of the fluctuations in US financial uncertainty can be traced out. In particular, we take the random coefficient approach to partially pool the cross-sectional information in the data and estimate average effects across EMEs of fluctuations in US uncertainty.

It is estimated that unanticipated changes in US financial market uncertainty have significant financial and macroeconomic effects on the EMEs. An unanticipated increase in US uncertainty, on average, sharply depreciates the local currency of the EMEs, leads to a decline in their local stock markets, increases long-term interest rate spreads (compared to the US), and is followed by capital outflows from them. These effects are statistically and economically significant. Specifically, on average across the EMEs, a 1% increase in US financial uncertainty leads to a 0.0035% point increase in the short-term interest rate, a 0.012% point increase in the long-term interest rate compared to the US, a 0.125% fall in the stock prices, a 0.045% depreciation of the local currency, and a 0.0175% point capital outflows relative to GDP. These are peak effects of US uncertainty fluctuations that occur 2-12 months after the impact. The effects on EME financial markets are uniformly adverse and significant for a time period of 2 years.

Importantly, we find that these financial effects transmit to the macroeconomy as they are accompanied by significant contractionary macroeconomic effects. It is estimated that in response to a 1% increase in US financial market uncertainty, on average, output drops by 0.035% and net exports from these countries to the US rise by about 0.0022% point relative to GDP. Again, these are peak effects, which occur after a delay of 4-8 months. Consumer prices increase persistently and reach about 0.004% higher, 24 months after the impact. These financial and macroeconomic influences on EMEs are potentially large as the standard deviation of unanticipated fluctuations in US uncertainty we estimate is about 14.4%.

The effects on financial variables suggest that a US uncertainty shock triggers a "flight to safety/quality" phenomenon as investors appear to pull capital out of the emerging markets that are perceived to be riskier than the US, thus negatively affecting asset prices such as stock prices and exchange rates, while pushing up their cost of borrowing as country spreads (compared to the US) increase. The increase in net exports and decrease in capital inflows illustrates that one of the channels through which the effects of the US uncertainty shock transmits to these countries is a reduction in spending.[4] Combined with the increase in interest rate spreads faced by these countries, the effects are thus qualitatively similar to a "current account reversal" or a "sudden stop" shock hitting the EMEs. Moreover, consumer prices increase, which illustrates that the US uncertainty shock leads to a major trade-off for central banks of these countries as it leads to output contraction together with an increase in inflation. These effects are thus similar to the effect of a "markup shock" in closed-economy macroeconomic models. In addition, comparing the peak response of exchange rates and consumer prices, the exchange rate pass-through is around 0.1. This illustrates a general phenomenon of "low exchange rate pass-through to prices," which we show conditionally on a specific shock that jointly affects exchange rate and prices.

We also assess the heterogeneity in responses between South American countries and the rest of EMEs by allowing the average effects of the US uncertainty shock to be different across these sub-groups. The negative effects on output are found to be bigger and more persistent for the rest of EMEs compared to South American countries: output drops less than 0.02% in South American countries while it drops more than 0.04% in the rest of EMEs. On the other hand, the estimated effects are bigger and more persistent on capital and trade flows for South American countries compared to the rest of EMEs. The peak effect on capital outflows of a 1% increase in US financial market uncertainty is estimated to be about 0.02% relative

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that are known to manage their exchange rates, such as China.

[4]Using interpolated quarterly data, we also find that both consumption and investment decline in the EMEs following an unanticipated increase in US uncertainty.

to GDP in South America while it is about 0.01% in the rest of the countries. In addition, net exports increase by about 0.004% point relative to GDP at its peak in South American countries but only about 0.001% point in the rest of the emerging countries. Finally, the effects on stock prices and exchange rates are bigger, and especially more persistent, for South American countries. Thus, South American countries suffer less in terms of output and decrease in asset prices but they experience a larger reversal in capital flows and a larger increase in net exports.

Importantly, the short-term (policy) rate of the rest of EMEs does not decrease by more compared to South American countries, even though the countries get affected much more negatively in terms of output (with similar effects in terms of consumer prices). Given such a larger output response, the short-term interest rates of the rest of EMEs can be considered "relatively high" and monetary policy "relatively tight." This can be successful in stemming capital outflows, but comes at the cost of a larger output contraction and larger drops in asset prices.

To help understand our empirical findings and study possible transmission mechanisms, we present a simple two-good small open economy (SOE) model with capital accumulation that features financial and nominal frictions. The model can account qualitatively for our empirical findings: In the model, a negative external shock that increases the interest rate spread faced by the SOE produces responses of macroeconomic and financial variables that are consistent with our estimated responses.[5] In particular, the increase in the country interest rate spread drives output as well as consumption and investment expenditures down. The driving force for these effects is the increased cost of financing consumption and investment due to a rise in the foreign interest rate. Given that the SOE cuts down on expenditure strongly, net exports increase in spite of the reduction in home production. Moreover, a reduction in borrowing from the rest of the world gets reflected in an improvement in the current account.[6]

Our model has two goods and nominal rigidities, which generates additional implications for prices that are also consistent with the empirical evidence. The strong decline in domestic spending leads to an equilibrium depreciation of the exchange rate in our two-good model such that relative price adjustment plays a role in market-clearing for the domestic goods. That is, in equilibrium, the relative price of the home good must decline given the strong reduction in demand. The decline in output, together with a fall in relative prices of the home output implied by the real exchange rate depreciation, leads to a fall in firm profits, and thereby, stock prices.

Next, goods prices increase following this external shock. In particular, in the model, both consumer and home good prices increase. What is the mechanism? Because of nominal rigidities and forward looking behavior of price-setting firms, home goods inflation is determined by the path of (expected future) marginal costs faced by the home firms. Importantly, the relevant marginal cost is in terms of the home good price. Thus, while components of the marginal cost such as real wages and rental rate of capital decline initially given the large drop in macroeconomic aggregates, because of the real exchange rate depreciation, the marginal cost in terms of the home good price actually increases.[7] This then leads to an increase in

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[5] We posit an external shock that increases the (level of) spread faced by the SOE, as it is consistent with our empirical findings. Thus we interpret this shock as capturing the belief of external investors that lending to the SOE is risky (which in the empirical exercise is proxied by VIX). It can also capture some "flight to safety/quality" phenomenon.

[6] These results are the same, qualitatively, as in the one-good SOE model, but as we discuss below and in detail later in the paper, there are some additional effects through the fall in relative price of the home good in our two good model. The extent of nominal rigidities can also affect these dynamics. Moreover, as is to be expected, the cyclicality of current account can depend on the persistence of the external shock. In our model, the current account is countercyclical for a persistent (enough) shock, as is the case in our baseline calibration.

[7] Note that even though the foreign interest rate increases, in equilibrium, because of the large fall in output, the rental rate of capital actually declines for the initial periods. It later however increases above steady-state.

home goods inflation. Given the home bias in aggregate consumption, consumer good prices are influenced strongly by home good prices. This translates into consumer good prices increasing in the model by a very similar amount.

Moreover, the model provides a possible explanation for the heterogeneity in macroeconomic and financial responses across countries depending on the differential endogenous response of the monetary policy instrument to the increase in interest rate spread. We model monetary policy as a Taylor type rule where in addition to the usual endogenous reaction of the home interest rate to inflation and output, the central bank might also respond to the country interest rate spread. This reflects a desire on the part of policy to stem capital outflows.[8] We show that in the case of such a response by central banks, capital flows are less volatile after the shock, but the response of output and asset prices is stronger. This is because such a policy is contractionary for macroeconomic activity, affecting output strongly. This variation in the monetary policy reaction function generates both a larger response of output and a smaller response of the current account, which is qualitatively consistent with the differential response of these variables that we estimate for South American countries versus the rest of EMEs.

Our paper is related to several strands of the literature. We build on the large body of work pioneered by Bloom (2009) that assesses the macroeconomic implications of fluctuations in uncertainty, especially changes in expected volatility in the US stock market, as well as constructs alternate measures of financial uncertainty. Bloom (2014) is a recent survey of important papers in this literature, which have provided evidence for contractionary domestic effects of US uncertainty shock. Rey (2013), which provides evidence for international implications of US uncertainty and constitutes key motivation for our paper, points out the correlation between US stock market volatility, as measured by VIX, and global asset prices and credit flows.

In terms of our empirical methodology, we use a random coefficients Bayesian panel VAR with an external shock approach, which builds on Canova (2007) and Canova and Ciccarelli (2013). We develop a Gibbs sampling algorithm that allows us to estimate a high-dimensional panel VAR while allowing for shocks across the countries to be correlated. This approach allows us to make inference on the average effect, across countries, of the external shock, while allowing for heterogeneous country-specific effects. Our framework also allows for the average effect to be different across sub-groups of countries.

In terms of theoretical modeling, we extend the classic one-good SOE business cycle model with an external financial shock, building on Uribe and Yue (2006) and Neumeyer and Perri (2005).[9] We extend this framework to a two-good setup with nominal rigidities and monetary policy, where external borrowing is in terms of the foreign currency, and solve it non-linearly. The two-good extension allows us to assess implications for the exchange rate while the introduction of nominal price level determination allows for foreign currency debt, which is an important aspect of EME borrowing. Finally, introducing nominal rigidities enables us to consider realistically the dynamics of inflation and the role of monetary policy.

Regarding the focus of the paper, our work is related to papers that assess empirically the effects of US shocks on EMEs. Our empirical work has a similar theme as Canova (2005), which studies transmission of US

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[8] In the past, tracking the foreign interest rate and in particular, conducting "tight monetary policy" to stem large movements in the exchange rate has been termed "fear of floating," of EMEs. Here, our model can be thought of as capturing a "fear of movements in external balance/capital flows" that also features "tight monetary policy."

[9] This same framework is also used in Fernandez-Villaverde et al (2011), which features time-varying volatility in the external shock. Our main focus is on the implications of a first-moment shock to the interest rate spread, but we also in extensions consider a pure second-moment shock to the spread as well as a foreign output/demand shock as other proxies for the US VIX shock. Note that we can consider a foreign demand/output shock because we have a two good open economy model. A pure second-moment shock to the spread faced by the SOE leads to similar effects qualitatively on other variables as the first-moment shock. Since it is a second-moment shock, it however does not increase the spread unlike the case in our empirical results. A negative shock to foreign output/demand does not account for dynamics of several variables, especially net exports and current account as they decrease following such a shock.

shocks to Latin American countries and Mackowiak (2007), which studies the effects of US monetary policy shocks on EMEs. In Bhattarai, Chatterjee, and Park (2016) we study the transmission of US unconventional monetary policy shocks on EMEs.

Even more closely related are Uribe and Yue (2006), who estimate the effects of foreign interest/interest spread shock on EMEs using an empirical VAR model, and Matsumoto (2011), Akinci (2013), and Carriere-Swallow and Cespedes (2013), who study effects of global financial conditions and/or VIX shocks on EMEs. These set of papers show that the macroeconomic effects of these shocks on EMEs are significant.

We contribute to this literature on the empirical front in terms of methodology and scope. Our method, instead of focusing on a single country estimation at a time or estimating fully pooled estimates, uses a partial pooling approach. This enables a joint estimation of an average/overall effect while allowing for heterogeneous effects across countries. We can also estimate average effects using all the countries in the sample as well as those pertaining to sub-groups of countries. This latter aspect of our empirical exercise led us to study how the differential response in short-term policy rate/monetary policy by the EMEs might affect the transmission of the US uncertainty shock.

In terms of the scope of the empirical study, we study the effects on a large number of macroeconomic and financial variables jointly, including consumer prices, several asset prices, and capital flows, for a large number of EMEs. Thus, we build on and extend the important empirical findings of the previous literature. In particular, an inclusion of a comprehensive set of open economy variables such as exchange rates, capital flows, and trade flows as well as relative variables such as long-term country spreads allows us to study particular cross-border effects and transmission of US uncertainty. That is, the differential effects on EMEs relative to the US/world economy can be inferred. For instance, while US uncertainty is known to have contractionary domestic macroeconomic effects and both the previous literature and our results also show evidence for contractionary EME effects, we find that the US/rest of the world actually experience capital inflows and exchange rate appreciation vis-a-vis EMEs. Finally, we also use a theoretical model to interpret these empirical findings, both the aggregate as well as the sub-group ones.

2 Data and empirical methodology

In this section we explain the methodology we adopt as well as the data for empirical analysis. Our empirical study is executed in two steps. We first estimate a VAR for the US economy to extract unanticipated and exogenous fluctuations in uncertainty in US financial markets, which is referred to as a US uncertainty shock. This shock is then included as an external regressor in a panel VAR for the emerging market countries (EM panel VAR) to estimate the spillover effects of the US uncertainty shock on these economies. Both the US VAR and the EM panel VAR are estimated using the Bayesian approach. The details of the Bayesian approach are explained in the Appendix.

2.1 US uncertainty shock

For the US economy, a VAR model

$$y_t = B_1 y_{t-1} + B_2 y_{t-2} + \cdots + B_k y_{t-k} + \varepsilon_t, \tag{1}$$

is used, where y_t is an $m_y \times 1$ vector of endogenous variables and $\varepsilon_t \sim \mathbb{N}\left(0, I_{m_y}\right)$ with $E\left(\varepsilon_t | y_{t-j} : j \geq 1\right) = 0$. The coefficient matrix B_j for $j = 0, \cdots, k$ is an $m_y \times m_y$ matrix. In our baseline specification y_t includes

the following three variables: the CBOE VIX index as a proxy of US financial uncertainty, the industrial production (IP) index as a measure of output, and the consumer price index (CPI) as the price level. A shock to the VIX is estimated, which we refer to as the US uncertainty shock, in (1) after we remove the endogenous influences of lags of output and the price level on uncertainty. In the baseline specification we use six lags. In an extended specification, we consider a VAR with eight variables, similar to Bloom (2009). In another extension, we use the financial uncertainty measure estimated by Ludvigson, Ma, and Ng (2015), instead of VIX.

We can interpret this as a "reduced-form" shock and thus we do not focus on impulse responses functions to this shock for the US economy.[10] Note however that for the purposes of studying the effects of the VIX shock, our reduced-form shock here will be identical to the "structural" one obtained by ordering VIX first in the VAR. We can interpret our shock in that way as well. Different orthogonalization/ordering schemes to identify structural uncertainty shocks are used in the literature, for example in Bloom (2009) and Rey (2013). In an extension, we show that even if we orthogonalize the shock with a particular ordering, it is quite similar to the one we use in our baseline analysis. That is, the reduced-form and identified shocks are essentially the same in our baseline specification of the three-variable VAR for the US economy (1). Moreover, in an extension where we use the same variables as in Bloom (2009), we use the particular ordering of Bloom (2009) where VIX is ordered second after stock prices, and use those identified uncertainty shocks in our empirical analysis of spillover effects on emerging markets.

Note that our approach of extracting unanticipated movements in VIX is different from the baseline approach of Bloom (2009). Bloom (2009) uses only very large movements in VIX that are associated with major political and economic events.[11] We choose to use unanticipated fluctuations of the VIX index as our measure of the uncertainty shock mainly because of the concern on the relatively short sample period in the EM panel VAR.[12] As we show later, in our sample period, about four major fluctuations in the VIX shock are identified: in periods of the 9/11 attack in 2001, the financial crisis in 2008-2009, and two European debt crisis events. The last three major events in our sample are associated with the US financial crisis and the European debt crisis. If we were to follow Bloom (2009), our analysis would be more closer to a case/narrative study on spillover effects of financial/debt crisis in advanced economies rather than estimating the effects of general uncertainty fluctuations. In fact we include dummy variables for these four events in the EME panel VAR and so essentially exclude them in estimation. Thus, we actually take a conservative approach in estimating the international spillover effects of US uncertainty shocks. If these four events are not excluded, the effects on the EMEs will be larger in general.

2.2 EM panel VAR

We now present in detail the baseline specification of an EM panel VAR model in which the spillover effects of the US uncertainty shock on the EM countries are estimated. We then describe its various extensions.

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[10] Our goal here is simply to compute an unanticipated component of the uncertainty measure, in particular by removing predictability coming from macroeconomic variables, which can then be used in the EM panel VAR as an external shock.

[11] This approach is also followed by Carriere-Swallow and Cespedes (2013).

[12] Bloom (2009) considers HP-filtered VIX index in a robustness exercise, which generates similar results to the baseline approach of his. Our method is closer to this approach in Bloom (2009). Gourio et al (2013) is another paper using this latter approach, where they construct a measure of realized volatility using point-wise averages of several advanced economy volatility measures, and then use that series in a VAR.

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2.2.1 Baseline specification

After extracting the surprise component in US financial uncertainty from the US VAR (1), we assess its spillover effects on the EMEs by including it in a system of equations for their economies. Suppose that our sample includes N countries indexed by $i = 1, 2, \cdots, N$. The dynamics of endogenous variables for country i are then represented as

$$z_{i,t} = \sum_{j=1}^{p} B_{i,j} z_{i,t-j} + \sum_{j=0}^{q} D_{i,j} \varepsilon_{VIX,t-j} + C_i x_t + u_{i,t}, \tag{2}$$

where $z_{i,t}$ is an $m_z \times 1$ vector of endogenous variables for country i, $\varepsilon_{VIX,t}$ is the median of the US uncertainty shock estimated in the US VAR, x_t is an $m_x \times 1$ vector of exogenous variables including a constant term, dummy variables, and some world variables that are common across countries, and u_t is an $m_z \times 1$ vector of the disturbance terms.[13] The coefficient matrix $B_{i,j}$ for $j = 1, \cdots, p$ is an $m_z \times m_z$ matrix, $D_{i,j}$ for $j = 0, \cdots, q$ is an $m_z \times 1$ vector, and C_i is an $m_z \times m_x$ matrix. It is assumed that for $\mathbf{u}_t = \left(u'_{1,t}, \cdots, u'_{N,t}\right)'$,

$$\mathbf{u}_t | \mathbf{z}_{t-1}, \cdots, \mathbf{z}_{t-p}, \varepsilon_{VIX,t}, \cdots, \varepsilon_{VIX,t-q}, x_t \sim \mathbb{N}\left(\mathbf{0}_{Nm_z \times 1}, \mathbf{\Sigma}\right), \tag{3}$$

where $\mathbf{z}_t = \left(z'_{1,t}, \cdots, z'_{N,t}\right)'$, $\mathbf{0}_{Nm_z \times 1}$ is an $Nm_z \times 1$ vector of zeros, and $\mathbf{\Sigma}$ is an $Nm_z \times Nm_z$ positive definite matrix.

In our baseline specification, $z_{i,t}$ includes five financial variables and three macroeconomic variables. Moreover, we use three lags (both $p=q=3$). In particular, we use short-term (policy) interest rates, long-term interest rate spreads of country i with respect to the 10-year Treasury yield in the US, the aggregate stock price, the nominal effective exchange rate of the local currency, capital inflows to country i, industrial production as output, CPI as consumer prices, and net exports to the US. These constitute a core set of financial and macroeconomic variable for a small open economy. Note that we include the short-term (policy) rate to control for monetary policy reaction by these countries, which helps us determine the dynamics of the macroeconomic variables here. Later we theoretically consider how the transmission of the shock can depend on the monetary policy reaction by the EMEs.

Some of the EMEs in our sample are commodity exporters. As commodity exports and prices can potentially affect the business cycles of those countries, a proxy of the world demand for commodities and a price index of commodities are included in the vector of exogenous variables x_t as control variables. In addition, we control for the world demand proxied by overall industrial production of the OECD countries. Dummy variables to control for the effect of the European debt crisis (May 2010 and February and August 2011) are also included in x_t. In particular, (3) implies that these variables in x_t are assumed exogenous in the system. This is because the EMEs in our sample can be plausibly considered as a small open economy. It is however likely that there are some other common factors that drive the business cycles of these countries. No restrictions on $\mathbf{\Sigma}$ in (3) except that it is positive definite are imposed so that the disturbance terms

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[13]We note that since we use the median of the US uncertainty shock estimated in the US VAR and its lags as regressors in (2), our estimation of its effects is subject to the so-called generated regressor problem. As we show in Section 3, however, the US uncertainty shock is very tightly estimated and thus the uncertainty around the estimates of the shock is not big, which suggests that the generated regressor problem is not very severe. Ideally, we can estimate the effect of the US uncertainty shock in a panel VAR that includes both the US and the EM countries with a block exclusion restriction that the EM countries do not influence the US economy at all, adopting the small open economy benchmark for these EM economies. We prefer our two-step estimation because of the computational burden to estimate a large panel VAR model for both the US economy and the EM countries, which makes it practically difficult to estimate various alternative specifications and do robustness exercises. As another check on this issue, we also use the growth rate of VIX as a measure of US uncertainty shock in the EME panel VAR.

$u_{i,t}$'s are freely correlated across the EM countries and could capture potential effects of the other common factors.

Note that the coefficient matrices in (2) are allowed to be different across the individual EMEs. We allow for such dynamic heterogeneities since the economies in our sample are almost certainly not homogeneous. However, they are small open economies and thus their economies are likely to be affected in a similar way by common shocks. To account for potential common dynamics, and especially common effects of the US uncertainty shock, we take the random coefficient approach and assume that the distribution of the coefficient matrices in (2) are centered around the common mean. This approach also allows us to partially pool the cross-country information and obtain the pooled estimator of the effects of the US uncertainty shock on the EMEs.

