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US Monetary Policy Spillovers

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Abstract

We study international spillover effects of US monetary policy. We use monthly panel data from fifteen major emerging market economies (EMEs), in a period where the countries have a flexible exchange rate regime and are integrated into global financial markets. We show that US monetary policy shocks have significant financial and macroeconomic effects abroad. A contractionary US monetary policy shock leads to an increase in long-term country spread and short-term policy rate, and a depreciation of the exchange rate, of the EMEs. Also, their domestic stock prices and capital inflows into these countries decline. These adverse financial effects are accompanied by a contraction in EME output and an increase in their external balance. The contraction in economic output is stronger, and the increase in external balance weaker, for countries that raise their monetary policy rate by more. These results suggest that US monetary policy spillovers lead to a non-trivial monetary policy trade-off for EMEs and that the classic open economy policy trilemma might be morphing into a policy dilemma.

Keywords: US Monetary Policy Spillovers, Emerging Market Economies, Policy Dilemma vs. Trilemma, Policy Tradeoffs, Panel VAR

JEL classification: C33, E44, E52, E58, F32, F41

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1. Introduction

In an era of financial globalisation and increasing integration of countries into a common world financial market, has the traditional open-economy policy trilemma converted to a dilemma? In particular, is it the case that small open emerging market economies (EMEs) can no longer have independent monetary policy and perfect capital mobility, even with flexible exchange rates? Are international policy spillovers so important, and the policy trade-offs they lead to so drastic, that central banks in small open EMEs are not free to pursue domestic stabilisation goals?

These issues have gained attention lately, especially following the provocative conclusions in Rey (2013). In particular, Rey (2013) provided evidence for the existence of a global financial cycle that affects asset prices and drives financial flows to EMEs. Rey (2013) suggested these developments, which are correlated with a measure of US financial uncertainty, might, at their core, be affected predominantly by US monetary policy actions. If so, these will amount to drastic international spillovers of US monetary policy, which can overturn prescriptions based on the traditional open-economy policy trilemma framework. That is, it might be the case that small open EMEs are exposed to spillovers of US monetary policy to such an extent that they effectively do not have freedom left to use their policy instrument for other purposes, such as managing variation in domestic output. The only way for these EMEs to maintain some independent monetary policy is to then impose capital controls. This means that the open-economy policy trilemma is instead just a dilemma, as EMEs must choose between independent monetary policy and free capital mobility.

We contribute to this topic in this paper by directly assessing the spillover effects of US monetary policy shocks on an important set of EMEs. We focus on a period (2004-2015) when the countries have a flexible exchange rate regime and are relatively integrated into global financial markets, as these features are critical to draw inference on the policy trilemma vs. dilemma debate. We study financial and macroeconomic spillovers and assess what trade-offs these spillovers present to EME policy-makers. We then explore how these effects are heterogeneous across sub-groups of countries and, in particular, assess whether the country's management of the trade-offs via differential changes in the policy rate can be behind these heterogeneous effects.

Specifically, we first estimate a series of US monetary policy shocks using US data and the standard VAR method and identification strategy. We then estimate a monthly panel VAR for the following fifteen EMEs: Chile, Colombia, Brazil, India, Indonesia, Malaysia, Mexico, Peru, Philippines, Russia, South Africa, South Korea, Taiwan, Thailand and Turkey.[1] The panel VAR includes the US monetary policy shock as a regressor so the spillover effects on the EMEs of US monetary policy actions can be traced out.[2] 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 the US monetary policy shock.

We find that unanticipated US monetary policy changes have significant financial and macroeconomic spillover effects on EMEs. On average, following an exogenous increase in US short-term interest rates, EME short-term interest rates, especially, EME long-term country spreads (EME long-term government yield compared to the 10-year US Treasury yield) increase persistently. In addition, stock prices decline and nominal exchange rates depreciate. Finally, capital flows out of these countries and net exports to the US increase.