Specifically, the random coefficient approach is undertaken following Canova (2007) and Canova and Ciccarelli (2013). Let us collect the coefficient matrices in (2) as $B_i = \left(\begin{array}{ccc} B_{i,1} & \cdots & B_{i,p} \end{array} \right)'$ and $D_i = \left(\begin{array}{ccc} D_{i,0} & \cdots & D_{i,q} \end{array} \right)'$ and let $\gamma_i = \mathrm{vec} \left(\begin{array}{ccc} B_i' & D_i' & C_i \end{array} \right)'$. Note that the size of γ_i is given as $m_\gamma = m_z m_w$ where $m_w = p m_z + (q+1) + m_x$ is the number of regressors in each equation. It is assumed that for $i = 1, \cdots, N$,

$$\gamma_i = \bar{\gamma} + v_i, \tag{4}$$

where $v_i \sim \mathbb{N} \left(\mathbf{0}_{m_\gamma \times 1}, \Sigma_i \otimes \underline{\Sigma}_i \right)$ with $\mathbf{0}_{m_\gamma \times 1}$ an $m_\gamma \times 1$ vector of zeros, Σ_i an $m_z \times m_z$ matrix that is the i-th block on the diagonal of $\mathbf{\Sigma}$, $\underline{\Sigma}_i$ an $m_w \times m_w$ positive definite matrix, and $E \left(v_i v_j' \right) = \mathbf{0}_{m_\gamma \times m_\gamma}$ for $i \neq j$. The common mean $\bar{\gamma}$ in (4) turns out to be the weighted average of the country-specific coefficients γ_i with their variances as weights in the posterior distribution conditional on γ_i's. For a particular value of $\bar{\gamma}$, the pooled estimates of the dynamics effects of the uncertainty shock $\varepsilon_{VIX,t}$ can be computed by tracing out the responses of $z_{i,t}$ to an increase in $\varepsilon_{VIX,t}$ over time with γ_i replaced by $\bar{\gamma}$.

2.2.2 Heterogeneities across subgroups of countries

In order to assess heterogeneities across subgroups of the EM countries, we also estimate the differential effects of the US uncertainty shock across two groups of the EMEs in our sample. Our baseline subgroup estimation consists of South American countries in one group and the rest of the EMEs in another. This choice is motivated by the close connections and linkages between the US and South American countries, as well as the existence of previous work that focuses on these countries, such as Canova (2005).

Specifically, the mean of the coefficients, $\bar{\gamma}$ in (4), is now different between two groups of the EMEs, denoted group 1 and 2. So the assumption for the random coefficient approach (4) is modified as follows: For $i = 1, \cdots, N$,

$$\gamma_i = \bar{\gamma}_1 \times I_1(i) + \bar{\gamma}_2 \times [1 - I_1(i)] + v_i, \tag{5}$$

where $I_1(i)$ is an indicator function that takes on 1 if country i is in group 1 and 0 otherwise, $v_i \sim \mathbb{N} \left(\mathbf{0}_{m_\gamma \times 1}, \Sigma_i \otimes \underline{\Sigma}_i \right)$. By comparing the impulse responses to the US uncertainty shock across these two groups, using $\bar{\gamma}_1$ and $\bar{\gamma}_2$, respectively, one can study whether these two groups were differentially sensitive to the US uncertainty shock. Note that, even with the heterogeneity in the mean of the coefficients, equations (2) of all the EMEs are jointly estimated with the disturbance terms $u_{i,t}$'s still correlated across all the EMEs.

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2.2.3 Alternate specifications

After estimating the baseline specification, we consider some alternate variables which will be useful to assess robustness of our results as well as relate to our theoretical model results. Due to the computational burden and sample size issues, we continue to use the baseline specification for the EM panel VAR that includes eight variables but replace one variable of the baseline specification with a new one. First, we consider different measures of economic activity. In the baseline specification, IP is included as a measure of economic activity, as it is the usual choice with monthly data. To assess the results based on a broader measure of activity as well as to help guide the theoretical results on measures of spending, we consider data on GDP, consumption, and investment, one variable at a time. Their quarterly observations are interpolated to get the monthly observations. Next, we use several alternate financial and open economy variables. In particular, we replace long-term interest rate spreads with a measure of long-term real interest rate spreads.[14] For open economy variables, we first replace the nominal effective exchange rate with the real effective exchange rate. We then use several alternate measures of external balance of the emerging market economies. We replace our baseline measure of net exports, which was to the US, with net exports to the rest of the world as well as net foreign asset position with the US. We then also use several capital inflow measures from the US, compared with our baseline measure which in principle also incorporates capital inflows from other countries. In particular, we use cumulated net foreign asset position of the US with these EMEs as well as the cumulated foreign asset position of the US with these EMEs. Table 1 presents all the specifications that we estimate.

2.3 Data

We use US data at the monthly frequency for the period from January 1990 through November 2014. In addition to VIX, IP, and CPI included in the baseline specification, we also use data on an alternate financial uncertainty measure, as well as on a short-term interest rate as a measure of monetary policy, the S&P 500 index, wages, hours, and employment in extended specifications for the US VAR. The data source for most of the US data is the FRED maintained by the St Louis Fed. The financial uncertainty measure is available from Ludvigson, Ma, and Ng (2015). For the period when the zero lower bound is binding, we use the shadow interest rate from Krippner (2016) as a measure of the short-term interest rate. As an alternative to it, we also use the 2-year Treasury yield.

Our sample includes fifteen important EMEs: Brazil, Chile, Colombia, India, Indonesia, Malaysia, Mexico, Peru, Philippines, Russian, South Africa, South Korea, Taiwan, Thailand, and Turkey. Our data for the EMEs is at the monthly frequency for the period from January 2004 through November 2014. We use data on IP, CPI, the trade-weighted effective nominal and real exchange rates, the aggregate stock price, long-term and short-term interest rates, long-term interest rate spreads with respect to the US 10-year Treasury yield, net exports to world and US, and capital inflows from the rest of the world. As an alternate measure of output, we also include data on gross domestic product (GDP), investment, and consumption. Moreover, for alternate external balance measures, we use data provided by Bertaut and Judson (2014), which is based on underlying data from US Treasury (TIC). In particular, from that data set, we use net foreign asset position and capital inflows from the US to the EMEs. Net exports and capital flows are normalized by the relevant nominal GDP. The data sources for the other EM country data include Datastream, Bloomberg, EPFR, BIS, IMF, and OECD.

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[14]While using long-term real interest rates requires us to take a stance on how expected inflation is determined, which is why we use the nominal long-term interest rate spread in our baseline estimation, it is still worthwhile to check this specification as in the theoretical model, the relevant spread increase we will study as a shock will be in real terms.

Table 1: Baseline and alternative specifications of the EM panel VAR

Specifications		Endogenous variables
Baseline		Short-term interest rates, long-term interest rate spreads with respect to the 10-year Treasury yield in the US, the aggregate stock price, the nominal effective exchange rate of the local currency, capital inflows, IP, CPI, and net exports to the US
Alternative		The same as the baseline specification except that
	1	IP is replaced with GDP
	2	IP is replaced with consumption
	3	IP is replaced with investment
	4	Long-term interest rate spread is replaced with long-term real interest rate spread
	5	Nominal effective exchange rate is replaced with real effective exchange rate
	6	Net exports to the US is replaced with net exports to the world
	7	Net exports to the US is replaced with net foreign asset position with the US
	8	Capital inflows from the world is replaced with various capital inflow measures from the US

Notes: For each of the EMEs in the EM panel VAR the endogenous variables listed above, the US uncertainty shock with its lags, a proxy of the world demand for commodities, a price index of commodities, and the European debt crisis dummy variables are included.

A detailed data description is provided in the data Appendix. Lastly, we emphasize that the data is not pre-processed before estimation except that we interpolate quarterly nominal GDP to monthly frequency to construct some ratios relative to GDP, and in an extension, interpolate quarterly real GDP, consumption, and investment into monthly series. The interpolation method is also described in the data Appendix. The variables are used in logs, in levels, or in ratios relative to GDP.

3 Empirical results

We now present our results on the spillover effects of US financial uncertainty on the EMEs. We start with our measure of the US uncertainty shock and then proceed to present the effects on the EMEs.

3.1 US uncertainty shock

Figure 1 presents the posterior median of the estimated US uncertainty shock, along with 90% error bands. For comparison, in Figure 1 we also plot the growth rate of VIX, which is very similar to the shock we estimate. This shows that VIX contains a large unpredictable component. Finally, around some important events that had worldwide effects, such as the US financial and Euro debt crisis events that are marked by vertical lines in the figure, the US uncertainty shock takes quite large values. To ensure that our results are
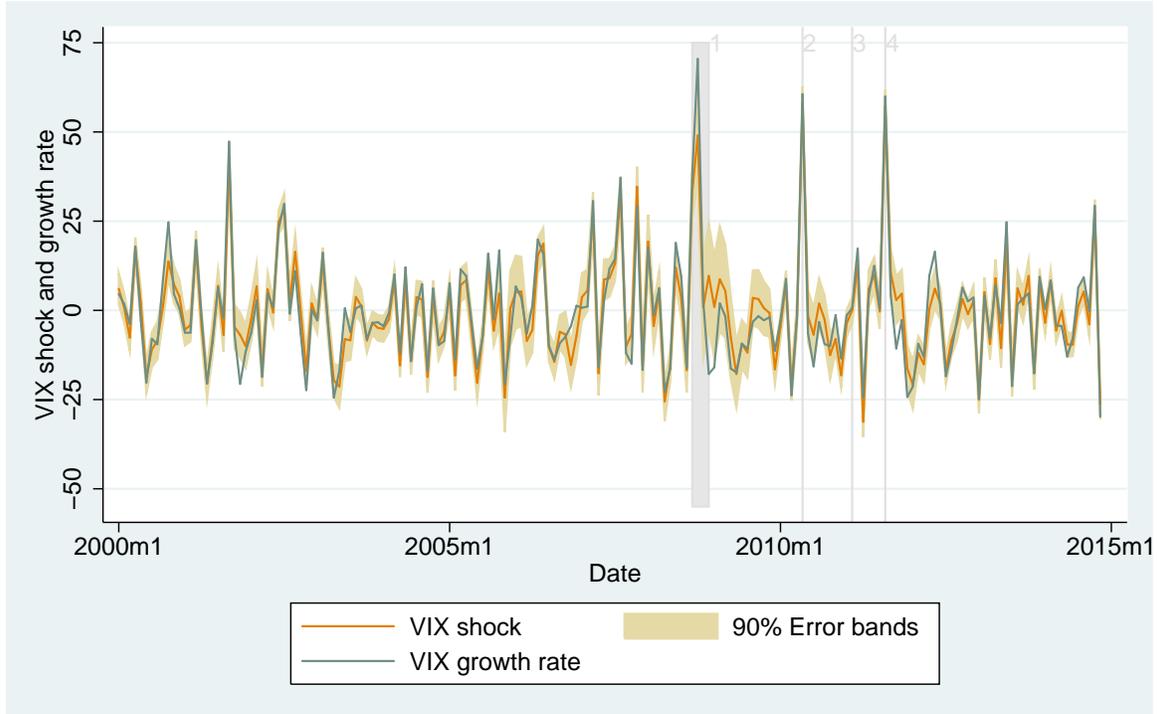
Figure 1: The estimated US uncertainty shock and the growth rate of VIX

Notes: The US uncertainty shock is 100 times the posterior median of the relevant shock in US VAR (1), which is presented together with 90% error bands. The growth rate of VIX is 100 times the first difference of the log of VIX. The vertical lines mark the financial crisis and the three major events of the Euro debt crisis: [1] September 2008 through December 2008, [2] May 2010 when the Eurozone members and the IMF agreed on a large bailout package for Greece, [3] February 2011 when the Eurozone bailout fund, the European Stability Mechanism, was set up, and [4] August 2011 when the European Commission President Jose Manuel Barroso warned that the sovereign debt crisis was spreading beyond the periphery of the Eurozone.

not driven by these outliers, we include dummy variables for these events in the EM panel VAR.

3.2   Spillover effects of the US uncertainty shock

We now estimate the uncertainty shock's spillover effects on the EMEs using a panel VAR where the US uncertainty shock estimated above is an external shock. The impulse responses presented in this section are the average effects of the US uncertainty shock across all the EMEs in the baseline specifications and the average effects among South American countries and the rest of the EMEs, respectively, in the subgroup analysis. The average effects are computed using $\bar{\gamma}$ in (4) for the baseline specification and using $\bar{\gamma}_1$ and $\bar{\gamma}_2$ in (5) for the subgroup analysis.

3.2.1   Benchmark specification

We present results from our baseline specification in Figure 2. We start by describing the results on financial market variables as they provide the first channel of possible transmission to the EMEs. On average, following an increase in US financial uncertainty, short-term interest rates and long-term country spreads (compared to the 10-year Treasury yield in the US) of these countries increase persistently. In addition, stock prices declines and nominal exchange rates depreciate persistently. Finally, capital flows out of these countries.

Specifically, on average across the EMEs, a 1% increase in US financial uncertainty leads to a 0.0035%
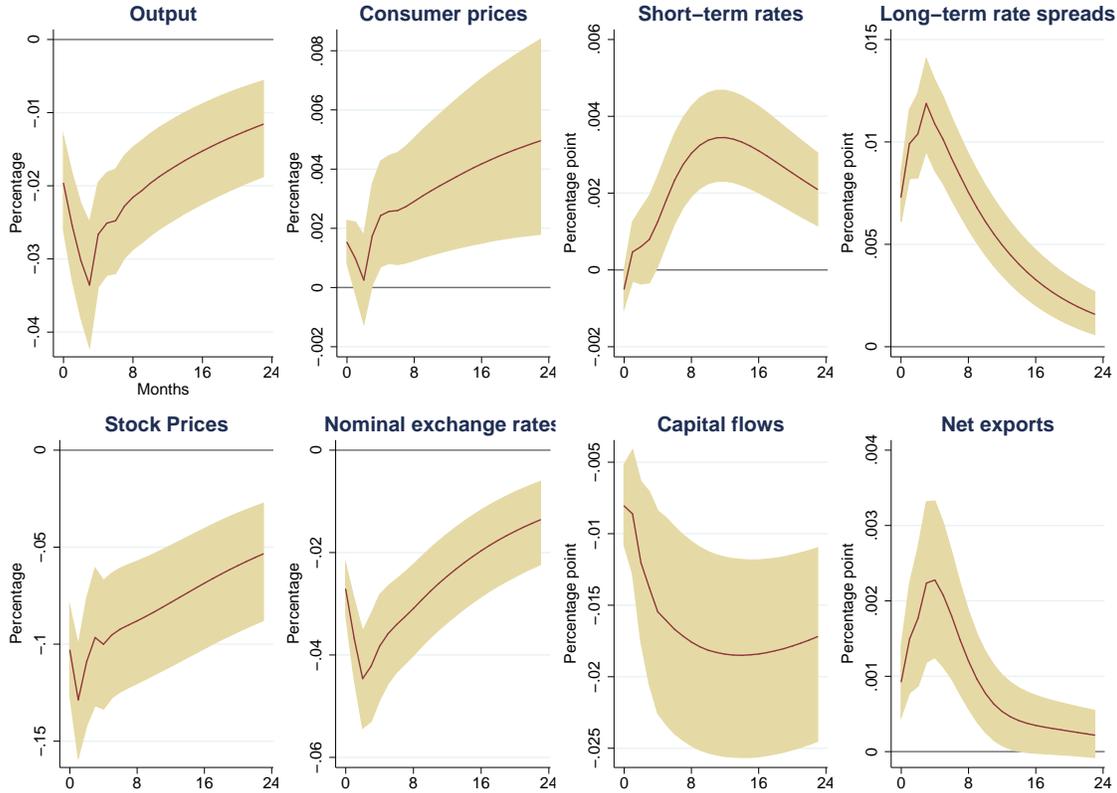
Figure 2: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the baseline specification that includes the both macroeconomic and financial variables. Output is the industrial production and consumer prices are the CPI in each of the EM countries. Net exports are the ratio of the net exports from the EM countries to the US and GDP of the EM countries. The long-term rate spread is the spread between the 10-year Treasury yields in the US and the long-term interest rate in the EM countries. Both US and EM interest rates are nominal. The stock price is the MSCI. The nominal exchange rate is the effective exchange rate of the EM countries so a decrease in the exchange rate implies depreciation of the local currency. The capital flow is the ratio of the cumulative sum of the equity and bond inflows to GDP of the EM countries.

point increase in the short-term interest rate, a 0.012 % point increase in the long-term interest rate compared to the US, a 0.125% fall in the stock prices, a 0.045% depreciation of the local currency, and a 0.0175% point capital outflows relative to GDP. These are peak effects of the US uncertainty fluctuation that occur about 2-12 months after the impact. The effects on EME financial markets are uniformly adverse and significant during the entire time period of 2 years after the initial shock. The effects on financial variables suggest that a US uncertainty shock triggers a "flight to safety/quality" phenomenon as investors appear to pull capital out of these markets that are perceived to be risky compared to the US, thus negatively affecting asset prices such as stock prices and exchange rates, while increasing their cost of borrowing as country spreads (compared to the US) increase.[15]

While the financial market effects are important, we are also interested in assessing the transmission to the real economy. Figure 2 shows that on average, an increase in US uncertainty had significant effects on

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[15]Caballero and Krishnamurthy (2006) is an early theoretical analysis of such a phenomenon for EMEs.

the macroeconomy in addition to the financial market effects. Output of these countries drops while net exports increase. Moreover, consumer prices increase in EMEs. Specifically, we estimate that in response to a 1% increase in US financial market uncertainty, on average, output falls by 0.035% and net exports from these countries to the US rise by about 0.0022% point relative to GDP. Again, these are peak effects, which occur after a delay of 4-8 months. Consumer prices increase persistently and reach about 0.004% higher, 24 months after the impact. These effects on EMEs are economically large as the standard deviation of unanticipated fluctuations in estimated US financial uncertainty is about 14.4%.

The decrease in output thus shows that increases in US financial uncertainty lead to a contractionary effect in EMEs. This is consistent with the concurrent financial market effects such as increases in long-term country spreads and decreases in stock prices. The increase in net exports and decrease in capital inflows illustrates that the effects of the US uncertainty shock transmits through these countries via a reduction in spending.[16] Combined with an increase in the interest rate spread, this is thus similar qualitatively to effects of a "current account reversal" or a "sudden stop" shock faced by these countries.[17]

Finally, consumer prices increase, which we conjecture is due to both the exchange rate depreciation that affects the prices of home goods, as well as, a subsequent import price increase.[18] It illustrates that the US uncertainty shock leads to a major trade-off for central banks of these countries as it leads to output contraction together with an increase in inflation. These effects are thus similar to the effect of a "markup shock" in closed-economy macroeconomic models. In addition, comparing the peak response of exchange rates and consumer prices, the exchange rate pass-through is around 0.1. This illustrates a well-known general phenomenon of "low exchange rate pass-through to prices," which we show conditionally on a specific shock while modeling endogenous dynamics of both exchange rates and prices.[19]

3.2.2 Subgroup analysis

We now present results based on the subgroup analysis where we split the EMEs in our sample into two subgroups: South American countries that include Brazil, Chile, Colombia, Mexico and Peru, and the rest. Figure 3 shows that clear and meaningful heterogeneity is present in responses of both macroeconomic and financial variables. In particular, the negative effects on output, stock prices, and exchange rates are bigger and more persistent for the rest of EMEs compared to South American countries. For instance, the peak effects on output and exchange rates are more than double for the rest of EMEs and for all these variables, the effects are significantly more persistent for the rest of EMEs as well. Specifically, output drops less than 0.2% in South American countries while it drops more than 0.4% in the rest of EMEs.

On the other hand, the effects are bigger and more persistent on capital flows and net exports for South American countries compared to the rest of EMEs. In fact, the peak effects on capital flows and net exports are more than double for South American countries compared to rest of EMEs. The peak effect on capital outflows of a 1 % increase in US financial market uncertainty is estimated to be about 0.002% relative to GDP in South American countries while it is about 0.001% in the rest of the emerging market countries.

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[16]In an extension, using interpolated data, we in fact show that both consumption and investment of EMEs decline in response to a US VIX shock.

[17]Dornbusch, Goldfajn, and Valdes (1995) and Edwards (2004) are well-known empirical treatments of such episodes.

[18]For example, in the theoretical model, a real depreciation contributes to increase in marginal costs in home currency, which in turn lead to an increase in prices of home goods through the usual price-setting channels. Note that in an extension we show that the real effective exchange rate also depreciates for these countries, in a manner very similar to the depreciation here of the nominal effective exchange rate.