Specifically, on average across the EMEs, a one standard deviation exogenous increase in US short-term interest rates (equivalent to an increase of 0.262% point) leads to a 0.015% point increase in the short-term interest rate, a 0.04% point increase in the long-term country spread, a 0.5% fall in the stock prices, a 0.15% depreciation of the local currency, and a 0.095% point capital outflow relative to GDP. These are peak effects of the US monetary policy shock that occur about 1-12 months after the impact. The effects on EME financial markets are uniformly adverse and significant during the two years after the initial shock. Note the country spread is in terms of long-term interest rates. While it is well-known that long-term US interest rates increase given a contractionary US monetary policy shock, from a relative perspective, as the country-spread increases, this means that the EMEs' long-term interest rates are affected more strongly. Therefore, these financial market spillover effects in this sense are quite substantial.[3]

[1] We choose these countries following classification of emerging economies by the IMF and Morgan Stanley. We exclude countries that recorded major economic crises during our sample period, such as Argentina and Venezuela, or are in the Euro zone (and hence might be affected differently because of monetary policy/exchange rate regime), as well as countries that are known to manage their exchange rates, such as China.

[2] As we describe in detail later, we estimate the US VAR from 1984 onwards to extract a US monetary policy shock. This series from 2004 onwards is then used as an external regressor in the EME panel VAR.

[3] We also present variance decomposition results so we have another metric to evaluate the economic significance of the spillover effects.

Importantly, we find that these financial effects are accompanied by significant contractionary macro-economic effects. The US monetary policy shock transmits to the real economy of EMEs: output of these countries drops while net exports increase. Specifically, we estimate that, in response to an exogenous one standard deviation increase in US short-term interest rates, on average, output falls by 0.14% and net exports from these countries to the US rise by about 0.005% point relative to GDP. Again, these are peak effects, which occur after a delay of about four months.

These spillover effects on EMEs of US monetary policy shock, in a period of financial integration and flexible exchange rate regimes, clearly show that EME countries' central banks face a non-trivial trade-off. Particularly important are our findings that the effects on output are negative while it is accompanied by a decline in capital flows and an improvement in trade balance. Faced with such an outcome, it is clear that if EME policy-makers were to decrease their policy rates to combat the negative effects on output, they will have to bear the consequences in terms of further increased capital outflows and/or increased net exports. In this context, it is especially important that the policy rate of the EMEs increases. Thus, a contractionary US monetary policy shock leads, on average, to an increase of policy rates by central banks of EMEs.

This evidence of a non-trivial trade-off for EMEs' central banks, and the increase in the policy rate by them, motivates us to investigate heterogeneity in responses across country sub-groups. This is an important exercise because different groups of countries might make different policy decisions in the face of such a trade-off. Our panel VAR method allows a straightforward joint estimation of this alternate model specification. We therefore assess the heterogeneity in responses between South American countries and the rest of the EMEs by allowing the average effects of the US monetary policy shock to be different across these sub-groups.

We find some clear and meaningful heterogeneity across the two sub-groups. In particular, the negative effects on output and exchange rates are bigger and more persistent for the rest of the EMEs, compared to South American countries. The effects on stock prices are similar, but they are more persistent and significant for longer for the rest of the EMEs. For instance, the peak effect on output is around double for the rest of the EMEs and, for all these variables, the effects are significantly more persistent for the rest of the EMEs. Specifically, output drops around 0.08% in South American countries and around 0.16% in the rest of the EMEs.

The effects are bigger and more persistent on capital flows and net exports for South American countries, compared to the rest of the EMEs. In fact, the effects on net exports are significant only for South American countries. The peak effect on capital outflows is estimated to be about 0.11% point relative to GDP in South American countries, while it is about 0.08% in the rest of the countries. Also, net exports increased by about 0.012% point relative to GDP at its peak in South American countries, but only about 0.003% point in the rest of the EMEs, with the latter effect not being significant at any horizon. Overall, South American countries suffered 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 the EMEs does not decrease by more compared to South American countries. Even though the countries are affected much more negatively in terms of output (with insignificant effects in terms of consumer prices), it is positively affected. The positive response of the policy rate is statistically significant only for the rest of the EMEs. Therefore, the policy rates of the rest of the EMEs can be considered too high and monetary policy tight, given the negative response of output.[4] In other words, faced with a non-trivial trade-off between output and external balance, South American countries appear to focus more on output stabilisation while the rest of the EMEs focus more on external balance stabilisation.