[19]These effects can arise in equilibrium models of "pricing-to-market" such as Dornbusch (1987) and Krugman (1987).
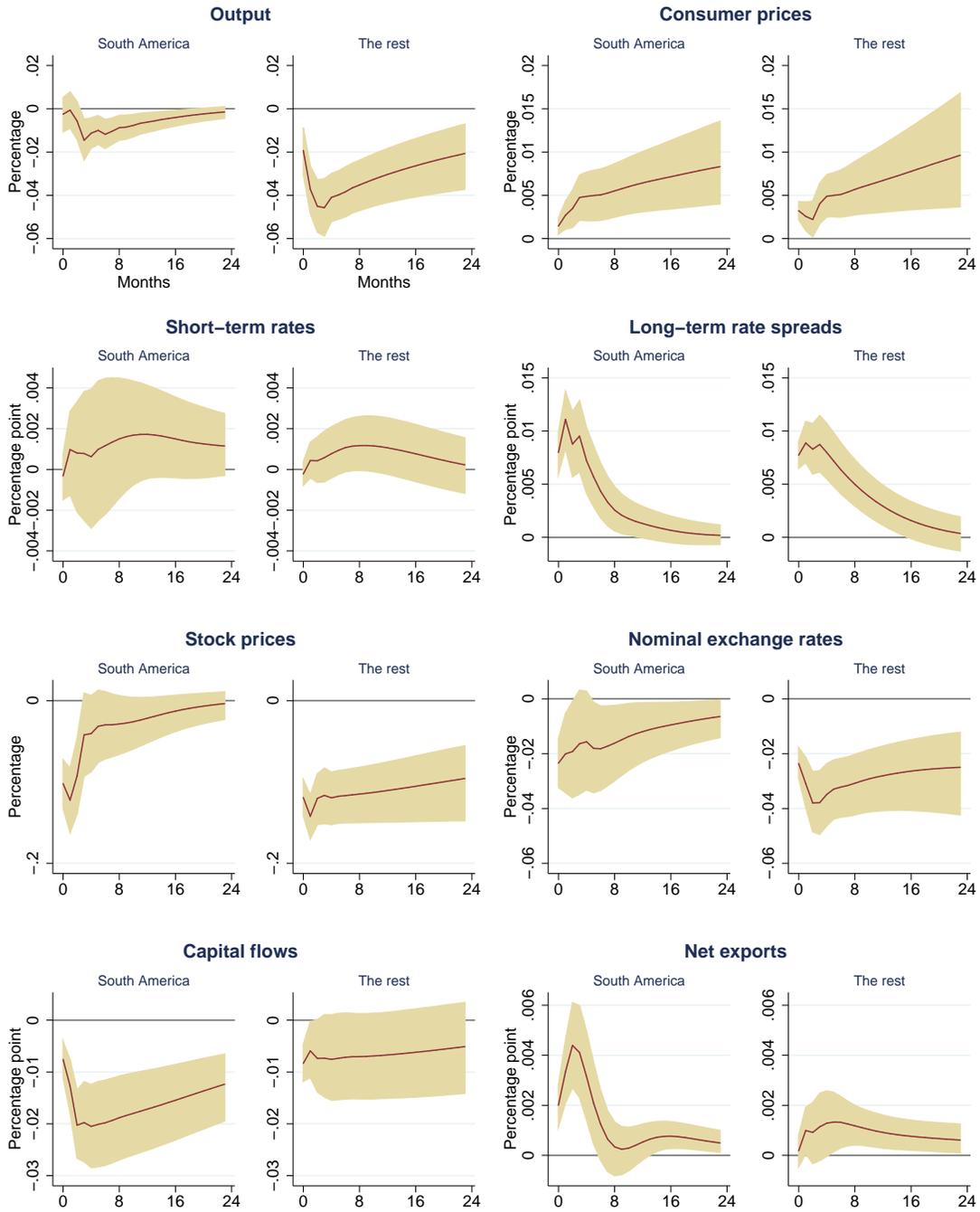
Figure 3: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables; South America vs. the rest

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error bands in the specification for subgroup analysis that includes both the macroeconomic and financial variables. Subplots are arranged by variables and shown for two groups of countries: South America including Brazil, Chile, Colombia, Mexico, Malaysia, and Peru and the rest of the EM economies. See the notes in Figure 2.

Also, net exports increases by about 0.004% point relative to GDP at its peak in South American countries but only about 0.001% point in the rest of EMEs. Thus, overall, South American countries suffer less in terms of output, stock prices and the exchange rate but there is a larger increase in net exports and a bigger reversal in capital flows.

Strikingly, the short-term (policy) rate of the rest of EMEs does not decrease by more compared to South American countries, even though the countries get affected much more negatively in terms of output (with similar effects in terms of consumer prices). Thus, the policy rates of the rest of EMEs can be considered to be "relatively high" and monetary policy "relatively more tight" given the negative response of output.

This heterogeneity in outcomes and the short-term policy rates then suggests an intriguing explanation that might be consistent with differential monetary policy reaction by these two groups of countries. It is well-known that many EMEs might be quite worried about sharp reversals in capital flows, even independently of the effects on output. Then, if the rest of EMEs are more concerned with capital outflows as a result of increased US uncertainty than South American countries, the central banks of these countries might keep their policy rates relatively high, in order to stem such capital outflows. This can be successful, but might come at the cost of larger drops in output as monetary policy will turn out to be unduly contractionary. This kind of trade-off is consistent with our empirical results above and guides the model we present in the next section where we introduce heterogeneity in monetary policy reaction function coefficients.[20]

3.2.3   Extensions and robustness

We conduct several extensions and robustness exercises. Our first set of extensions focus on effects of the baseline uncertainty shock on alternate measures of real economic activity and of open economy variables including measures of external balance. These are the various alternative specifications outlined in Table 1 and the results are shown in Figures A.1 and A.2 of the Appendix. Figure A.1 shows that all these measures of economic activity and aggregate spending decline persistently when US uncertainty increases unexpectedly. The response of investment is bigger than GDP and consumption as expected. The first row of Figure A.2 shows that long-term real interest rate spreads increase, real exchange rates depreciate, and net exports to the world increase. In particular, note that the effects on the real exchange rates are essentially the same as those on the nominal exchange rates presented in Figure 2, which shows that nominal and real exchange rates are very strongly correlated in our sample. The second row of Figure A.2 shows that the net foreign asset position of the US, the cumulated net foreign asset position of the US, as well as the cumulated foreign asset position of the US with these EMEs all decreases. These variables are again based on US Treasury data (TIC) and the results are all consistent with net exports from the EMEs to the US increasing and capital inflows to the EMEs decreasing that we find in our baseline specification. In particular, as our baseline measure of capital flows from EPFR is a gross capital inflow measure, which we use in cumulated form in the panel VAR, the cumulated foreign asset position of the US is a quite direct alternative measure for capital inflows to the EMEs.

Next, we conduct a series of robustness exercises for our measure of shock, and both our baseline as well as

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[20]We leave it for future research to identify empirically the monetary policy reaction functions of these countries and directly test this hypothesis. Here we note that there is some anecdotal evidence consistent with our interpretation of conventional monetary policy heterogeneity to deal with capital flows/foreign interest rate changes. For instance, SEACEN, the research network of Asian central banks has established since 2000 an expert group on capital flows whose "main objectives are: to develop a regional framework to promote information sharing on capital flows among members; and to draw up concrete and practical proposals that members can implement individually or collectively to enhance the management of capital flows." Asian countries are the majority in the group of other EMEs in our sample. The rest of the countries in the group include Russia, Turkey, and South Africa.

sub-group panel VAR estimations. First, in the three variable VAR, we impose a particular orthogonalization scheme and estimate the shock series. The estimated shock is almost identical the baseline series.[21] Second, we extend the US VAR to include more financial and real variables and use a version of Bloom (2009)'s eight variable VAR. In particular, we use his identification scheme that orders VIX second after S&P 500 Index, to estimate a US uncertainty shock. The results using this measure of US uncertainty shock are in Figure A.3.

Third, we simply use the growth rate of VIX as a measure of uncertainty shock in the EME panel VAR. This partly addresses the generated regressor problem that arises in our two-step estimation procedure. The results are presented in Figure A.4. Finally, in the three variable VAR specification, we replace VIX with the financial uncertainty measure of Ludvigson, Ma, and Ng (2015). The results are presented in Figure A.5. Overall, these exercises show that using three alternate measures of the US uncertainty shock in the EME panel VAR leads to similar results as our baseline specification.

We also check that our main results are not sensitive to lag length selection in the panel VAR. Results using four lags of the US uncertainty shock in the panel VAR are reported in the Appendix in Figure A.6 for the baseline case and in Figure A.7 for the sub-group analysis. For the sub-group estimation, we have also checked our results on using other activity measures and other financial and open economy variables. As one example, we report results using long-term real rate spreads in the Appendix in Figure A.8.[22]

As a final extension we consider a variance decomposition analysis. So far we have focused on transmission mechanisms as depicted by impulse responses of EME variables to a 1% US uncertainty shock. One natural question is how much does the US uncertainty shock contribute to explaining the variation in macroeconomic and financial variables in EMEs? To answer this question, we turn to a standard variance decomposition analysis. The appendix describes the method we use to compute the contribution of the shock at different horizons in explaining the forecast error variance. We start with the results based on all countries, which is in Table A.1, where for concreteness we focus on the five most salient variables. The US VIX shock explains a non-trivial fraction of the variation of these variables, for instance around 15% at the 3 month horizon for output and 20% at the 12 month horizon for long-term interest rate spreads. We then present results based on the sub-group estimation, in Table A.2 for South American countries and in Table A.3 for the rest of EMEs. Consistent with the impulse response results, they show that for South American countries, the US VIX shock explains relatively more the variation in capital flows compared to output while for the rest of EMEs, it explains relatively more the variation in output compared to capital flows.

4 Model

There are two countries, home and foreign, and two goods, one produced by each country, that are traded. The home country is a small open economy (SOE) while the foreign country is effectively a closed economy as home country variables have negligible effects on foreign variables. In terms of our empirical analysis, the home country is essentially an EME while the foreign country is the US. The home and foreign goods are imperfect substitutes of each other. The composite good used for consumption and investment is the same bundle of the home and foreign goods. Monetary policy at home is determined by an interest rate feedback rule. International risk-sharing is incomplete since home households can borrow and lend internationally using a one-period non-state contingent real bond denominated in foreign currency. Firms are subject to a

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[21] The shock series from ordering VIX first would be identical to our baseline "reduced-form" series.

[22] To conserve space, we do not show all the results of the robustness exercises, except those in Appendix, but they are available upon request.

working capital constraint and face price-adjustment costs. The model is thus a two-good, nominal, foreign currency debt, sticky prices extension of the classic SOE business cycle model in Neumeyer and Perri (2005) and Uribe and Yue (2006).

We now describe the model in detail. Note that the variables that are specific to the home and foreign country are subscripted with H and F, respectively. Those variables that are defined in relation to the composite good of both home and foreign goods are denoted with an $*$ if they are relevant for the foreign country but without an $*$ if they are relevant for the home country.

4.1 Private sector

We start with the description of the environment and the maximization problems faced by households and firms in our model. The decentralized economy we present is one where households own the capital stock and make investment decisions while firms rent capital and hire labor in competitive factor markets and make price-setting decisions. The firms are owned by the domestic households.

4.1.1 Households

A representative household at home maximizes expected discounted utility over the infinite horizon

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t - \mu \tilde{c}_{t-1}, h_t\right), \tag{6}$$

where $0 < \beta < 1$ is the discount factor, $0 < \mu < 1$ is the external habit formation parameter, c_t is household consumption of the composite consumption good, $\tilde{c}_{t-1}$ is aggregate consumption that the household takes as given, and h_t is hours supplied by the household. E_0 is the mathematical expectation operator conditional on period-0 information and $U\left(c_t - \mu \tilde{c}_{t-1}, h_t\right)$ is concave, twice continuously differentiable, and increasing in $c_t - \mu \tilde{c}_{t-1}$ and decreasing in h_t.

The composite consumption good c_t is an aggregate of the home good, $c_{H,t}$, and the foreign good, $c_{F,t}$

$$c_t = \left[(1-\chi)^{\frac{1}{\varepsilon}} c_{H,t}^{\frac{\varepsilon-1}{\varepsilon}} + \chi^{\frac{1}{\varepsilon}} c_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{7}$$

where $\varepsilon > 0$ is the elasticity of substitution between the goods and $0 < \chi < 1$ denotes the weight of the foreign good in the home consumption basket and therefore, also measures the degree of home bias.[23] The home and foreign goods are, in turn, aggregates of a continuum of differentiated varieties indexed by $i \in [0, 1]$. The consumption goods are thus defined as: $c_{H,t} = \left[\int_0^1 c_{H,t}(i)^{\frac{\nu-1}{\nu}} di\right]^{\frac{\nu}{\nu-1}}$ and $c_{F,t} = \left[\int_0^1 c_{F,t}(i)^{\frac{\nu-1}{\nu}} di\right]^{\frac{\nu}{\nu-1}}$, where $\nu > 1$ is the elasticity of substitution among the varieties. The home and foreign investment goods are similar aggregates of the varieties as well. The composite investment good i_t is defined as an aggregate of the home goods $i_{H,t}$, and foreign goods, $i_{F,t}$: $i_t = \left[(1-\chi)^{\frac{1}{\varepsilon}} i_{H,t}^{\frac{\varepsilon-1}{\varepsilon}} + \chi^{\frac{1}{\varepsilon}} i_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}$, in the same way as the composite consumption good.

Before presenting the flow budget constraint, it is useful to briefly discuss two static expenditure minimization problems faced by households in order to set some notation. First, define the nominal price (in terms of the home currency) of the aggregate consumption and investment good as p_t and the nominal prices (in terms of the home currency) of the home and foreign goods as $p_{H,t}$ and $p_{F,t}$ respectively. Similarly, denote the nominal prices of home variety i as $p_{H,t}(i)$ and of foreign varieties as $p_{F,t}(i)$.

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[23]We will also refer to $\varepsilon > 0$ as the trade elasticity. Moreover note that since the home country is small compared to the rest of the world, $\chi < 1$ constitutes home bias in preferences.

We can now derive p_t as the minimum-expenditure price index as well as the appropriate demand functions, where the household minimizes total expenditure across the two goods: $p_{H,t}c_{H,t} + p_{F,t}c_{F,t}$.[24] The expenditure minimization problem over the purchase of investment goods takes the same form as that over the consumption goods and thus there is a single aggregate price index in the economy. Next, the household also faces a static expenditure minimization problem over the differentiated varieties, where, the household minimizes expenditures : $\int_0^1 c_{H,t}(i)p_{H,t}(i)di$ and $\int_0^1 c_{F,t}(i)p_{F,t}(i)di$. From this problem, one can derive $p_{H,t}$ and $p_{F,t}$ as the minimum-expenditure price indices as well as the appropriate demand functions.[25] Similar expenditure minimization problems also apply for the investment good and are omitted for brevity.

The household's flow budget constraint is then given by

$$\frac{Q_t}{p_t^*}d_t^* + \frac{I_{t-1}}{\Pi_t}b_{t-1} = \frac{Q_t}{p_t^*}R_{t-1}d_{t-1}^* + b_t + \frac{Q_t}{p_t^*}\Psi\left(d_t^*\right) - w_th_t - u_tk_t + c_t + i_t - \varphi_t, \tag{10}$$

where d_t^* is the international debt position in terms of the foreign currency at the beginning of period $t+1$, R_{t-1} is the gross nominal interest rate in foreign currency terms faced by households at the beginning of period t for international borrowing, w_t is real wages, u_t is the real rental rate of capital, k_t is the capital stock at the beginning of period t, and φ_t is profits from home firms which are all held domestically.[26]

In addition, Q_t is the real exchange rate and p_t^* the foreign aggregate price level, which reflects the assumption that international borrowing and the real interest rate are in terms of the foreign currency. Here, we are using the conventional notation that $Q_t \equiv S_t p_t^*/p_t$, where S_t is the nominal exchange rate between the home and foreign country, defined as the price of a unit of the foreign currency in terms of the home currency. Thus, an increase in S_t is a depreciation of the home currency. Finally, $\Psi\left(d_t^*\right)$ denotes debt-adjustment costs faced by the households where $\Psi\left(.\right)$ is a convex function, which induces stationarity of debt positions and consumption in this incomplete market small open economy model. In addition to international borrowing, the household also can trade in domestic, one-period, non-state contingent nominal bonds (in home currency terms).[27] b_t is domestic bond holdings, expressed in real terms $b_t = B_t/p_t$, at the beginning of period $t+1$, I_{t-1} is the gross nominal interest rate faced by households at the beginning of period t, and $\Pi_t \equiv p_t/p_{t-1}$ is gross inflation. The household is also subject to a no-Ponzi game condition.

The capital accumulation equation is given by

$$k_{t+1} = (1-\delta)k_t + k_t\Phi\left(\frac{i_t}{k_t}\right), \tag{11}$$

where k_{t+1} is the capital stock at the beginning of period $t+1$ and $0 < \delta < 1$ is the rate of depreciation of

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[24]Formally, the household chooses $\{c_{H,t}, c_{F,t}\}_{t=0}^{\infty}$ to minimize $p_{H,t}c_{H,t} + p_{F,t}c_{F,t}$ subject to

$$\left[(1-\chi)^{\frac{1}{\varepsilon}}c_{H,t}^{\frac{\varepsilon-1}{\varepsilon}} + \chi^{\frac{1}{\varepsilon}}c_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} \geq c_t, \tag{8}$$

while taking as exogenously given $\{p_{H,t}, p_{F,t}\}_{t=0}^{\infty}$. Then, the shadow price on (8) is equal to p_t, the home currency nominal price of the aggregate consumption good. The demand functions take standard forms.

[25]Formally, for instance, the household chooses $\{c_{H,t}(i)\}_{t=0}^{\infty}$ to minimize $\int_0^1 c_{H,t}(i)p_{H,t}(i)di$ subject to

$$\left[\int_0^1 c_{H,t}(i)^{\frac{\nu-1}{\nu}}di\right]^{\frac{\nu}{\nu-1}} \geq c_{H,t}, \tag{9}$$

while taking as exogenously given $\{p_{H,t}(i)\}_{t=0}^{\infty}$. Then, the shadow price on (9) is equal to $p_{H,t}$, the home currency nominal price of the home consumption good. The demand functions take standard forms. Similar expenditure minimization problems also apply for the foreign consumption goods and the investment good.

[26]Note that the flow budget constraint is written in terms of real values, where the deflator is the common price level of the aggregate consumption and investment baskets. Also international borrowing/lending is through a one-period non-state contingent real bond.

[27]We introduce this asset to introduce a nominal interest rate, which is the monetary policy instrument in the model.

the capital stock . Here, $\Phi(i_t/k_t)$ represents investment adjustment cost where $\Phi(.)$ is an increasing concave function.[28]

Given the two first-stage, static expenditure minimization problems discussed above, the problem of the home household then is to choose $\{c_t, h_t, d_t^*, b_t, k_{t+1}, i_t\}_{t=0}^{\infty}$ to maximize (6) subject to a sequence of constraints (10) and (11), while taking as exogenously given initial wealth, initial capital stock, and $\{\Pi_t, \varphi_t, R_{t-1}, \tilde{c}_{t-1}, w_t, u_t, Q_t, I_{t-1}, p_t^*\}_{t=0}^{\infty}$.

The problem faced by the foreign country household is the same as above, but since the home country is a small open economy, the home good will have a negligible weight on the foreign consumption basket. Thus, we have $p_{F,t}^* = p_t^*$ where $p_{F,t}^*$ is the foreign currency price of the foreign goods. Moreover, as we explain more later, from the perspective of the home country, the sum of foreign aggregate consumption and investment, $y_t^* = c_t^* + i_t^*$, evolves exogenously.

4.1.2   Firms

At home there are a continuum of monopolistically competitive firms that produce differentiated varieties. The firms are of measure 1 and indexed by $i \in [0, 1]$. Firm i produces output y_t using labor and capital as inputs

$$y_t(i) = F(k_t(i), h_t(i)),\tag{12}$$

where the production function $F(.)$ is constant returns to scale, concave, and increasing in $k_t(i)$ and $h_t(i)$. Firms rent capital and hire labor in perfectly competitive factor markets. There is a working capital requirement that firms need to hold non-interest bearing assets, $\kappa_t(i)$, to finance a fraction of wage bill each period

$$\kappa_t(i) \geq \eta w_t h_t(i),\tag{13}$$

where $\eta \geq 0$. Thus $\kappa_t(i)$ has the interpretation of working capital held by the firm and (13) represents the financial friction on the firm side in a simple formulation.

Firm i sets prices $p_{H,t}(i)$ for its goods. We introduce nominal rigidities following Rotemberg (1983). Thus, firms face a cost of adjusting prices given by $d(p_{H,t}(i)/p_{H,t-1}(i))$ where $d(.)$ is a convex function. Moreover, the demand function for variety i is derived from the cost-minimization problem of the household over differentiated varieties discussed above and given by

$$\frac{y_t(i)}{y_t} = \left(\frac{p_{H,t}(i)}{p_{H,t}}\right)^{-\nu},\tag{14}$$

where y_t is aggregate world demand that is taken as given by the firms. As we emphasize below, there is no price discrimination between home and foreign markets in the model.

In addition to the non-interest bearing assets $\kappa_t(i)$, the balance sheet of the firm has one-period interest bearing liabilities, denoted by $d_t^f(i)$. These one-period riskless liabilities bear gross interest rate R_t^d in terms of price of the home good. The evolution of the liabilities is then governed by

$$d_t^f(i) = R_{t-1}^d d_{t-1}^f(i) - \frac{p_{H,t}(i)}{p_{H,t}} F(k_t(i), h_t(i)) + d\left(\frac{p_{H,t}(i)}{p_{H,t-1}(i)}\right) + \frac{p_t}{p_{H,t}}\left[w_t h_t(i) + u_t k_t(i) + \varphi_t(i) - \kappa_{t-1}(i) + \kappa_t(i)\right],$$

where $\varphi_t(i)$ is profits of the firm. Next, defining the net liabilities of the firm as $a_t(i) \equiv R_t^d d_t^f(i) - \frac{p_t}{p_{H,t}}\kappa_t(i)$

---

[28]Capital adjustment costs serve to temper the fluctuations in the small open economy's investment in response to interest rate spread or foreign interest rate shocks.

gives a law of motion for $a_t(i)$ as

$$
\begin{aligned}
\frac{a_t(i)}{R_t^d} =\, & a_{t-1}(i) - \frac{p_{H,t}(i)}{p_{H,t}} F(k_t(i), h_t(i)) + d\left(\frac{p_{H,t}(i)}{p_{H,t-1}(i)}\right) + \frac{p_t}{p_{H,t}}\left[w_t h_t(i) + u_t k_t(i) + \varphi_t(i)\right] \\
& + \frac{p_t}{p_{H,t}}\kappa_t(i)\left(1 - \frac{1}{R_t^d}\right) + \left(\frac{p_{t-1}}{p_{H,t-1}} - \frac{p_t}{p_{H,t}}\right)\kappa_{t-1}(i).
\end{aligned}
\tag{15}
$$

The firm is also subject to a no-Ponzi game condition.

We assume that the home firm is owned by the home household. The firm then maximizes expected discounted profits over the infinite horizon

$$
E_0 \sum_{t=0}^{\infty} \rho_{0,t}\varphi_t(i),
\tag{16}
$$

where the discounting is done using the stochastic discount factor of the home household $\rho_{0,t} = \beta^t \frac{U_c(c_t - \mu\tilde{c}_{t-1}, h_t)}{U_c(c_0 - \mu\tilde{c}_{-1}, h_0)}$. The problem of firm i at home is then to choose $\{a_t(i), h_t(i), k_t(i), p_{H,t}(i)\}_{t=0}^{\infty}$ to maximize (16) subject to a sequence of constraints (13) and (15), the production function (12), and the demand curve (14), while taking as exogenously given initial net liabilities, non-interest bearing assets, and $\{\frac{p_{t-1}}{p_{H,t-1}}, R_{t-1}^d, p_{H,t}, y_t, \rho_{0,t}, w_t, u_t\}_{t=0}^{\infty}$. As is standard, we will focus on a symmetric equilibria where all firms choose the same price and produce the same amount of output.

4.2 International pricing and market clearing

There is no international price discrimination in the model and thus the law of one price holds. As a good sells at the same price, once converted in the same currency, both at home and abroad, we have

$$
p_{H,t} = S_t p_{H,t}^* \text{ and } p_{F,t} = S_t p_{F,t}^*.
$$

We also define the terms of trade $\varsigma_t \equiv p_{F,t}/p_{H,t}$ and a relative price $r_t \equiv p_t/p_{H,t}$. Then, we have $\varsigma_t = \frac{p_{F,t}}{p_{H,t}} = \frac{p_{F,t}^*}{p_{H,t}^*} = \frac{p_t^*}{p_{H,t}^*}$, where the last equality follows as $p_{F,t}^* = p_t^*$.

The goods, factor, and bonds markets clear in equilibrium.[29] In particular, the social resource constraint, at the variety level, is given by

$$
y_t(i) = c_{H,t}(i) + i_{H,t}(i) + c_{H,t}^*(i) + i_{H,t}^*(i) + d\left(\frac{p_{H,t}(i)}{p_{H,t-1}(i)}\right)
$$

where we incorporate the resource cost of adjusting prices. The foreign demand for the home good $c_{H,t}^*(i) + i_{H,t}^*(i)$ will in equilibrium be a function of the terms of trade and foreign aggregate demand $y_t^* = c_t^* + i_t^*$, as we show later in detail in the Appendix while discussing all the optimality conditions. Finally, we assume a zero net supply of the home nominal bond

$$
B_t = 0.
\tag{17}
$$

---

[29]Our notation already imposes that factor markets clear in equilibrium.

4.3 Monetary policy

Monetary policy in the home country is determined according to an interest-rate feedback rule

$$\beta I_t = [\beta I_{t-1}]^{\rho_I} \left[\left(\frac{\Pi_t}{\Pi} \right)^{\phi_\pi} \left(\frac{y_t}{y_{t-1}} \right)^{\phi_y} (\beta R_t)^{\phi_{RI}} \right]^{(1-\rho_I)}, \tag{18}$$

where $\rho_I \geq 0$ is the interest-rate smoothing parameter, $\phi_\pi \geq 0$, $\phi_y \geq 0$, and $\phi_{RI} \geq 0$ are feedback parameters, and Π is the steady state value of gross inflation. Thus, the nominal interest rate responds, as is standard, to inflation and output growth, but also could additionally, to the international borrowing/lending rate. The latter aspect of the monetary policy rule will be used to interpret the heterogeneity across countries that we find in the empirical results and reflects a concern that some central banks might have in keeping the home nominal interest rate close to the foreign interest rate, in order for instance to stem rapid movements of capital flows.[30]

4.4 Exogenous processes

We define the interest rate spread $R_t^S \equiv R_t - R_t^*$ as the difference between the domestic household international borrowing rate and foreign interest rate and posit an ARMA (1,3) process for R_t^S

$$R_t^S = \rho_S R_{t-1}^S + \exp(\sigma_0)\varepsilon_{R^S,t} + \exp(\sigma_1)\varepsilon_{R^S,t-1} + \exp(\sigma_2)\varepsilon_{R^S,t-2} + \exp(\sigma_3)\varepsilon_{R^S,t-3}, \tag{19}$$

where $\varepsilon_{R^S,t}, \varepsilon_{R^S,t-1}, \varepsilon_{R^S,t-2}, \varepsilon_{R^S,t-3} \sim N(0,1)$ and $\exp(\sigma_0), \exp(\sigma_1), \exp(\sigma_2), \exp(\sigma_3) > 0$. We posit this more general process to match the hump-shaped response of country spread that we estimate empirically. Thus, this spread measure is the theoretical counterpart to our empirical measure of country spread. This will be the main baseline shock, as a proxy for the empirical US uncertainty shock, we consider in the paper.[31]

In the baseline set of results, we do not consider time varying volatility in the interest rate spread process. In an extension, we will consider a stochastic volatility process by making σ_0 time-varying as

$$\sigma_t - \sigma = \rho_\sigma (\sigma_{t-1} - \sigma) + \varepsilon_{\sigma,t} \tag{20}$$

where $\varepsilon_\sigma \sim N(0,1)$. We then explore macroeconomic implications of a pure second-moment shock that does not change the level of the spread R_t^s. Finally, we assume that foreign output and prices evolve exogenously following AR(1) processes in terms of deviations from their respective deterministic steady-states. Thus, we have

$$y_t^* - y^* = \rho_{y^*} \left(y_{t-1}^* - y^* \right) + \varepsilon_{y,t}^* \text{ and } p_t^* - p^* = \rho_{p^*} \left(p_{t-1}^* - p^* \right) + \varepsilon_{p,t}^*. \tag{21}$$

In particular, in an extension, we will explore macroeconomic implications of a negative foreign output/demand shock, as that could be considered as another proxy for the empirical US uncertainty shock.

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[30]In the past, tracking the foreign interest rate to stem large movements in the exchange rate has been termed "fear of floating," of EMEs. Here, our model can be thought of as capturing a "fear of movements in external balance" of EMEs.

[31]Also, note that we assume a common steady state for R_t and R_t^* and that since we will not model a process for R_t^* separately, we can consider the shock to spread as a shock to the international borrowing rate R_t. We will therefore use them interchangeably.

4.5 Equilibrium

We now define the equilibrium in our economy and discuss the aggregate optimality and feasibility conditions that characterize it.

4.5.1 Definition

An equilibrium is a collection of allocations (of goods varieties and aggregates) for the household, $\{c_{H,t}(i), c_{F,t}(i), i_{H,t}(i), i_{F,t}(i), c_t, \tilde{c}_{t-1}, h_t, d_t^*, b_t, k_{t+1}, i_t\}_{t=0}^{\infty}$, allocations and goods prices for the firms $\{a_t(i), h_t(i), k_t(i), p_{H,t}(i)\}_{t=0}^{\infty}$, a sequence of aggregate prices $\{S_t, p_{H,t}, p_{F,t}, p_t, R_t, w_t, u_t, \rho_{0,t}, R_t^d\}_{t=0}^{\infty}$ and output $\{y_t\}_{t=0}^{\infty}$, and monetary policy instrument $\{I_t\}_{t=0}^{\infty}$ such that

(i) Given prices and monetary policy, the allocations are such that they satisfy the maximization problems of the household,

(ii) Given aggregate prices, aggregate output, and monetary policy, the goods prices and allocations are such that they satisfy the maximization problem of the firms,

(iii) The allocations and goods prices across firms are symmetric,

(iv) Individual and aggregate consumption is equal,

(v) The nominal interest rate is determined by the monetary policy rule, and

(vi) Goods, factor, and bonds markets clear,

given the initial capital stock, consumption, household debt, firm net asset position, firm non-interest bearing asset, relative price, aggregate price, interest rates, and an exogenous process for $\{R_t^s, y_t^*, p_t^*, \sigma_t\}_{t=0}^{\infty}$.

4.5.2 Optimality and market clearing conditions

We present in detail in Appendix, the non-linear, aggregate equilibrium conditions of the model that determine the dynamics of the seventeen endogenous aggregate variables $\{d_t, w_t, h_t, u_t, k_t, c_t, i_t, R_t^d, y_t, \tilde{c}_t, \varphi_t, \varsigma_t, \Pi_t, \Pi_{H,t}, b_t, I_t, \xi_t\}$. The economic interpretation of these equilibrium conditions is relegated to Appendix. We only focus on an equilibrium where R_{t-1}^d is strictly positive. This means that the working capital constraint (13) will always bind. It is assumed that the firms start with no net liabilities.

We here also define three variables for later use in the model simulations and results. Net exports as a ratio of output is given by $\frac{nx_t}{y_t} = \frac{y_t - r_t \left[c_t + i_t + \frac{Q_t}{p_t^*} \Psi(d_t^*) \right]}{y_t}$ while the current account as a ratio of output is given by $\frac{ca_t}{y_t} = -r_t \left(\frac{Q_t}{p_t^*} d_t^* - \frac{Q_t}{p_t^*} d_{t-1}^* \right)$. Finally, to compare with the empirical results, we price a stock as a claim to the (future) stream of firm profits using the stochastic discount factor of the home household. Thus the stock price is given by the usual asset pricing recursion $\Omega_t = E_t \left[\frac{\rho_{t+1}}{\rho_t} \left(\Omega_{t+1} + \varphi_{t+1} \right) \right]$.

4.6 Results

We solve the model non-linearly, where in period 0, an unexpected shock to the interest rate spread, ε_{R^s}, hits the economy, and then the economy evolves deterministically thereafter.[32] As we discussed before, we interpret this shock as proxying for the foreign uncertainty shock in our empirical exercise. Thus, it is used

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[32]We use a non-linear solver to compute this perfect foresight solution. In an extension, when we consider a second-moment shock to the interest rate spread, we use a third-order perturbation solution method. For conciseness, we do not show explicitly results on the foreign output and price shock later in the paper. In the Appendix, we report results on the effects of a negative foreign output shock.

to roughly capture the belief of external investors that lending to the SOE is risky. It can also capture some "flight to safety/quality" phenomenon.[33]

4.6.1 Functional forms and parameterization

We use the same functional forms for utility, production function, and real adjustment costs as in Uribe and Yue (2006) and a standard specification for price-adjustment costs

$$U\left(c - \mu\tilde{c}, h\right) = \frac{\left[c - \mu\tilde{c} - \omega^{-1}h^{\omega}\right]^{1-\gamma} - 1}{1 - \gamma}, \ F(k, h) = k^{\alpha}h^{1-\alpha},$$

$$\Phi\left(x\right) = x - \frac{\phi}{2}\left(x - \delta\right)^2, \Psi\left(d\right) = \frac{\psi}{2}\left(d_t^* - \bar{d}\right), \ d(\Pi_H) = \frac{d_1}{2}\left(\Pi_H - \bar{\Pi}_H\right)^2.$$

For the parameters common to Uribe and Yue (2006), we use the same values as theirs. Note however that our model is calibrated to the monthly frequency and some parameters are modified accordingly. Then for the new parameters in our model, we conduct detailed comparative statics. The numerical values for parameters common with Uribe and Yue (2006) we use in simulation of our model are given below in Table 2. We note that as in Uribe and Yue (2006), we calibrate the debt-adjustment function parameter, $\bar{d}$, to achieve a steady-state net exports to GDP ratio of 0.02. Then we consider three alternate values for the home-bias, trade elasticity, and price-adjustment costs parameters: χ=0.3, 0.35, 0.4, ε=0.7, 1.5, 4, and d_1=35, 50, 75. Our baseline choices are χ=0.35, ε=1.5, and d_1=35. This parameterization implies a moderate trade elasticity and quite flexible prices. For the elasticity of substitution across differentiated varieties, we use a standard value of 7.

Table 2: Parameterization of the model based on Uribe and Yue (2006)

Parameter	Value	Parameter	Value
μ	0.204	ω	1.455
δ	0.025/3	γ	2
β	0.99	ϕ	72.8
α	0.32	ψ	0.00042
$\frac{\bar{d}}{y}$	1.37	η	1.2

We use parameters for the shock process such that it matches exactly the dynamics of the interest rate spread we estimate empirically in Figure 2. For the monetary policy reaction function, as baseline, we consider the usual Taylor rule parameter values: ρ_I= 0.8, ϕ_π= 1.5, and ϕ_y= 0.5/12. Finally, in a model variant to interpret the heterogeneous responses across different sub-groups of countries that we estimate empirically in Figure 3, we allow a response in the monetary policy reaction function directly to the foreign interest rate spread: ϕ_{RI}= 0.5/12.[34]

4.6.2 Steady-state

The deterministic steady-state of our model is relatively straightforward to derive and the details are in the Appendix. It is nevertheless useful to note some properties of the steady-state as for our non-linear impulse

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[33] In a SOE model, it is not clear how to directly model an uncertainty shock in a foreign country. We leave for future research to model a general equilibrium global economy with countries of different sizes where an increase in expected volatility in the stock markets of a large economy can be considered directly.

[34] In this case, since the shock is persistent, we remove the interest rate smoothing component of the Taylor rule.

responses, we will start the economy in the deterministic steady-state and the economy will transition back to this same steady-state in the long run. First, as is well known, given the debt adjustment cost function, $\bar{d}$ pins down the steady-state external debt of this economy. Moreover, we pick a zero net inflation steady-state. Then, the interest rates are equal to $\frac{1}{\beta}$: $I = R^d = R = \frac{1}{\beta}$. We also normalize the terms-of-trade ς in steady-state to be 1.[35] Together, this implies that all relative prices and exchange rates are also1 in the steady state. The investment to capital stock ratio is equal to δ, which implies $u = \frac{1}{\beta} - (1 - \delta)$, and $w = \left[\left(\frac{\varepsilon-1}{\varepsilon} \right) (1 - \alpha)^{1-\alpha} \alpha^\alpha u^{-\alpha} \right]^{\frac{1}{1-\alpha}} (1 + \eta (1 - \beta))^{-1}$. Finally, given these solutions for factor prices and the investment to capital stock ratio, variables in levels such as hours, consumption, output, investment, and capital in steady-state can be derived.

4.6.3 Impulse responses

We now present impulse responses when an unexpected shock $\varepsilon_{R^S,t}$ hits the economy in the initial period. After the unexpected shock in the initial period, the economy proceeds in a deterministic fashion. Before the shock hits the economy in the initial period, the economy is in the deterministic steady state described above and the responses below are shown in terms of percent deviation from the steady state or in percentage points for variables in ratios and interest rates. Our solution is one where in the long run, the economy transitions back to the deterministic steady state. Note again that our model frequency is monthly, the same frequency as in the empirical section, and for direct comparison with the empirical results, we annualize the responses of the interest rate variables.

The baseline impulse responses from the model are shown in Figure 4, which are all qualitatively consistent with our empirical impulse responses in Figure 2. When the cost of borrowing in international market increases, it generates contractionary macroeconomic effects as is the case empirically. Consumption, investment, and output all decrease in the small open economy. Consumption and investment decline for, by now well understood, mechanisms inherent even in classic one-good SOE models like Neumeyer and Perri (2005) and Uribe and Yue (2006). The major mechanism is an increased cost of borrowing, and thus of financing spending, which drives lower consumption as well as investment. Because of the working capital constraint, investment gets additionally negatively affected in the model as wage bill increases with increased interest rates. Output of the home good declines following this reduction in spending.

In our two-good model, there are additional implications for prices that are consistent with our empirical results, which in turn also affect dynamics of macroeconomic quantities. First, because of decreased demand, through the market-clearing condition for home goods, a clear prediction is that the real exchange rate depreciates.[36] That is, the relative price of the home good must decline in equilibrium as demand for the good falls strongly. The extent of the fall in the relative price of the home good (and real exchange rate) depends on the trade elasticity, as we show later in an extension. The decline in output, together with a fall in relative price of the home good, leads to a fall in firm profits and thereby, stock prices.

Moreover, associated with the decrease in aggregate demand is also an increase in net exports (as a ratio of GDP), as spending contracts more compared to output. Compared to a one-good model, in our two-good model, the contraction in spending gets additionally magnified as the relative price of the home good

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[35]We have this freedom, given that we choose the steady-state of foreign demand to be consistent with the market clearing condition for goods.

[36]Note that in the model, as is the convention, our notation is such that an increase in the exchange rate constitutes a depreciation. Here we focus on the real exchange rate as the nominal exchange rate is non-stationary in the model, but empirically, as we show in the Appendix, the response of the real exchange rate in the EM VAR is basically identical to the nominal exchange rate.
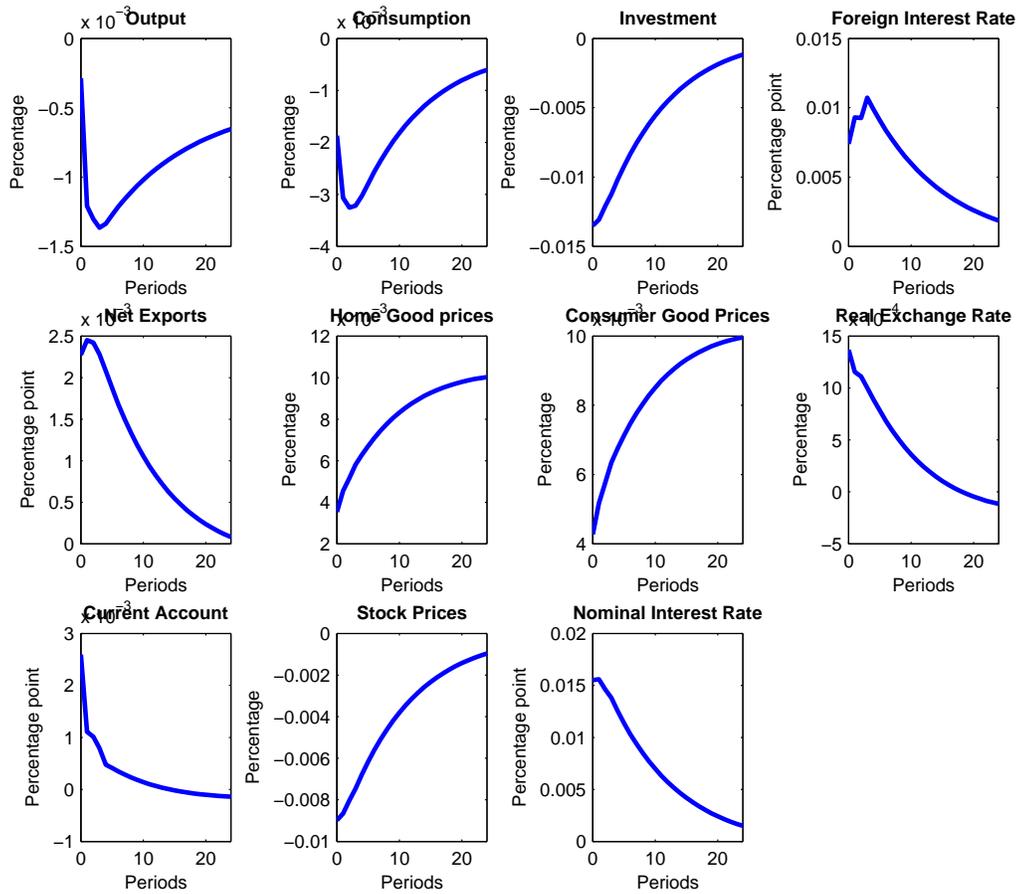
Figure 4: Impulse responses of the small open economy model to a shock to the foreign interest rate spread

Notes: These non-linear impulse responses are those computed when an unexpected foreign interest rate (spread) shock hits the economy in the initial period and then the economy evolves deterministically thereafter. The economy is in the deterministic steady-state initially and the response of the variables are presented in terms of % or % points deviation from the steady-state. The economy transitions back to the deterministic steady-state in the long-run. The choice of model parameter values, including the size and persistence of the shock, is described in the text.

declines (or equivalently the real exchange rate depreciates). Thus, net exports is persistently positive for a long period of time following the shock. Finally, as a reflection of the reduction in debt of the SOE following this shock, there is a positive current account balance (as a ratio of GDP).[37] These are consistent with the empirical responses in Figure 2 where net exports increase while capital inflows decline in the EMEs.

Next, again as is consistent with our empirical responses, goods prices increase. In particular, in the model, both consumer and home good prices increases. What is the mechanism? Because of nominal rigidities and forward looking behavior of price-setting firms, in our model, home good inflation is determined by the path of (expected future) marginal costs faced by the home firms. Importantly, the relevant marginal cost is in terms of the home good price. Thus, while components of the marginal cost such as real wages and rental rate of capital decline initially given the large drop in macroeconomic aggregates, because of the real

---

[37]As is to be expected, the cyclicality of current account can depend on the persistence of the external shock. In our model, the current account is countercyclical for a persistent enough shock, as is the case in our calibration.

exchange rate depreciation, the marginal cost in terms of the home good prices actually increases.[38] This then leads to an increase in home goods prices. Given the home bias in consumption, consumer good prices are influenced strongly by home good prices. This then translates also into consumer good prices increasing in the model by a very similar amount.

To help interpret the heterogeneity in responses across sub-groups of countries that we find empirically, we now consider a case where the central bank, in addition to inflation and output, also responds to the foreign interest rate. This is meant to capture an inclination on the part of some central banks to keep the home interest rate at a similar level as the foreign interest rate, in order to avoid large swings in capital flows. The impulse responses from this variation in the model are shown in Figure 5. It is clear that because of such policy, which turns out to be contractionary, output and consumption, and by more limited amount also investment, decline by more. In addition, while the differential effects are smaller, the decline in stock prices is also larger.