Our paper is related to several strands of the literature. Rey (2013), which 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. Rey (2013) suggests that US monetary policy may drive, at least some of the movements in, the US stock market volatility and this could suggest that the international policy trilemma has converted to a policy dilemma. We contribute to this discussion by directly assessing the spillover effects of US monetary policy, using an identified US monetary policy shock. This is important because, to assess the implications for policy trilemma, it is important to directly estimate the effects of US monetary policy developments and assess if EMEs have effectively sacrificed monetary independence by integrating into global financial markets.

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 de-

[4] Many EMEs might be worried about sharp reversals in capital flows, even independently of the effects on output. If the rest of the EMEs are more concerned with capital outflows as a result of increased US interest rates than South American countries, the central banks of these countries might keep their policy rates relatively high to stem such capital outflows. This can be successful, but could come at the cost of larger drops in output as monetary policy will turn out to be unduly contractionary.

velop 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 an inference on the average effect, across countries, of the external US monetary policy shock, while allowing for heterogeneous country-specific effects. Our framework also allows for the average effect to be different across country sub-groups.

Regarding the focus of the paper, our work is clearly 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 shocks to Latin American countries. It is also related to Bhattarai, Chatterjee, and Park (2016b), which studies transmission of US financial uncertainty shock to EME countries, as well as Fink and Schuler (2015), which provides evidence on how US systemic financial stress shocks transmit to EMEs.[5]

Additionally, in terms of method and broad focus, it is also close to Miyajima et al (2014). Miyajima et al (2014) estimate effects of a shock to US long-term bond yields on five Asian countries for two periods (2003-07 and 2009-12) using a panel VAR. Such a shock increases short-term and long-term interest rates in Asia for the 2009-12 period, a result that is consistent with ours. They also find that inflation increases, which is what we also find, but, unlike us, they find that the output effect is not statistically significant and the bilateral exchange rate appreciates briefly. While estimating the effects of a shock to US short-term interest rates, which is most directly linked to our analysis, they find that, although Asian countries' exchange rates depreciate and output drops, which is consistent with our findings, the effects on short and long-term interest rates are not significant. This difference in results from our paper is likely due to a different sample of countries, variables used in the analysis, sample period and estimation method.[6]

There are also other papers that study spillover effects of US monetary policy on EMEs.[7] For instance, Mackowiak (2007) studies the effects of US monetary policy shocks on a different sample period and group of EMEs. In Bhattarai, Chatterjee, and Park (2016a) we study the transmission of

[5] See also Yamamoto (2014) and Nguyen, Tran and Le (2014) for evidence on transmission of US and external shocks to Asian economies.

[6] As we also emphasise later, given the high dimensional empirical model we use, a sub-sample study of 2009-2015 only is not feasible. Additionally, Miyajima et al (2014)'s panel VAR model with country fixed effects is different from the random coefficients panel VAR model we use.

[7] Cushman and Zha (1997) is a well-known paper on identifying domestic monetary policy shock in small open economies. Kim (2006) is a well-known paper on the spillover effects of US monetary policy on other advanced economies.

the Federal Reserve's balance sheet policies on EMEs.[8] Chen et al. (2016) also study the effect of US quantitative easing on emerging and advanced economies using a global VECM model. Georgiadis (2016) studies global output spillovers from US conventional monetary policy, while Feldkircher and Huber (2016) analyse international spillovers of expansionary US aggregate demand and supply shocks, as well as a contractionary US monetary policy shock, using global VAR models.[9]

We contribute to this literature in terms of methodology and scope. Our method, rather than 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 in a panel VAR set up. We can also estimate average effects using all the countries in the sample and those pertaining to country sub-groups. This latter aspect of our empirical exercise allows us to study how the differential response in monetary policy by the EMEs, reflecting a differential management of policy trade-offs, might affect transmission of the US monetary policy shock.[10]

In terms of the scope of the empirical study, we study the effects on many macroeconomic and financial variables jointly, including consumer prices, several asset prices and capital flows, for a large number of EMEs. 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 monetary policy. That is, the differential effects on EMEs relative to the US/world economy can be inferred.