On the other hand, the response of current account is lower.[39] Thus the small open economy limits the capital outflows from it to the rest of the world as a result of such a policy. Thus, at least qualitatively, for many variables, this is consistent with the heterogeneity in responses we find in Figure 3, where in particular, South American countries suffer less in terms of output and stock prices but there is a larger increase in current account following a US uncertainty shock. Our model based interpretation for this heterogeneity then is that it can arise if the rest of EMEs, compared to South American countries, put a larger weight in the monetary policy reaction function to the foreign interest rate.

4.6.4 Extensions and robustness

We consider several model extensions and robustness exercises. The results are reported in the Appendix. The most important extension we consider is one where we introduce a second-moment shock to the foreign interest rate process. We then compute the responses of the model variables to a purely second-moment shock, that is, one where we hold the first-moment shock at its steady-state. We use a third-order accurate perturbation solution method to compute the stochastic equilibrium.[40] Figure A.9 shows the results, where in term of parameterization of the second-moment shock, we use estimates in Fernandez-Villaverde et al (2011) for Brazil. While the response of most variables are similar qualitatively to our baseline, with magnitudes being smaller, by definition, this shock does not lead to an increase in the level of foreign interest rate spread. This increase in the level of country spread is a robust robust feature of the VIX shock on EMEs, which we have shown in the empirical section.

For the baseline first-moment shock to the foreign interest rate spread case, we show in the Appendix in Figures A.10 and A.11, results we obtain when we use a greater level of price stickiness (d_1=50) and a lower trade elasticity (ε=0.9) respectively. The price adjustment cost parameterization in this case is close to the one used in Ireland (2001), while a below unit trade elasticity calibration is often used in the open economy macroeconomics literature. As is clear, our results are robust. With increased price stickiness, both output and goods prices respond less. This is so because as we mentioned before, the foreign interest rate shock

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[38]Note that even though the foreign interest rate increases, in equilibrium, because of the large fall in output, the rental rate of capital actually declines for the initial periods. It later however increases above steady-state.

[39]Note that some of the differences across the figures, such as those in stock prices, are small. But our point here is just qualitative. We can make the differences larger by increasing the weight on the foreign interest rate in the monetary policy reaction function.

[40]For the first-moment shock to the foreign interest rate spread, if we were to use a third-order accurate perturbation solution method, the impulse responses are quite similar even quantitatively to the baseline non-linear ones that we compute in a deterministic framework. These results are not shown to conserve space.
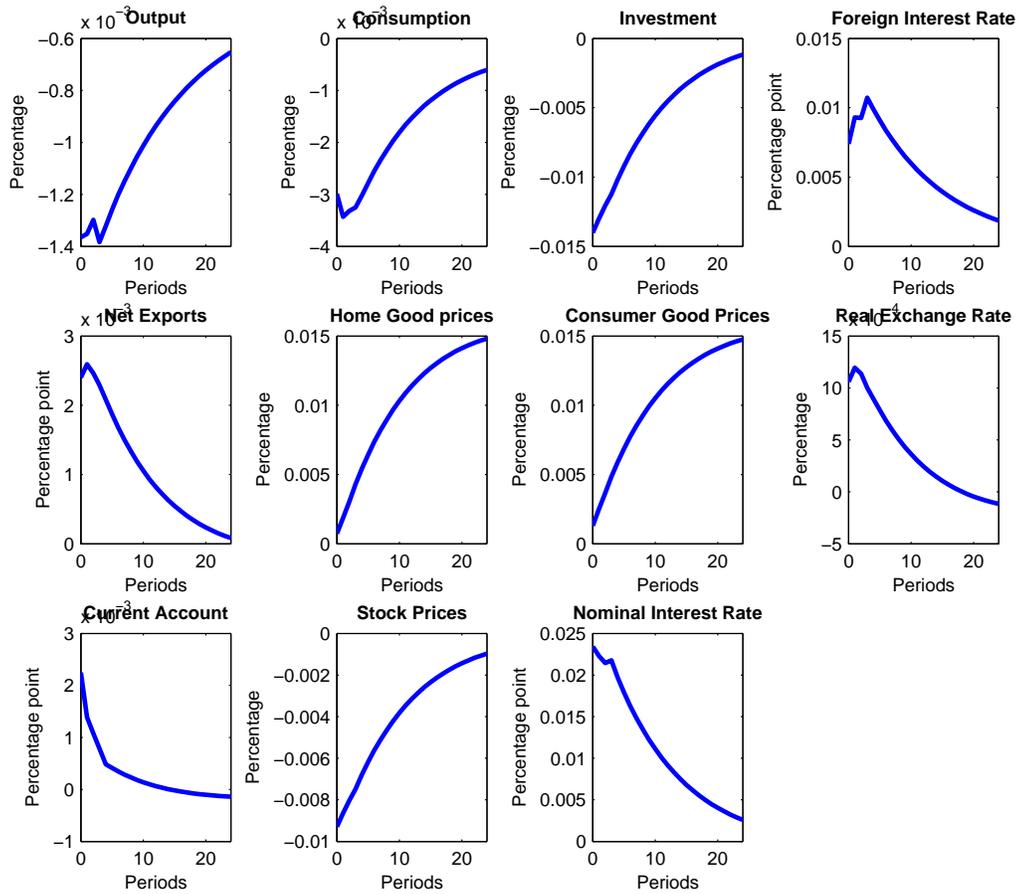
Figure 5: Impulse responses of the small open economy model to a shock to the foreign interest rate spread when the central bank reaction function includes the shock

Notes: Compared to the baseline in 4, the central bank interest rate reaction function now also includes a feedback to the foreign interest rate. Also, see the notes in Figure 4.

acts like a markup shock in a closed-economy model. In such a situation, increased price stickiness not only decreases the response of prices, but also of output. Next, as to be expected, with a lower trade elasticity, the effects on macroeconomic quantities such as output are more pronounced while those on prices such as the real exchange rate and goods prices are lower.

Finally, we also consider a negative foreign income/output shock as a possible proxy for the US uncertainty shock. The results are reported in the Appendix in Figure A.12, where we use the same parameter values for the size of the shock as we did for the foreign interest rate spread shock and use a random walk specification for persistence that is common in business cycle studies. Since such a shock constitutes an exogenous drop in demand for the SOE produced good, it does generate a drop in the SOE output and also, consumption and investment. But a counterfactual prediction is that net exports decrease, which is also a direct result of the drop in demand for the SOE produced home good.

5   Conclusion

We study, empirically and theoretically, spillover effects on emerging market economies (EMEs) of fluctuations in US uncertainty. We find that an unanticipated change in US financial uncertainty has significant financial and macroeconomic effects on the EMEs. An unanticipated increase in US uncertainty, on average, sharply depreciates the local currency of the EMEs, leads to a decline in their local stock markets, increases long-term interest rate spreads, and capital flows out from them. Moreover, we find that these financial effects transmit to the macroeconomy as they are accompanied by large and persistent macroeconomic effects. We estimate a significant drop in output, a rise in consumer prices, and a rise in net exports from these countries in response to a rise in US uncertainty.

We find economically meaningful heterogeneity in responses among the fifteen EMEs. In particular, the negative effects on output, stock prices, and exchange rates are bigger and more persistent for the rest of EMEs compared to South American countries. On the other hand, the effects are bigger and more persistent on capital and trade flows for South American countries compared to the rest of EMEs. We find that the short-term (policy) rate of the non-South American EMEs stays relatively high, given the large negative macroeconomic effects, thereby suggesting that the monetary policy response can play a critical role in the transmission of the external US uncertainty shock.

We present a two-good small open economy (SOE) model with financial and nominal frictions that can account for our empirical findings. A negative external shock that increases the interest rate spread faced by the SOE produces responses of macroeconomic and financial variables that are consistent with our estimated responses. Moreover, the model provides a possible explanation for the heterogeneity in responses across countries depending on the endogenous response of the monetary policy instrument to the increase in interest rate spread.

In future work, it will be worthwhile to explore if the spillovers effects of US uncertainty we estimate are also important for advanced small open economies, such as Canada, Australia, Sweden, Norway, and Switzerland. Moreover, it will be interesting to consider a model with global financial intermediaries and investors that can provide an even deeper understanding of how US financial uncertainty propagates to the financial and macroeconomic sectors of EMEs. In doing so, we can build on existing work such as Caballero and Krishnamurthy (2001) that features a richer set of collateral constraints, Caballero and Krishnamurthy (2008) that models a flight to quality episode, and Calvo, Izquierdo, and Talvi (2006) that features sudden stops in emerging market economy models.

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A   Data description

See the data appendix for the complete list of the data with detailed descriptions and their sources. It also explains how quarterly GDP, consumption, and investment series are interpolated to monthly series for the US and the emerging market countries. For the latter countries, monthly GDP is used to normalize capital flows and net exports.

B   Details of the empirical methodology

We start with a description for the baseline case where we include all emerging market economies together. We then proceed to describing the method when we do estimation across two sub-groups of countries.

B.1   A case with a single group

Suppose that there are N countries indexed by i. We have an $m_z \times 1$ vector of endogenous variables $z_{i,t}$ for country i and an $m_x \times 1$ vector of exogenous variables x_t that can include a constant, a time trend or other exogenous variables and are common across countries. The sample covers the period from $t = 1, \cdots, T$. We condition the inference on initial p observations for $t = 0, -1, \cdots, -(p-1)$.

The dynamics of endogenous variables for country i can be written as

$$z_{i,t}^o = \sum_{j=1}^{p} B_{i,j} z_{i,t-j}^o + \sum_{j=0}^{q} D_{i,j} \varepsilon_{VIX,t-j} + C_i x_{i,t}^o + u_{i,t}^o, \tag{A.22}$$

where $B_{i,j}$ for $j = 1, \cdots, p$ is $m_z \times m_z$, $D_{i,j}$ for $j = 1, \cdots, p$ is $m_z \times 1$, C_i is $m_z \times m_x$, and $u_{i,t}^o$ is $m_z \times 1$. The superscript o means that the variables are observables and the disturbance term is one for observable variables. Later we augment the sample with dummy observations with superscript d. Let us collect the regressors on the right hand side of (A.22) in $w_{i,t}^o$ as

$$w_{i,t}^o = \left[\begin{array}{cccccccc} z_{i,t-1}^{o\prime} & \cdots & z_{i,t-p}^{o\prime} & \varepsilon_{VIX,t-0} & \cdots & \varepsilon_{VIX,t-q} & x_{i,t}^{o\prime} \end{array} \right]',$$

and write (A.22) as

$$z_{i,t}^{o\prime} = w_{i,t}^{o\prime} \Gamma_i + u_{i,t}^{o\prime}, \tag{A.23}$$

where Γ_i collects the coefficient matrices on the right hand side of (A.22)

$$\Gamma_i = \left[\begin{array}{cccccc} B_{i,1} & \cdots & B_{i,p} & D_{i,0} & \cdots & D_{i,q} & C_i \end{array} \right]'.$$

Note that $w_{i,t}^o$ is an $m_w \times 1$ vector with $m_w = m_z p + (q+1) + m_x$ and Γ_i is an $m_w \times m_z$ matrix. Now vectorize equation (A.23) as

$$z_{i,t}^o = \left(I_{m_z} \otimes w_{i,t}^{o\prime} \right) \gamma_i + u_{i,t}^o, \tag{A.24}$$

where $\gamma_i = \text{vec}\left(\Gamma_i \right)$, and stack (A.24) for $i = 1, \cdots, N$ as

$$\boldsymbol{z}_t^o = \boldsymbol{W}_t^o \boldsymbol{\gamma} + \boldsymbol{u}_t^o, \tag{A.25}$$

where

$$\boldsymbol{z}_t^o = \begin{bmatrix} z_{1,t}^o \\ \vdots \\ z_{N,t}^o \end{bmatrix}, \ \boldsymbol{W}_t^o = \begin{bmatrix} \left(I_{m_z} \otimes w_{1,t}^{o\prime}\right) & & 0 \\ & \ddots & \\ 0 & & \left(I_{m_z} \otimes w_{N,t}^{o\prime}\right) \end{bmatrix}, \ \boldsymbol{\gamma} = \begin{bmatrix} \gamma_1 \\ \vdots \\ \gamma_N \end{bmatrix}, \text{ and } \boldsymbol{u}_t^o = \begin{bmatrix} u_{1,t}^o \\ \vdots \\ u_{N,t}^o \end{bmatrix}.$$

Note that $\boldsymbol{z}_t^o$ is $Nm_z \times 1$, W_t^o is $Nm_z \times Nm_z m_w$, $\boldsymbol{\gamma}$ is $Nm_w m_z \times 1$ and $\boldsymbol{u}_t^o$ is $Nm_z \times 1$. It is assumed that $\boldsymbol{u}_t^o \sim \mathbb{N}\left(\boldsymbol{0}, \boldsymbol{\Sigma}\right)$ with $\boldsymbol{\Sigma}$ being $Nm_z \times Nm_z$ and positive definite. Let $m_\gamma = m_w m_z$ and $m_{\gamma N} = Nm_\gamma$.

B.1.1 Prior and posterior distribution of $\boldsymbol{\gamma}$ (γ_i's) and $\boldsymbol{\Sigma}$

We describe the prior and posterior distributions of $\boldsymbol{\gamma}$ (γ_i's) ad $\boldsymbol{\Sigma}$ next.

Prior distribution We take the random coefficient approach as discussed in the main text: γ_i is given as

$$\gamma_i = \bar{\gamma} + v_i, \tag{A.26}$$

for $i = 1, \cdots, N$, where $\bar{\gamma}$ is an $m_\gamma \times 1$ vector and $v_i \sim \mathbb{N}\left(0, \Sigma_i \otimes \underline{\Sigma}_i\right)$. Note that Σ_i is an $m_z \times m_z$ matrix that is the i-th block on the diagonal of $\boldsymbol{\Sigma}$ and $\underline{\Sigma}_i$ is an $m_w \times m_w$ positive definite matrix. Equation (A.26) can be written as

$$\gamma_i | \bar{\gamma}, \boldsymbol{\Sigma} \sim \mathbb{N}\left(\bar{\gamma}, \Sigma_i \otimes \underline{\Sigma}_i\right).$$

We assume that γ_i's are independent of each other conditional on $\bar{\gamma}$ and $\boldsymbol{\Sigma}$. That is, $E\left(v_i v_j'\right) = 0$ for $i \neq j$. The prior distribution for $\bar{\gamma}$ is described below. We set $\underline{\Sigma}_i = 5 \times I_{m_w}$.

The prior distribution for $\boldsymbol{\Sigma}$ is inverted-Wishart, or alternatively, the prior distribution for $\boldsymbol{\Sigma}^{-1}$ is Wishart as

$$\boldsymbol{\Sigma}^{-1} \sim \mathbb{W}\left(\underline{\nu}, \underline{S}^{-1}\right),$$

where $\underline{\nu} > Nm_z + 1$ and $\underline{S}$ is $Nm_z \times Nm_z$ and positive definite. We set $\bar{\nu} = Nm_z + 2$ that leads to a loose prior on $\boldsymbol{\Sigma}^{-1}$. For $\underline{S}$, ideally we would use a training sample to get the estimate of the variance matrix of residuals from a VAR model. However, because of the small size of our sample and the fact that it falls on the normal times immediately before our sample, we do not use such a training sample. We take a practical approach and use the estimated variance matrix of OLS residuals from an individual VAR model with the same specification for each country.

Posterior distribution We derive the posterior distribution of $\boldsymbol{\gamma}$ (γ_i's) conditional on $\boldsymbol{\Sigma}$ and $\bar{\gamma}$ and the posterior distribution of $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$ and $\bar{\gamma}$. Let

$$\tilde{\boldsymbol{\gamma}} = \left(\sum_{t=1}^T \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\Sigma}_\gamma^{-1}\right)^{-1} \left[\left(\sum_{t=1}^T \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o\right) \hat{\boldsymbol{\gamma}} + \left(\underline{\Sigma}_\gamma^{-1}\right) \bar{\boldsymbol{\gamma}}\right],$$

where $\bar{\boldsymbol{\gamma}} = 1_N \otimes \bar{\gamma}$ with 1_N being an $N \times 1$ vector of 1's,

$$\hat{\boldsymbol{\gamma}} = \left(\sum_{t=1}^T \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o\right)^{-1} \left(\sum_{t=1}^T \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{z}_t^o\right),$$

and

$$\underline{\boldsymbol{\Sigma}}_\gamma = \begin{bmatrix} \Sigma_1 \otimes \underline{\Sigma}_1 & & 0 \\ & \ddots & \\ 0 & & \Sigma_N \otimes \underline{\Sigma}_N \end{bmatrix}.$$

It follows that

$$\boldsymbol{\gamma} | \bar{\boldsymbol{\gamma}}, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N}\left[\tilde{\boldsymbol{\gamma}}, \left(\sum_{t=1}^T \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\boldsymbol{\Sigma}}_\gamma^{-1} \right)^{-1} \right], \qquad (\text{A.27})$$

and

$$\boldsymbol{\Sigma}^{-1} | \boldsymbol{\gamma}, \bar{\boldsymbol{\gamma}}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{W}\left(T + \underline{\nu}, \tilde{S}^{-1} \right), \qquad (\text{A.28})$$

where

$$\tilde{S} = \sum_{t=1}^T \left(\boldsymbol{z}_t^o - \boldsymbol{W}_t^o \boldsymbol{\gamma} \right) \left(\boldsymbol{z}_t^o - \boldsymbol{W}_t^o \boldsymbol{\gamma} \right)' + \underline{S}.$$

B.1.2   Prior and posterior distribution for $\bar{\gamma}$

We now describe the prior and posterior distributions of $\bar{\gamma}$. It is assumed that before observing the data,

$$\bar{\gamma} \sim \mathbb{N}\left(\bar{\hat{\gamma}}, \underline{\Sigma}_{\bar{\gamma}} \right),$$

where $\bar{\hat{\gamma}}$ is the mean of the vectorized OLS estimator of γ_i's on the augmented data matrix that includes the actual data for country i and the dummy observations

$$\bar{\hat{\gamma}} = \frac{1}{N} \sum_{i=1}^N \hat{\gamma}_i^{o+d},$$

and

$$\underline{\Sigma}_{\bar{\gamma}} = s_{\bar{\gamma}} I_{m_\gamma}.$$

The factor $s_{\bar{\gamma}}$ controls the tightness of the prior distribution for $\bar{\gamma}$ and is set to 0.005.

Dummy observations in the data matrix are in the spirit of the Minnesota prior and as implemented in the code `rfvar3` written by Chris Sims. Therefore, the prior distribution for $\bar{\gamma}$ is in fact a mixture of three different prior distributions after some adjustment: a normal distribution centered around the mean of the OLS estimates of VARs for individual entities and two dummy observations prior distributions. Again, because of the small size of our sample, we take a practical approach and use the OLS estimates from an individual VAR model with the same specification for each country to guide the posterior distribution.

Specifically, we include the following two types of dummy observations. The first type represents a prior belief that there exists co-persistence among endogenous variables. Let $\bar{z}_{i,0}^o = p^{-1} \sum_{j=1}^p z_{i,1-j}^o$ and $\bar{x}_0 = p^{-1} \sum_{j=1}^p x_{1-j}$ which are the sample mean of the initial observations for country i and the common exogenous variables. Then we include in the data matrix an observation $\left\{ \lambda \boldsymbol{z}_1^d, \lambda \boldsymbol{W}_1^d \right\}$ where $\boldsymbol{z}_1^d = \begin{bmatrix} \bar{z}_{1,0}^{o\prime} & \cdots & \bar{z}_{N,0}^{o\prime} \end{bmatrix}'$, and

$$\boldsymbol{W}_1^d = \begin{bmatrix} \left(I_{m_z} \otimes w_{1,1}^{d\prime} \right) & & 0 \\ & \ddots & \\ 0 & & \left(I_{m_z} \otimes w_{N,1}^{d\prime} \right) \end{bmatrix},$$

with $w_{i,1}^d = \begin{bmatrix} \bar{z}_{i,0}^{o\prime} & \cdots & \bar{z}_{i,0}^{o\prime} & 0 & \cdots & 0 & \bar{x}_0^{o\prime} \end{bmatrix}'$ for $i = 1, 2, \cdots, N$. When it is substituted in (A.25), it would imply

$$\lambda \boldsymbol{z}_1^d = \lambda \boldsymbol{W}_1^d \boldsymbol{\gamma} + \boldsymbol{u}_1^d.$$

The hyperparameter λ controls how the tightness of the first type of dummy observations.

The second type of dummy observations represents a prior belief in favor of own-persistence of endogenous variables. Let $\bar{Z}_{i,0}^o$ denote an $m_z \times m_z$ symmetric diagonal matrix with $\bar{z}_{i,0}$ on the diagonal and zeros off the diagonal. We include, in the data matrix, m_z observations $\left\{ \mu \boldsymbol{z}_t^d, \mu \boldsymbol{W}_t^d \right\}_{t=2}^{m_z+1}$ such that

$$\begin{pmatrix} \boldsymbol{z}_2^d \\ \vdots \\ \boldsymbol{z}_{m_z+1}^d \end{pmatrix} = \text{vec} \begin{pmatrix} \bar{Z}_{1,0}^o \\ \vdots \\ Z_{N,0}^o \end{pmatrix},$$

and

$$\boldsymbol{W}_t^d = \begin{bmatrix} \left(I_{m_z} \otimes w_{1,t}^{d\prime} \right) & & 0 \\ & \ddots & \\ 0 & & \left(I_{m_z} \otimes w_{N,t}^{d\prime} \right) \end{bmatrix},$$

for $t = 2, \cdots, m_z + 1$ where $w_{i,t}^d = \begin{bmatrix} \left(\bar{z}_{i,0}^o \right)'_{(t-1)} & \cdots & \left(\bar{z}_{i,0}^o \right)'_{(t-1)} & 0 & \cdots & 0 & 0'_{m_x \times 1} \end{bmatrix}'$ for $i = 1, 2, \cdots, N$ and $\left(\bar{z}_{i,0}^o \right)_{(t-1)}$ is an $m_z \times 1$ vector of zeros except that the $(t-1)$-th element is equal to the $(t-1)$-th element of $\bar{z}_{i,0}^o$. The second type implies that the j-th equation of the i-th unit implies that there is a unit root for the j-th variable of $z_{i,t}$. Note that the exogenous variables are assumed to take on zeros. The hyperparameter μ controls the tightness of the second type of dummy observations.

We set $\lambda = 5$ and $\mu = 2$ as is recommended in the literature. It follows that

$$\bar{\boldsymbol{\gamma}} | \boldsymbol{\gamma}, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N} \left[\tilde{\bar{\gamma}}, \left(\sum_{i=1}^N \left(\Sigma_i \otimes \underline{\Sigma}_i \right)^{-1} + \underline{\Sigma}_{\bar{\gamma}}^{-1} \right)^{-1} \right], \quad \text{(A.29)}$$

where

$$\tilde{\bar{\gamma}} = \left(\sum_{i=1}^N \left(\Sigma_i \otimes \underline{\Sigma}_i \right)^{-1} + \underline{\Sigma}_{\bar{\gamma}}^{-1} \right)^{-1} \left(\sum_{i=1}^N \left(\Sigma_i \otimes \underline{\Sigma}_i \right)^{-1} \gamma_i + \underline{\Sigma}_{\bar{\gamma}}^{-1} \bar{\bar{\gamma}} \right).$$

B.1.3   Posterior simulation

We use the Gibbs sampler to alternatingly draw $\boldsymbol{\gamma}$ conditional on $\boldsymbol{\Sigma}$ and $\bar{\gamma}$ from (A.27), $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$ and $\bar{\gamma}$ from (A.28), and $\bar{\gamma}$ conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ from (A.29). We make 200,000 draws and use only the last 100,000 draws to make posterior inferences.

B.2   A case with two groups

Now we consider a case where there are two groups with different average effects. Without loss of generality, the first group consistent of countries $i = 1, \cdots, N_1$ and the second group consists of countries $i = N_1 + 1, \cdots, N$. We reuse some notations from the previous section. But their meaning should be clear from the context.

We assume that for $i = 1, \cdots, N$

$$\gamma_i = \bar{\gamma}_1 \times I_F(i) + \bar{\gamma}_2 \times [1 - I_F(i)] + v_i,$$

where $I_F(i)$ is an indicator function that takes on 1 if country i belongs to the first group and 0 otherwise, $v_i \sim \mathbb{N}(0, \Sigma_i \otimes \underline{\Sigma}_i)$. Independence between α_i's is assumed within each group and across groups: $E\left(v_i v_j'\right) = 0$ for $i \neq j$.

B.2.1 Prior and posterior distribution for $\boldsymbol{\gamma}$ (γ_i's) and $\boldsymbol{\Sigma}$

We use the same hyperparameters for the prior distribution of $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ as in the single group case. It follows that

$$\boldsymbol{\gamma} | \bar{\gamma}_1, \bar{\gamma}_2, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N}\left[\tilde{\gamma}, \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\Sigma}_\gamma^{-1} \right)^{-1} \right], \tag{A.30}$$

where

$$\bar{\boldsymbol{\gamma}} = \left(\begin{array}{ccc} I_F(1) & \cdots & I_F(N) \end{array} \right)' \otimes \bar{\gamma}_1 + \left(\begin{array}{ccc} 1 - I_F(1) & \cdots & 1 - I_F(N) \end{array} \right)' \otimes \bar{\gamma}_2,$$

$$\hat{\boldsymbol{\gamma}} = \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o \right)^{-1} \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{z}_t^o \right),$$

$$\tilde{\boldsymbol{\gamma}} = \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\Sigma}_\gamma^{-1} \right)^{-1} \left[\left(\sum_{t=1}^{T} \boldsymbol{X}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{X}_t^o \right) \hat{\boldsymbol{\gamma}} + \left(\underline{\Sigma}_\gamma^{-1} \right) \bar{\boldsymbol{\gamma}} \right],$$

and that is common in business cycle studies.

$$\boldsymbol{\Sigma}^{-1} | \boldsymbol{\gamma}, \bar{\gamma}_1, \bar{\gamma}_2, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{W}\left(T + \underline{\nu}, \tilde{S}^{-1} \right), \tag{A.31}$$

where

$$\tilde{S} = \sum_{t=1}^{T} \left(\boldsymbol{z}_t^o - \boldsymbol{W}_t^o \boldsymbol{\gamma} \right) \left(\boldsymbol{z}_t^o - \boldsymbol{W}_t^o \boldsymbol{\gamma} \right)' + \underline{S}.$$

B.2.2 Prior and posterior distribution for $\bar{\gamma}_1$ and $\bar{\gamma}_2$

A priori, we assume that

$$\begin{aligned} \bar{\gamma}_1 &\sim \mathbb{N}\left(\bar{\hat{\gamma}}_1, \underline{\Sigma}_{\bar{\gamma}} \right), \\ \bar{\gamma}_2 &\sim \mathbb{N}\left(\bar{\hat{\gamma}}_2, \underline{\Sigma}_{\bar{\gamma}} \right), \end{aligned}$$

where $\bar{\hat{\gamma}}_1$ and $\bar{\hat{\gamma}}_2$ are the mean of the vectorized OLS estimator of γ_i's for the first and second group, respectively, on the augmented data matrix that includes the actual data for unit i and the dummy observations

$$\begin{aligned} \bar{\hat{\gamma}}_1 &= \frac{1}{N_1} \sum_{i=1}^{N_1} \hat{\gamma}_i^{o+d}, \\ \bar{\hat{\gamma}}_2 &= \frac{1}{N - N_1} \sum_{i=N_1+1}^{N} \hat{\gamma}_i^{o+d} \end{aligned}$$

and

$$\underline{\Sigma}_{\bar{\gamma}} = s_{\bar{\gamma}} I_{m_\gamma}.$$

We use the same hyperparameters for the prior distribution of $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ as in the single group case.

Conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$, the posterior distribution for $\bar{\gamma}_1$ is

$$\bar{\gamma}_1 | \boldsymbol{\gamma}, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N} \left[\tilde{\bar{\gamma}}_1, \left(\sum_{i=1}^{N_1} (\Sigma_i \otimes \underline{\Sigma}_i)^{-1} + \Sigma_{\bar{\gamma}}^{-1} \right)^{-1} \right], \tag{A.32}$$

and the posterior distribution for $\bar{\gamma}_2$ is

$$\bar{\gamma}_2 | \boldsymbol{\gamma}, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N} \left[\tilde{\bar{\gamma}}_2, \left(\sum_{i=N_1+1}^{N} (\Sigma_i \otimes \underline{\Sigma}_i)^{-1} + \Sigma_{\bar{\gamma}}^{-1} \right)^{-1} \right], \tag{A.33}$$

where

$$
\begin{aligned}
\tilde{\bar{\gamma}}_1 &= \left(\sum_{i=1}^{N_1} (\Sigma_i \otimes \underline{\Sigma}_i)^{-1} + \Sigma_{\bar{\gamma}}^{-1} \right)^{-1} \left[\left(\sum_{i=1}^{N_1} (\Sigma_i \otimes \underline{\Sigma}_i)^{-1} \right) \gamma_i + \left(\Sigma_{\bar{\gamma}}^{-1} \right) \bar{\bar{\gamma}}_1 \right], \\
\tilde{\bar{\gamma}}_2 &= \left(\sum_{i=N_1+1}^{N} (\Sigma_i \otimes \underline{\Sigma}_i)^{-1} + \Sigma_{\bar{\gamma}}^{-1} \right)^{-1} \left[\left(\sum_{i=N_1+1}^{N} (\Sigma_i \otimes \underline{\Sigma}_i)^{-1} \right) \gamma_i + \left(\Sigma_{\bar{\gamma}}^{-1} \right) \bar{\bar{\gamma}}_2 \right].
\end{aligned}
$$

B.2.3 Posterior simulation

We use the Gibbs sampler to alternatingly draw $\boldsymbol{\gamma}$ conditional on $\boldsymbol{\Sigma}$, $\bar{\gamma}_1$ and $\bar{\gamma}_2$ from (A.30), $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$, $\bar{\gamma}_1$ and $\bar{\gamma}_2$ from (A.31), and $\bar{\gamma}_1$ and $\bar{\gamma}_2$ conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ from (A.32) and (A.33). We make 200,000 draws and use only the last 100,000 draws to make posterior inferences.

B.3 Contribution of the VIX shock

We compute the contribution of the VIX shock to the dynamics of the endogenous variables in $z_{i,t}^o$ as follows. Here we treat the VIX shock as a stochastic shock that varies over time while the exogenous variables in $x_{i,t}^o$ are perfectly predictable over time. Under this assumption, we can write

$$z_{i,t+h}^o - E_t z_{i,t+h}^o = \sum_{j=0}^{h-1} \left(\Phi_{h,h-j}^{VIX} \varepsilon_{VIX,t+h-j} + \Phi_{h,h-j}^u u_{i,t+h-j}^o \right),$$

for $h \geq 1$, where E_t is the expectation operator given the information set available in time period t. Note that an $m_z \times 1$ matrix $\Phi_{h,h-j}^{VIX}$ is the impulse response of $z_{i,t+h}^o$ to a shock to $\varepsilon_{VIX,t+h-j}$ and an $m_z \times m_z$ matrix $\Phi_{h,h-j}^u$ is the impulse response of $z_{i,t+h}^o$ to a shock to $u_{i,t+h-j}^o$. The impulse responses can be easily computed using a recursive algorithm. The VIX shock is assumed to be exogenous to the innovations for the endogenous variables and also a white noise over time with mean 0 and variance σ_{VIX}^2. It follows that

$$E_t \left[\left(z_{i,t+h}^o - E_t z_{i,t+h}^o \right)^2 \right] = \sum_{j=0}^{h-1} \left[\Phi_{h,h-j}^{VIX} \left(\Phi_{h,h-j}^{VIX} \right)' \sigma_{VIX}^2 + \Phi_{h,h-j}^u \Sigma_i \left(\Phi_{h,h-j}^u \right)' \right].$$

Let us denote
$$\Sigma_{i,(t+h,t)} = E_t\left[\left(z_{i,t+h}^o - E_t z_{i,t+h}^o\right)^2\right] = \Sigma_{i,(t+h,t)}^{VIX} + \Sigma_{i,(t+h,t)}^u,$$
where

$$\Sigma_{i,(t+h,t)}^{VIX} = \sum_{j=0}^{h-1}\left[\Phi_{h,h-j}^{VIX}\left(\Phi_{h,h-j}^{VIX}\right)' \sigma_{VIX}^2\right],$$

$$\Sigma_{i,(t+h,t)}^u = \sum_{j=0}^{h-1}\left[\Phi_{h,h-j}^u \Sigma_i \left(\Phi_{h,h-j}^u\right)'\right].$$

Then the contribution of the VIX shock in the h-period ahead forecast error variance of $z_{i,t}^o$ is given by $\operatorname{diag}\left(\Sigma_{i,(t+h,t)}^{VIX}\right)/\operatorname{diag}\left(\Sigma_{i,(t+h,t)}\right)$, where diag is the operator that extracts the diagonal elements of a given matrix.

C   Details of the theoretical model

We here describe the non-linear aggregate equilibrium conditions and the deterministic steady-state of the baseline model in detail.

C.1   Non-linear equilibrium conditions

We present here in detail all the non-linear, aggregate equilibrium conditions of the model. First, note that given our definition of relative prices and exchange rate, we have the following relationships that will be useful for exposition

$$r_t \equiv \frac{p_t}{p_{H,t}} = \left[(1-\chi) + \chi\varsigma_t^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} = r(\varsigma_t), \tag{A.34}$$

$$Q_t \equiv \frac{S_t p_t^*}{p_t} = \frac{S_t \frac{p_t^*}{p_{F,t}^*}}{\frac{p_t}{p_{H,t}}} \frac{p_{F,t}^*}{p_{H,t}} = \frac{1}{\left[(1-\chi) + \chi\varsigma_t^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}} \frac{p_{F,t}}{p_{H,t}} = \frac{\varsigma_t}{r(\varsigma_t)} = q(\varsigma_t), \tag{A.35}$$

$$\frac{r\left(\varsigma_t\right)}{r(\varsigma_{t-1})} = \frac{\Pi_t}{\Pi_{H,t}} \tag{A.36}$$

where $\varsigma_t \equiv \frac{p_{F,t}}{p_{H,t}}$, $\frac{p_t}{p_{t-1}} = \Pi_t$, and $\frac{p_{H,t}}{p_{H,t-1}} = \Pi_{H,t}$.

The home household's optimality conditions from one of the first-stage static expenditure minimization problems are standard and given by

$$p_t = \left[(1-\chi)\, p_{H,t}^{1-\varepsilon} + \chi p_{F,t}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}},$$

$$\frac{c_{H,t}}{c_t} = \frac{i_{H,t}}{i_t} = (1-\chi)\, r(\varsigma_t)^\varepsilon, \quad \frac{c_{F,t}}{c_t} = i_{F,t} = \chi q(\varsigma_t)^{-\varepsilon}. \tag{A.37}$$

Given these, the other household optimality conditions from the second-stage dynamic maximization problems are

$$\frac{-U_h\left(c_t - \mu\tilde{c}_{t-1}, h_t\right)}{U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right)} = w_t, \tag{A.38}$$

$$\frac{Q_t}{p_t^*} U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right) = \beta \frac{R_t}{\left(1 - \Psi'\left(d_t^*\right)\right)} E_t\left[\frac{U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right) Q_{t+1}}{p_{t+1}^*}\right], \tag{A.39}$$

$$U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right) = \beta I_t E_t\left[\frac{U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)}{\Pi_{t+1}}\right], \tag{A.40}$$

$$\begin{aligned}
\frac{U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right)}{\Phi'\left(\frac{i_t}{k_t}\right)} &= \beta E_t\left[\frac{U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)}{\Phi'\left(\frac{i_{t+1}}{k_{t+1}}\right)}\left((1-\delta) + \Phi\left(\frac{i_{t+1}}{k_{t+1}}\right) - \frac{i_{t+1}}{k_{t+1}}\Phi'\left(\frac{i_{t+1}}{k_{t+1}}\right)\right)\right] \\
&\quad + \beta E_t\left[U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)u_{t+1}\right].
\end{aligned} \tag{A.41}$$

In addition, a standard Transversality condition is part of the optimality conditions as well. The household optimality conditions above have a standard interpretation. (A.38) equates the real wage with the marginal rate of substitution between consumption and labor supply. (A.39) is an Euler equation where the interest rate on international borrowing has an adjustment term related to cost of debt adjustment as well as the exchange rate. (A.40) is an Euler equation obtained from optimal choice over the domestic currency bond. (A.41) determines optimal investment in the model, given that there are investment adjustment cost with the same interpretation as in the q-theory of investment.

For the firm's optimality conditions, first note that we only focus on an equilibrium where R_{t-1}^d is strictly positive. This means that the working capital constraint (13) will always bind, giving us $\kappa_t(i) = \eta w_t h_t(i)$. To conserve space, we will now present the aggregate optimality conditions obtained after imposing symmetric prices and allocations across firms.[41] Then, the firm optimality conditions are given by

$$U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right) = \beta E_t\left[U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)\frac{R_t^d r(\varsigma_t)}{r(\varsigma_{t+1})}\right], \tag{A.42}$$

$$\xi_t F_h(k_t, h_t)\frac{1}{r(\varsigma_t)} = w_t\left(1 + \eta\left(1 - \frac{1}{R_t^d}\right)\right) + \beta\eta w_t E_t\left[\left(\frac{U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)}{U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right)}\right)\left(\frac{r(\varsigma_t)}{r(\varsigma_{t+1})} - 1\right)\right], \tag{A.43}$$

$$\xi_t F_k(k_t, h_t)\frac{1}{r(\varsigma_t)} = u_t, \tag{A.44}$$

$$\begin{aligned}
&\left[\left(\frac{\nu - 1}{\nu}\right) - \xi_t\right]\nu Y_t + d'\left(\Pi_{H,t}\right)\Pi_{H,t} \\
&= E_t\left[\beta\frac{U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)}{U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right)}\frac{r(\varsigma_t)}{r(\varsigma_{t+1})}d'\left(\Pi_{H,t+1}\right)\Pi_{H,t+1}\right],
\end{aligned} \tag{A.45}$$

where ξ_t is the shadow price on the demand function constraint (14).[42] In addition, a standard Transversality condition is part of the optimality conditions as well. Finally, note that we assume that the firm starts with no net liabilities. Thus, $a_{-1} = 0$. Then, it is optimal that $a_t = 0$ for all t as well. Thus, we have the equilibrium expression for firm profits as

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[41] Thus in we omit for instance, a presentation of the optimality condition given by choice over goods prices.

[42] This shadow price can in turn be written as a function of factor prices in the model. In particular, given our functional form assumption on the production function that we present later, we have

$$\frac{\xi_t}{r(\varsigma_t)} = \frac{1}{(1-\alpha)^{1-\alpha}\alpha^\alpha}u_t^\alpha\left[w_t\left(1 + \eta\left(1 - \frac{1}{R_t^d}\right)\right) + \beta\eta w_t E_t\left[\left(\frac{U_c\left(c_{t+1} - \mu\tilde{c}_t, h_{t+1}\right)}{U_c\left(c_t - \mu\tilde{c}_{t-1}, h_t\right)}\right)\left(\frac{r(\varsigma_t)}{r(\varsigma_{t+1})} - 1\right)\right]\right]^{1-\alpha}.$$

$$\varphi_t = \frac{1}{r(\varsigma_t)} F(k_t, h_t) - \frac{1}{r(\varsigma_t)} d(\Pi_{H,t}) - w_t h_t \left(1 + \eta \left(1 - \frac{1}{R_t^d}\right)\right) - u_t k_t - \left(\frac{r(\varsigma_{t-1})}{r(\varsigma_t)} - 1\right) \eta w_{t-1} h_{t-1}. \quad \text{(A.46)}$$

The firm optimality conditions above have a standard interpretation, subject to the additional features in our model of two goods as well as a working capital constraint. (A.42) is an Euler equation where since the liabilities of the firms are in terms of home goods prices, an adjustment for relative prices appears. (A.43) is a optimality condition linking the marginal product of labor to real wage and it features a wedge due to imperfect competition as well as a wedge due to the working capital constraint.[43] (A.44) is a optimality condition linking the marginal product of capital to the rental rate and it features a wedge due to imperfect competition.[44] Finally, (A.45) is a non-linear Phillips curve in the model arising because of nominal rigidities that governs the dynamics of home inflation.

For the goods market clearing condition, using the relative demand conditions (A.37) above, symmetry across firms, the law of one price for the home good, and imposing symmetry for the demand from the foreign country for the home good, we have

$$y_t = (1 - \chi) r(\varsigma_t)^\varepsilon [c_t + i_t] + \chi \varsigma_t^\varepsilon [c_t^* + i_t^*] + d(\Pi_{H,t}) \quad \text{(A.47)}$$

where again, we take the term $y_t^* = c_t^* + i_t^*$ as given exogenously. We also have that in equilibrium

$$\tilde{c}_{t-1} = c_{t-1}. \quad \text{(A.48)}$$

Thus, the dynamics of the 17 endogenous aggregate variables $\{d_t, w_t, h_t, u_t, k_t, c_t, i_t, R_t^d, y_t, \tilde{c}_t, \varphi_t, \varsigma_t, \Pi_t, \Pi_{H,t}, b_t, I_t, \xi_t\}$ can be solved using the 17 equilibrium conditions given by (10), (11), (12), (17), (18), (A.36), (A.38), (A.39), (A.40), (A.41), (A.42), (A.43), (A.44), (A.45), (A.46), (A.47), and (A.48).[45] In terms of the exogenous variable, our baseline specification features a first-moment shock to the interest rate spread, while the extended specification also considers a second-moment shock to the interest rate spread and a shock to foreign income/demand.

C.2 Steady-state

The deterministic steady-state of the model is relatively straight-forward to derive in closed-form. We have, as described in the main text

$$d^* = d, \ \Pi = \Pi_H = 1, \ I = R^d = \bar{R} = \frac{1}{\beta}, \ \varsigma = r(\varsigma) = q(\varsigma) = 1.$$

Next, we have as investment to capital stock ratio and the two factor prices

$$\frac{i}{k} = \delta, u = \frac{1}{\beta} - (1 - \delta), w = \left[\left(\frac{\varepsilon - 1}{\varepsilon}\right)(1 - \alpha)^{1-\alpha} \alpha^\alpha u^{-\alpha}\right]^{\frac{1}{1-\alpha}} (1 + \eta(1 - \beta))^{-1}.$$

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[43]In addition, relative prices appear here to express the variables in the same units. Note here that because our model has two-goods, relative prices introduce a dynamic wedge in the model, unlike a simple static $\eta \left(1 - \frac{1}{R_t^d}\right)$ wedge that would appear in a one good model.

[44]Again, relative prices appear here so that variables are in terms of same units.

[45]We can then determine the good specific consumption and investment, given solution for the aggregates and terms of trade $\{c_t, i_t, \varsigma_t\}$, from (A.37).