Lastly, we include the pre and post-global financial crisis period in our sample so as to jointly assess the international spillover effects of conventional, as well as unconventional, US monetary policy shock. In particular, we use the shadow federal funds rate estimated by Krippner (2016) as the US monetary policy instrument during the zero lower bound period. This enables us to identify the US monetary policy shock in a single framework over the whole sample that covers the period when the

[8] See also Mohanty (2014) for an overview of some papers on this theme.

[9] See also Zuniga (2011), which provides evidence on how US monetary policy shocks transmit to Brazil and Mexico using a factor-augmented VAR framework.

[10] We use this methodology also in Bhattarai, Chatterjee, and Park (2016 a and b).

zero lower bound was binding for the US.[11]

2. Data and empirical methodology

In this section we explain the methodology we adopt and the data for empirical analysis. Our empirical study is executed in two steps. We first estimate an identified VAR for the US economy to extract unanticipated changes in US monetary policy, which is referred to as a US monetary policy 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 monetary policy on these economies. 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 monetary policy shock

For the US economy, an identified VAR model

$$A_0 y_t = A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_k y_{t-k} + \varepsilon_t, \tag{1}$$

is estimated, where y_t is an $m_y \times 1$ vector of endogenous variables and $\varepsilon_t \sim \mathrm{N}\left(0, I_{m_y}\right)$ with $E\left(\varepsilon_t \mid y_{t-j} \;:\; j \geq 1\right) = 0$. The coefficient matrix A_j for $j = 0, \cdots, k$ is an $m_y \times m_y$ matrix. In our baseline specification y_t includes the following five important variables: the industrial production (IP) index as a measure of output, the PCE index as a measure of consumption, the PCE deflator as a measure of consumer prices, the CRB BLS spot price index as a measure of commodity prices, and a short-term interest rate as the measure of monetary policy instrument. In the baseline specification we use six lags. Our baseline specification is therefore standard and quite parsimonious.

[11] We do acknowledge a shortcoming of this approach that implicitly assumes transmission occurs similarly, conditional on using a shadow interest rate, between (conventional) policy implemented via short-term interest rates and (unconventional) policy implemented via asset purchases. The relatively high dimensional empirical model that we use unfortunately precludes a sub-sample study in this paper, with split samples from 2004-2008 and 2009-2015, which would be able to assess the validity of this assumption. The two sample periods would be too short.

We use a standard recursive identification strategy on the impact matrix A_0, ordering the short-term interest rate last, and estimate the US monetary policy shock and its effects on the rest of the economy. We use zero short-run restrictions for identification. For the purposes of inference on the effects of the US monetary policy shock, the ordering of other variables does not affect results. This identification strategy embodies two sets of identification restrictions. First, other variables in y_t do not respond on impact to the monetary policy shock. Second, the monetary policy reaction function (or the information set of the central bank) includes current and lagged values of these other variables in y_t.

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 monetary policy shock on the EM countries are estimated. We then describe its various extensions.

2.2.1 Baseline specification

After estimating the US monetary policy shock from the identified 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

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

where $z_{i,t}$ is an $m_z \times 1$ vector of endogenous variables for country i, $\varepsilon_{MP,t}$ is the median of the US monetary policy 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 common across countries, and u_t is an $m_z \times 1$ vector of the disturbance terms.[12] The coefficient matrix $B_{i,j}$ for $j = 1, \cdots, p$ is an

[12] We note that, since we use the median of the US MP 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. Ideally, we can estimate the effect of the US MP shock in a panel VAR that includes the US and EM countries with a block exclusion restriction that the EM countries do not influence the US economy, adopting the small open economy benchmark for these EM economies. We prefer our two-step

$m_z \times m_z$ 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 $\mathbf{u}_t = \left(u_{1,t}^{'}, \cdots, u_{N,t}^{'}\right)'$,

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

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. 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 variables 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.