Finally, we can derive variables in levels as

$$h = \left[\left(\frac{\nu - 1}{\nu} \right) (1 - \alpha)^{1-\alpha} \, \alpha^{\alpha} \left(\frac{1}{\beta} - (1 - \delta) \right)^{-\alpha} (1 + \eta (1 - \beta))^{-(1-\alpha)} \right]^{\frac{1}{1-\alpha} \frac{1}{\omega - 1}},$$

$$\xi = \left(\frac{\nu - 1}{\nu} \right), k = h \left(\frac{w}{u} \frac{(1 + \eta (1 - \beta))}{1} \right) \frac{\alpha}{1 - \alpha}, y = h \left(\frac{k}{h} \right)^{\alpha},$$

$$i = h\delta \left(\frac{w}{u} \frac{(1 + \eta (1 - \beta))}{1} \right) \frac{\alpha}{1 - \alpha}, \varphi = y - wh (1 + \eta (1 - \beta)) - uk,$$

$$c = \left(1 - \frac{1}{\beta} \right) d^* - i + y - wh\eta (1 - \beta), y^* = (y - (1 - \chi) [c + i]) \frac{1}{\chi}.$$

D Extensions and robustness

D.1 Empirical results

Figure A.1 presents the spillover effects on the alternative measures of economic activity and aggregate spending in EMEs where to conserve space we only present the responses of the alternative measures. GDP, consumption, and investment all respond negatively to the uncertainty shock with investment responding most strongly. Figure A.2 in the first row, reports the spillover effects of the US uncertainty shock on long-term real interest rate spreads, real effective exchange rates, and net exports to the world and in the second row, reports the spillover effects on alternate measures of external balance and capital flows that use TIC data. Again, to conserve space we only present the responses of the alternate variables.
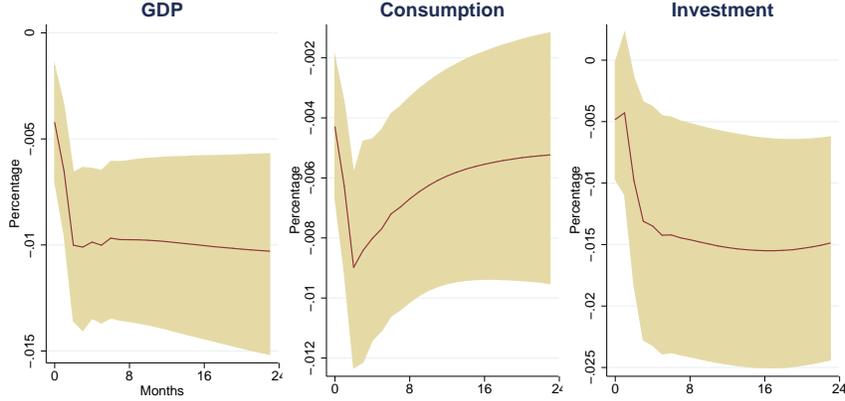
Figure A.1: Impulse responses of the EM panel VAR to the US uncertainty shock: other macroeconomic activity variables

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error bands in an alternative specification that includes GDP, consumption and investment as a measure of economic activity. The EM panel VAR includes the baseline seven variables except IP plus an alternative measure of economic activity but only the impulse response of the different measures of economic activity is displayed. Quarterly data on GDP, consumption and investment is interpolated into monthly observations. For the details, see the Data Appendix.
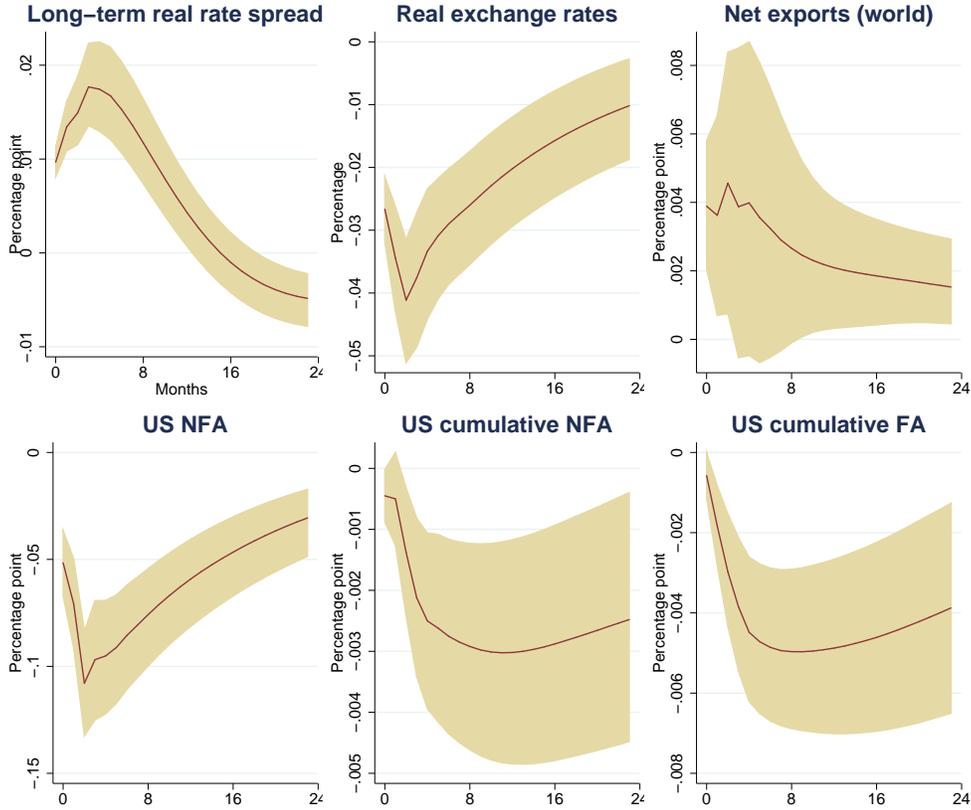
Figure A.2: Impulse responses of the EM panel VAR to the US uncertainty shock: other open economy and financial variables

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error bands in alternative specifications. In the first row, these are where the long-term nominal interest rate is replaced with the long-term real interest rate, the nominal effective exchange rate is replaced with the real effective exchange rate, and the net exports to the US is replaced with the net exports to the world, respectively. In the second row, these are where net exports to the US is replaced with net foreign asset position of the US on the EMEs, capital flows is replaced with cumulated net foreign asset position of the US on the EMEs, and capital flows is replaced with cumulated US foreign asset positions. Only the impulse response of the alternative variables is displayed. For the details, see the Data Appendix.

We do some robustness exercises on our measure of shock, and both our baseline as well as sub-group panel VAR estimations. First, the US VAR is extended to include eight total variables, as in Bloom (2009). We then identify US VIX shock by ordering VIX second, after S&P 500. This is the order used in Bloom (2009). The results are presented in Figure A.3. Second, we compare the baseline reduced-form shock to the identified shock from the orthogonalization scheme that orders VIX last. The identified shock is very similar to the baseline shock. The largest difference between the two shock series is less than 0.03 while the standard deviation of the two shock series is about 1.05. We do not present the orthogonalized shock since it is hardly distinguishable from the reduced-form shock. Note again that the shock series from ordering VIX first would be identical to our baseline series. Third, we simply use the growth rate of VIX as a measure of uncertainty shock in the EME panel VAR. This partly addresses the generated regressor problem that arises in our two-step estimation procedure. The results are presented in Figure A.4. Fourth, in the three variable VAR specification, we replace VIX with the financial uncertainty measure of Ludvigson, Ma, and Ng (2015). The results are presented in Figure A.5.
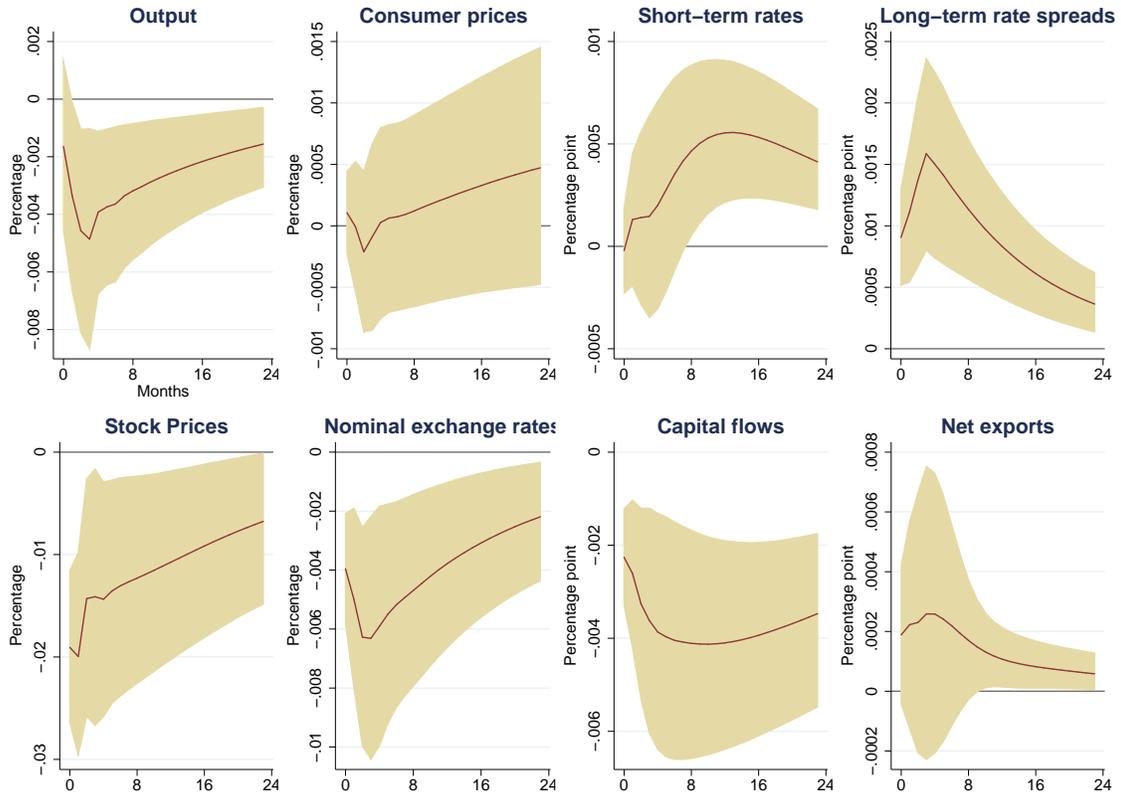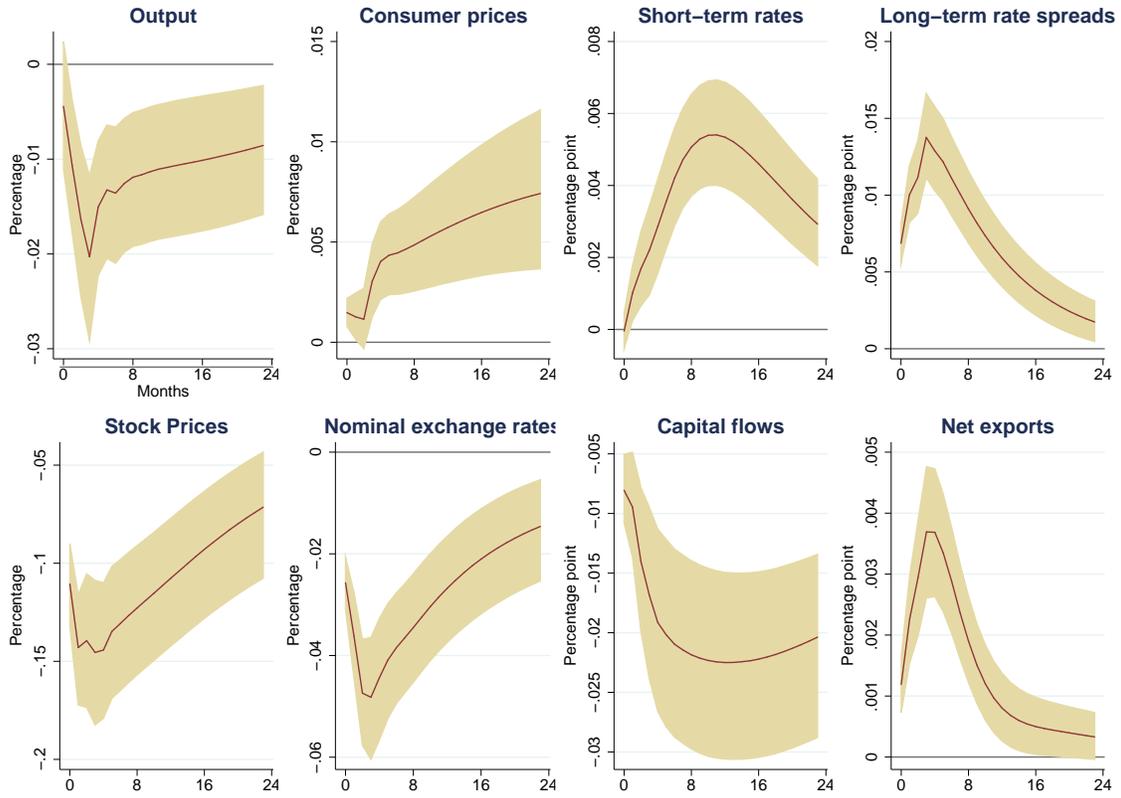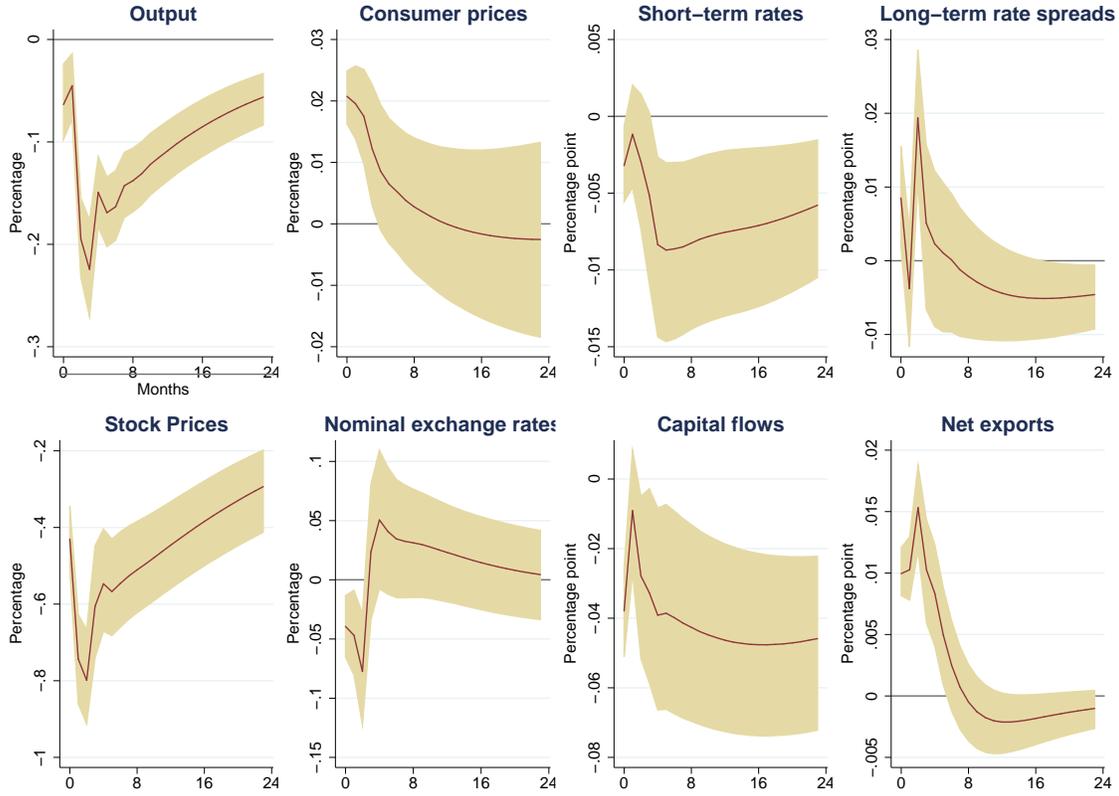
Figure A.3: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the baseline specification that includes the both macroeconomic and financial variables. The US uncertainty shock is an identified shock in a eight variable US VAR specification where the identification scheme follows Bloom (2009). See notes in Figure 2.

Figure A.4: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the baseline specification that includes the both macroeconomic and financial variables. The US uncertainty shock is simply the growth rate of VIX. See notes in Figure 2.

Figure A.5: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the baseline specification that includes the both macroeconomic and financial variables. The US uncertainty shock is computed from a three variable US VAR specification, like the baseline specification, but uses the financial uncertainty measure of Ludvigson, Ng, and Ma (2015), instead of the VIX. See notes in Figure 2.

Next, we check that our main results are not sensitive to lag length selection in the panel VAR. Results using four lags of the US uncertainty shock in the panel VAR are reported in Figure A.6 and A.7. The results with five and six lags of the US uncertainty shock show similar responses and are available upon request.
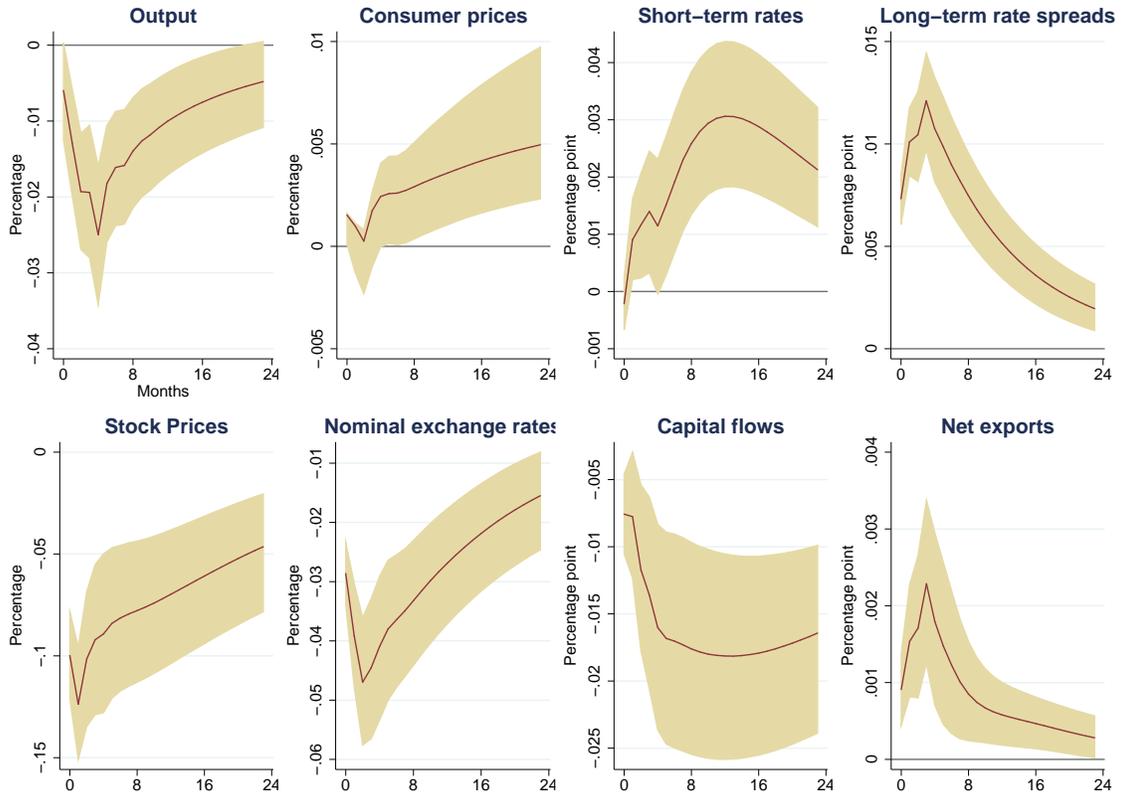
Figure A.6: Impulse responses of the EM panel VAR to the US uncertainty shock: with four lags of the US uncertainty shock

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the baseline specification that includes the both macroeconomic and financial variables. Four lags of the US uncertainty shock are included. See notes in Figure 2.
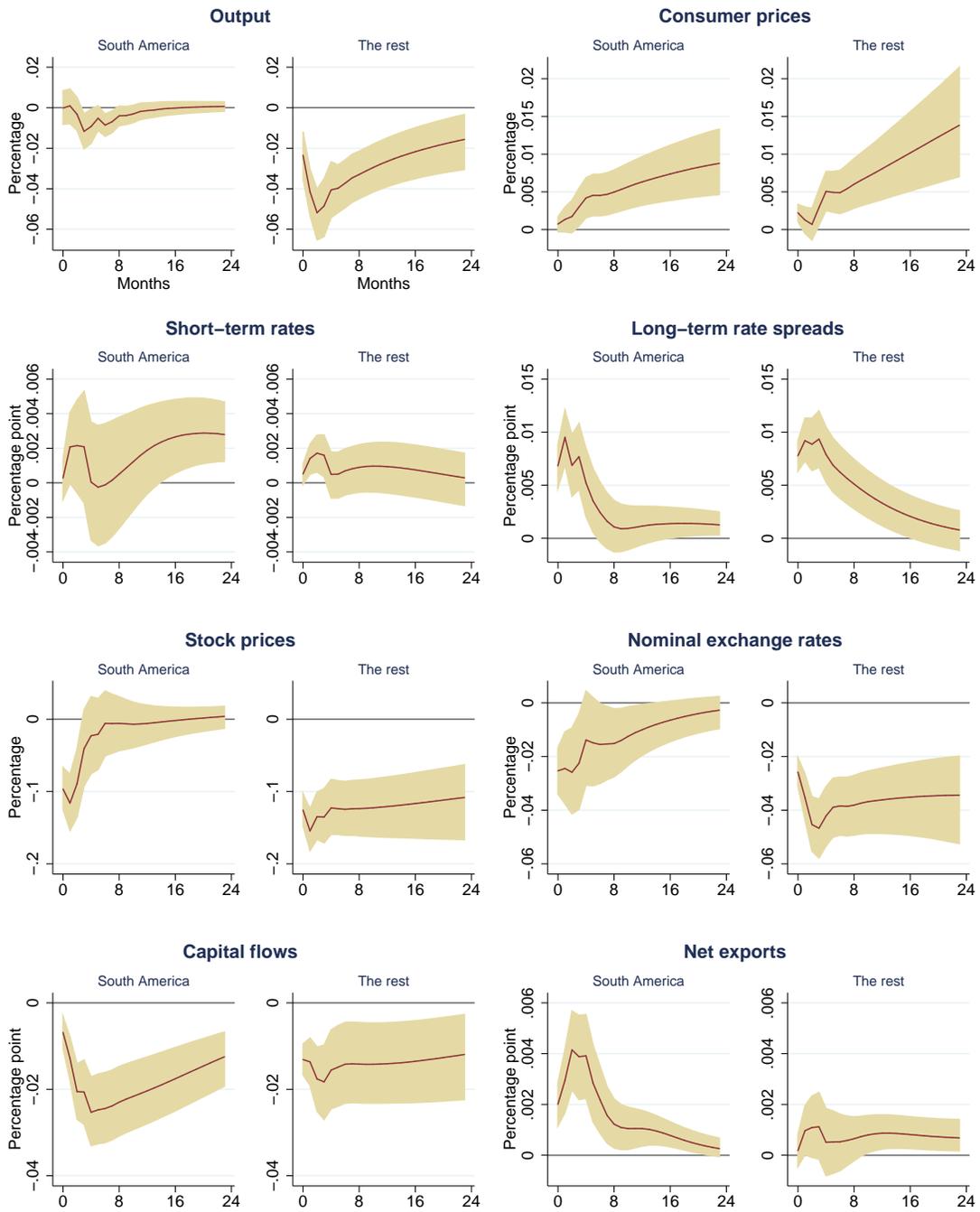
Figure A.7: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables; South America vs. the rest; with four lags of the US uncertainty shock

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the specification for subgroup analysis that includes both the macroeconomic and financial variables. Four lags of the US uncertainty shock are included. Subplots are arranged by variables and shown for two groups of countries: South America including Brazil, Chile, Colombia, Mexico, Malaysia, and Peru and the rest of the EM economies. See the notes in Figure 2.