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) suggests 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 a positive definite, which is imposed so the disturbance terms $u_{i,t}$ are freely correlated across the EM countries and could capture potential effects of the other common factors.

estimation because of the computational burden to estimate a large panel VAR model for the US economy and the EM countries, which makes it practically difficult to estimate various alternative specifications and do robustness exercises.

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 monetary policy 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 monetary policy 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 $B_i = \left(B_{i,1} \quad \cdots \quad B_{i,p}\right)'$ and $D_i = \left(D_{i,0} \quad \cdots \quad D_{i,q}\right)'$ and let $\gamma_i = \mathrm{vec}\left(B_i' \quad D_i' \quad C_i\right)'$. Note that the size of γ_i is given as $m_\gamma = m_z m_w$ where $m_w = pm_z + (q+1) + m_x$ 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 $v_i \sim \mathrm{N}\left(\mathbf{0}_{m_\gamma \times 1}, \Sigma_i \otimes \underline{\Sigma}_i\right)$ 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 $\boldsymbol{\Sigma}$, $\underline{\Sigma}_i$ 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. For a particular value of $\bar{\gamma}$, the pooled estimates of the dynamics effects of the US monetary policy shock $\varepsilon_{MP,t}$ can be computed by tracing out the responses of $z_{i,t}$ to an increase in $\varepsilon_{MP,t}$ over time with γ_i replaced by $\bar{\gamma}$.

2.2.2 Heterogeneities across country subgroups

To assess heterogeneities across EM country subgroups, we also estimate the differential effects of the US monetary policy shock across two groups of 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 links between the US and South American countries, as well as the existence of previous work that focuses on these countries, such as Canova (2005) and Bhattarai, Chatterjee, and Park (2016b).

Specifically, the mean of the coefficients, $\bar{\gamma}$ in (4), is now different between two groups of the EMEs, denoted groups one and two. 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 one if country i is in group one and zero otherwise, $v_i \sim \mathrm{N}(\mathbf{0}_{m_\gamma \times 1}, \Sigma_i \otimes \underline{\Sigma}_i)$. By comparing the impulse responses to the US monetary policy 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 monetary policy 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 $u_{i,t}$ still correlated across all the EMEs.

2.2.3 Alternate specifications

After estimating the baseline specification, we consider some alternate variables that will be useful to assess the robustness of our results. Due to 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 replace long-term interest rate spreads with a measure of long-term real interest rate spreads.[13] We then use several alternate measures of external balance of the emerging market economies. We first replace our baseline measure of net exports, which was to the US, with 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. Table 1 presents the specifications that we estimate.

[13] 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 worth while to check this specification.

2.3 Data

We use US data at the monthly frequency for the period from January 1984 to November 2015 to estimate the US monetary policy shock.[14] The data source for most of the US data is the FRED maintained by the St Louis Fed. We use Datastream for the commodity price index data. For the period when the zero lower bound is not binding, we use the federal funds rate as a measure of the short-term interest rate. 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.

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 until November 2014. We use the US monetary policy shock that we estimate from January 2004 until November 2014 as an external shock in the EME panel VAR. We use EME data from 2004 onwards to avoid crisis periods in these countries and focus on a policy regime characterised by flexible exchange rates and integration into financial markets.[15]

We use EME data on IP, CPI, the nominal effective exchange rate, 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 US, and capital inflows from the rest of the world. For alternate external balance measures, we use data provided by Bertaut and Judson (2014), which is based on underlying data from US Treasury. In particular, from that dataset, we use net foreign asset position and capital inflows from the US to the EMEs. Net exports and capital flows are normalised by the relevant nominal GDP. The data sources for the other EM country data include Datastream, Bloomberg, EPFR, BIS, IMF and OECD.

A detailed data description is provided in the data Appendix. Lastly, we emphasise that the data is not processed before estimation except that we interpolate quarterly nominal GDP to monthly frequency to construct some ratios relative to GDP. The interpolation method is also described in the data Ap-

[14] We do not use data before the Volcker period as there is fairly extensive evidence for regime change in monetary policy and, in particular, for indeterminacy in the pre-Volcker period (Bhattarai, Lee, and Park (2016)).