For the sub-group estimation, we have also checked our results on using other activity measures and other financial and open economy variables. As one example, we report results using long-term real rate spreads in Figure A.8.
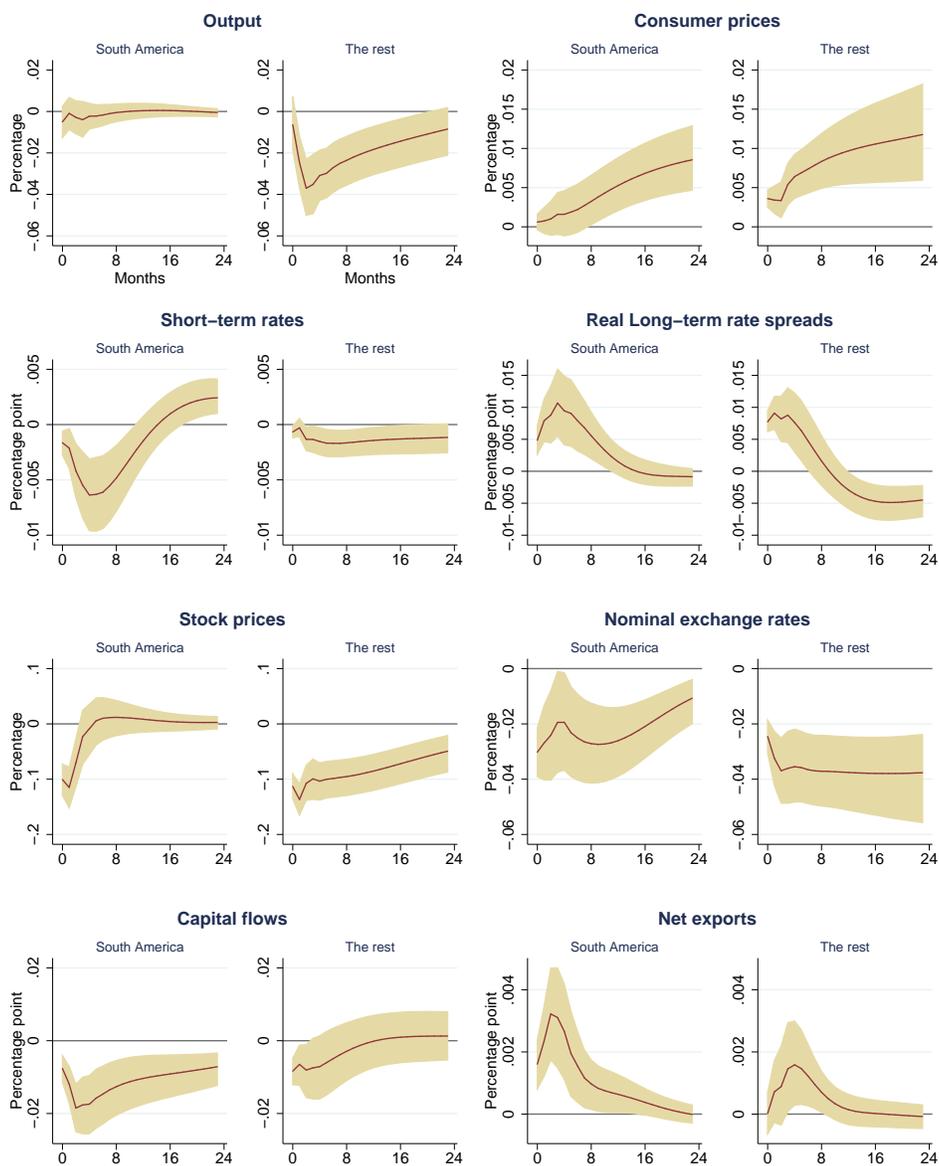

Figure A.8: Impulse responses of the EM panel VAR to the US uncertainty shock: macroeconomic and financial variables; South America vs. the rest; with real long-term rate spreads

Notes: Each plot presents the posterior median of the impulse responses to a 1% increase in the US uncertainty shock along with the 90% error band in the specification for subgroup analysis that includes both the macroeconomic and financial variables. Nominal long-term interest rate spreads are replaced with real long-term interest rate spreads. Subplots are arranged by variables and shown for two groups of countries: South America including Brazil, Chile, Colombia, Mexico, Malaysia, and Peru and the rest of the EM economies. See the notes in Figure 2.

We now present the contribution of the US uncertainty shock in the h-period ahead forecast error variance

of the EME variables. The method used to compute these variance decomposition results is described above in the Appendix.

Table A.1: Forecast error variance decomposition (%)

Horizon	Output	Short rate	LR spread	Exch Rate	Cap Flows
1	1.74	0.37	10.67	7.49	2.70
3	15.02	0.63	14.89	12.18	3.39
12	11.62	6.35	20.04	13.49	8.63
24	11.11	9.59	12.52	12.43	12.76

Notes: Forecast error variance decomposition at different horizons in the specification for all EMEs that includes financial and macroeconomic variables. See the Appendix for details on the method used to compute these variance decomposition results.

Table A.2: Forecast error variance decomposition for South American EMEs (%)

Horizon	Output	Short rate	LR spread	Exch Rate	Cap Flows
1	0.48	0.28	6.55	4.39	2.71
3	9.79	0.97	8.88	4.37	13.88
12	12.07	5.42	6.56	8.77	17.75
24	10.85	6.05	5.27	12.96	18.91

Notes: Forecast error variance decomposition at different horizons for South American EMEs in the sub group specification that includes financial and macroeconomic variables. See the Appendix for details on the method used to compute these variance decomposition results.

Table A.3: Forecast error variance decomposition for Rest of EMEs (%)

Horizon	Output	Short rate	LR spread	Exch Rate	Cap Flows
1	1.72	0.40	15.16	6.70	2.91
3	14.71	1.46	14.37	11.71	1.96
12	13.24	5.54	13.07	12.77	3.52
24	11.00	9.88	12.93	13.97	6.84

Notes: Forecast error variance decomposition at different horizons for rest of EMEs in the sub group specification that includes financial and macroeconomic variables. See the Appendix for details on the method used to compute these variance decomposition results.

D.2 Theoretical results

We now consider a second-moment shock to the foreign interest rate and compute the responses of the model variables to a purely second-moment shock, that is, one where we hold the first-moment shock at its steady-state. We use a third-order accurate perturbation solution method to compute the stochastic equilibrium. For the parameterization of the second-moment shock, we use estimates in Fernandez-Villaverde et al (2011) for Brazil and use a simple AR(1) process for the interest rate shock as opposed to an ARMA (1,3), so that it is easily comparable to the literature. Figure A.9 shows the results.
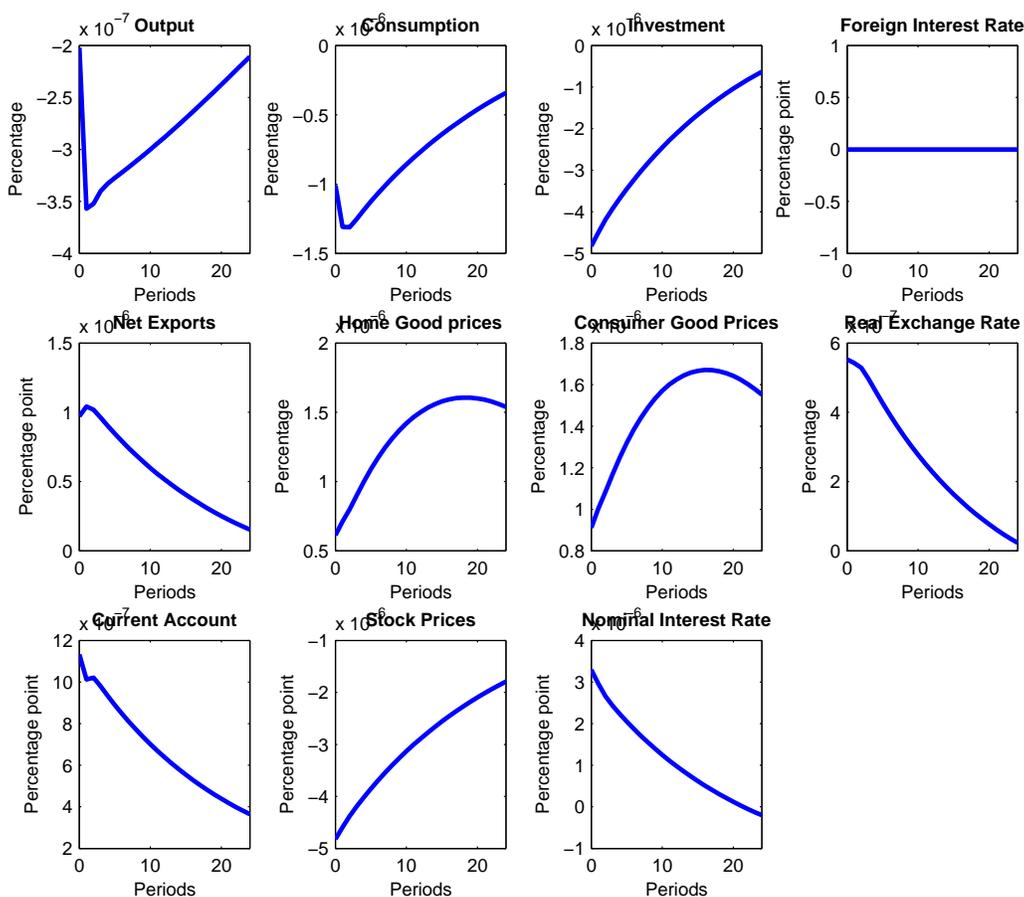
Figure A.9: Impulse responses of the small open economy model to a shock to the volatility of the foreign interest rate spread

Notes: These are non-linear impulse responses to a second-moment shock (volatility shock) to the foreign interest rate spread. The solution method is a third-order perturbation.

For the baseline case, we show in Figures A.10 and A.11, results when we use a greater level of price stickiness (d_1=50) and a lower trade elasticity (ε=0.9) respectively. Finally, we also consider a negative foreign income/output shock as a possible proxy for the US uncertainty shock. We use the same parameters for the size of this shock as the baseline interest rate spread shock and for persistence use a random walk specification that is common in business cycle studies. The results are reported in Figure A.12.
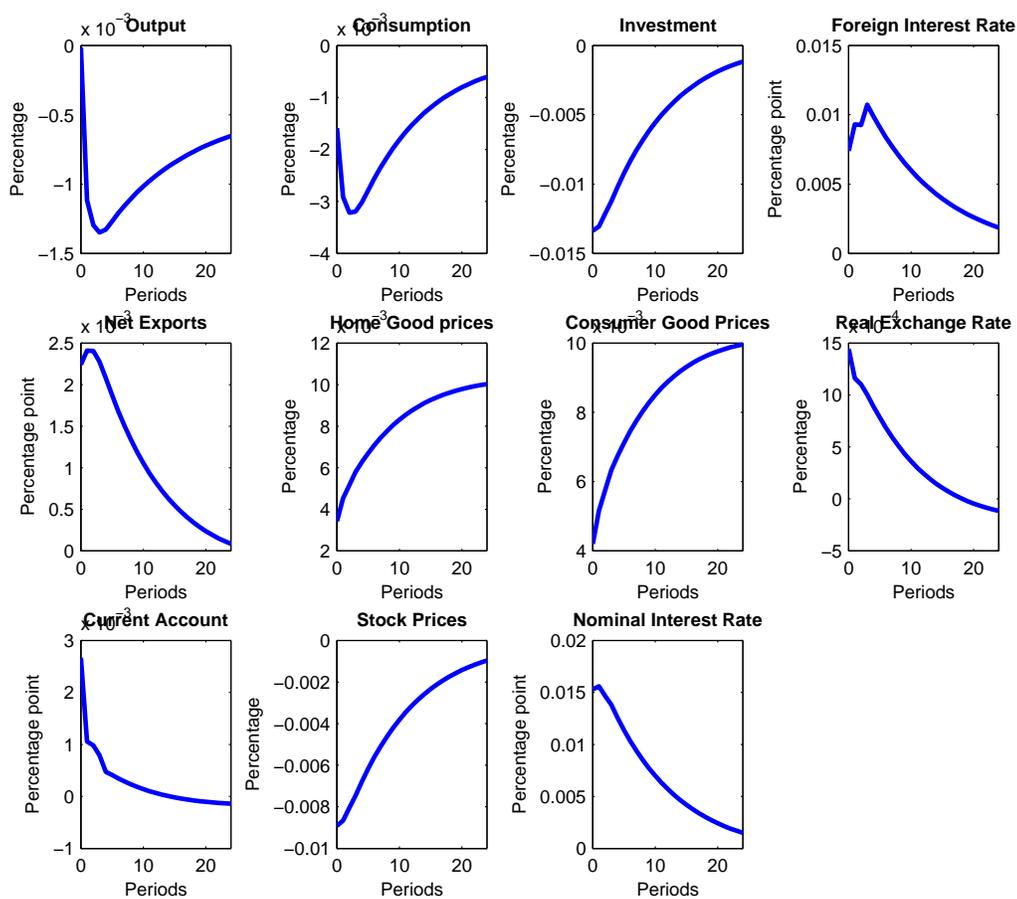
Figure A.10: Impulse responses of the small open economy model to a shock to the foreign interest rate spread with stronger nominal rigidities than baseline

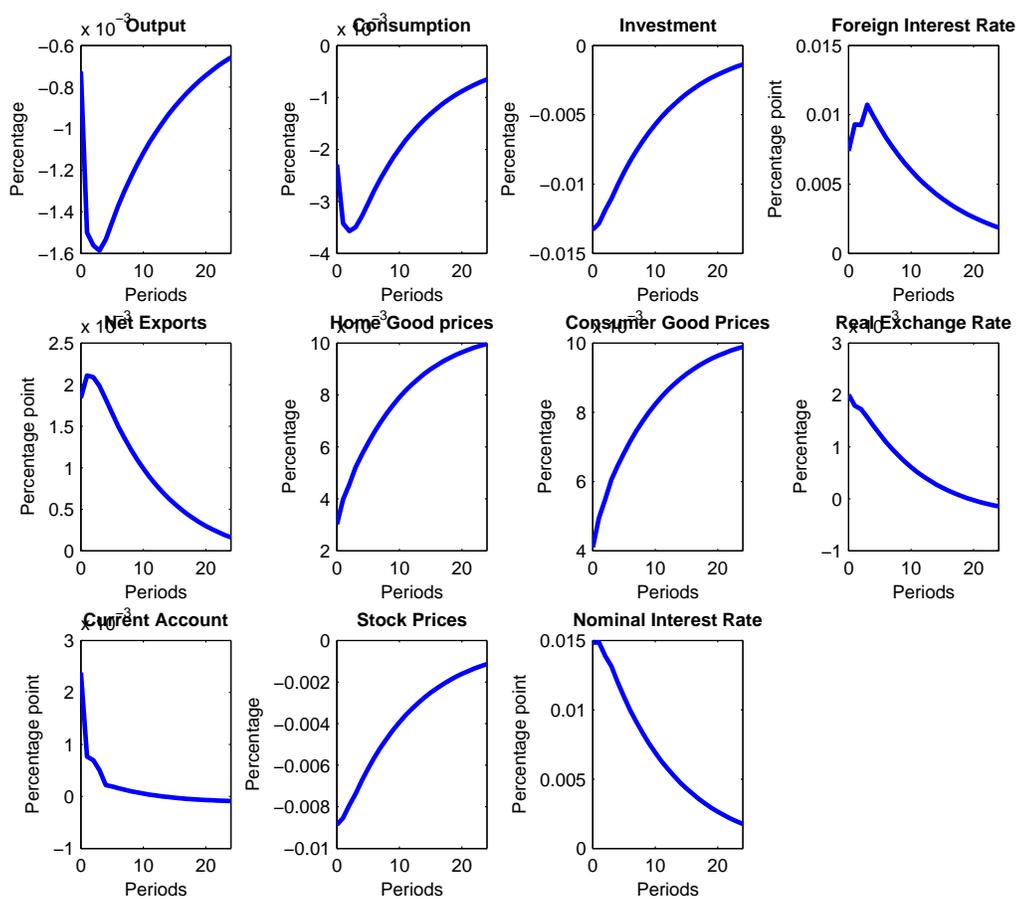*Notes*: Compared to the baseline in 4, prices are more sticky. Also, see the notes in Figure 4.

Figure A.11: Impulse responses of the small open economy model to a shock to the foreign interest rate spread with lower trade elasticity than baseline

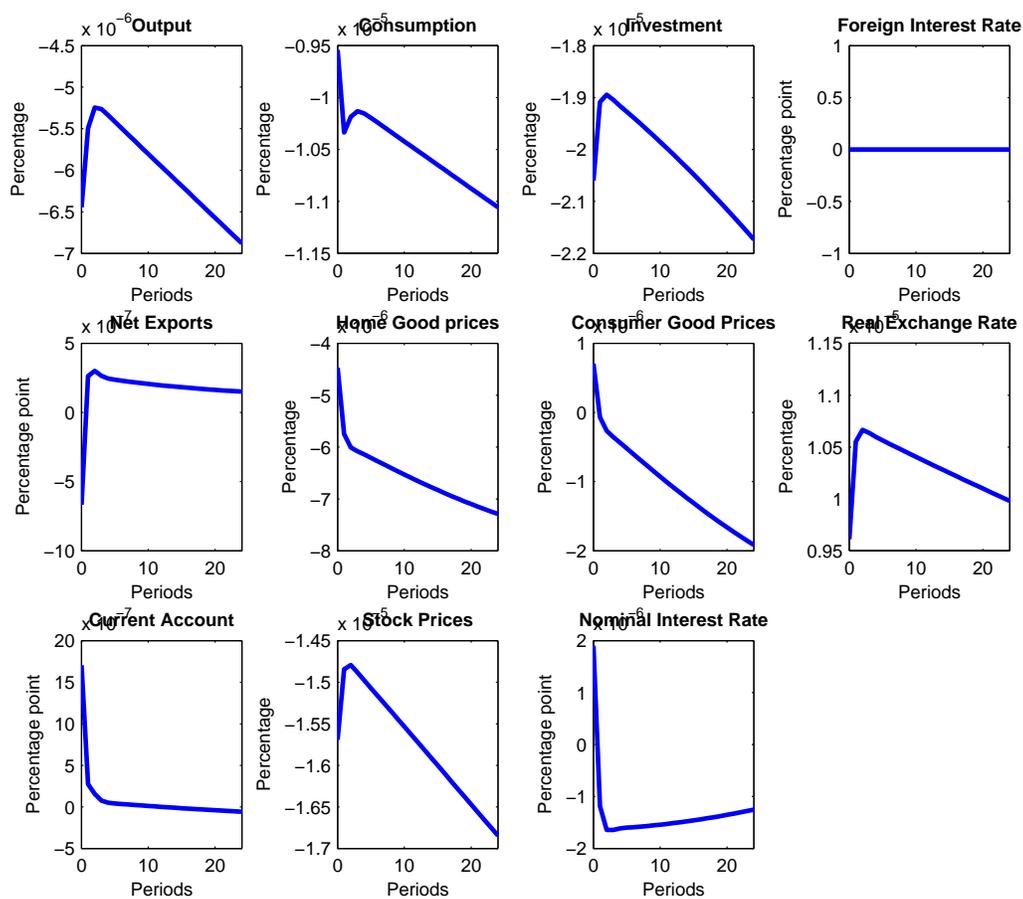*Notes*: Compared to the baseline in 4, the trade elasticity is lower. Also, see the notes in Figure 4.

Figure A.12: Impulse responses of the small open economy model to a shock to foreign income

Notes: These are non-linear impulse responses to a shock to foreign income/demand. Also, see the notes in Figure 4.