[15] Data limitations, especially on long-term government bonds, precluded us from starting a few years before 2004.

pendix. The variables are used in logs, levels, or ratios relative to GDP.

3. Empirical results

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

3.1 US monetary policy shock

We present the posterior median of the estimated US monetary policy shock in Figure 1. We use this series as an external shock in the EME panel VAR.[16] As to be expected, before the financial crisis, the monetary policy shocks are small. They are larger after September 2008, and especially during the period when the ZLB was binding. The responses of US variables to the monetary policy shock are shown in the Appendix. While there is some uncertainty in the estimates, the point estimates show that an exogenous increase in the short-term interest rate leads to a decrease in consumption, output and consumer prices.[17]

3.2 Spillover effects of the US monetary policy shock

We now estimate the US monetary policy shock's spillover effects on the EMEs using a panel VAR where the US monetary policy shock estimated above is an external shock. The impulse responses presented in this section are the average effects of the US monetary 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

[16] Note that while we estimate the US monetary policy shock using data from 1984 onwards, in Figure 1, we only show the shock series over the time-period that is used in the EME panel VAR analysis.

[17] The uncertainty in the estimates, especially output, is partly due to the period we focus on, which is the post-Volcker era.

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 exogenous increase in US short-term interest rates, EME short-term interest rates and, especially, EME long-term country spreads (EME long-term government yield compared to the 10-year Treasury yield in the US) increase persistently. In addition, stock prices declines and nominal exchange rates depreciate persistently. Finally, capital flows out of these countries and net exports to the US increases.

Specifically, on average across the EMEs, a one standard deviation exogenous increase in US short-term interest rates (equivalent to an increase of 0.262% point) leads to a 0.015% point increase in the short-term interest rate, a 0.04% point increase in the long-term interest rate compared to the US, a 0.5% fall in the stock prices, a 0.15% depreciation of the local currency, and a 0.095% point capital outflows relative to GDP. These are peak effects of the US monetary policy shock that occur about 1-12 months after the impact. The effects on EME financial markets are uniformly adverse and significant during the entire time period of two years after the initial shock.

The effects on EME financial variables suggest that a contractionary US monetary policy shock leads to investors pulling capital out of these emerging markets. It then negatively affects EME asset prices, such as stock prices and exchange rates, while increasing their cost of borrowing as country spreads (compared to the US) increase. Note that the country spread is in terms of long-term interest rates. While it is well-known that long-term US interest rates increase given a contractionary US monetary policy shock, from a relative perspective, as the country-spread increases, this means the long-term interest rate of the EMEs is affected more strongly.

While the financial market effects are important, we are equally interested in assessing the transmission to the real economy. Figure 2 shows that, on average, a contractionary US monetary policy shock had significant effects on the macroeconomy of the EMEs, in addition to the financial market effects. Output of these countries drops while net exports increase. Specifically, we estimate that, in response to an exogenous one standard deviation increase in US short-term interest rates, on average, output falls by 0.14% and net exports from these countries to the US rise by about 0.005% point relative to GDP. Again, these are peak effects, which occur after a delay of about four months. The effects on net exports are significant at longer horizons as initially there is large uncertainty in the estimates. Overall, these effects on EMEs are economically large. Finally, while the point estimates show that consumer prices increase, the effects are not statistically significant.

The decrease in output shows that a contractionary US monetary policy shock leads to a contractionary effect in EMEs. There are therefore non-trivial macroeconomic spillovers to emerging markets from US monetary policy actions.[18] This is consistent with 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 illustrate that the effects of the US monetary policy shock transmits through these countries via a reduction in spending. Combined with an increase in the interest rate spread, this is similar qualitatively to effects of a "current account reversal" or a "sudden stop" shock faced by these countries.[19]

Taken together with the contractionary effects on output, it is intriguing that the short-term rate of the EMEs increases and is persistent. This is surprising at first because, given the contractionary effects on macroeconomic activity, a natural inclination would be to suggest that EME central banks would follow expansionary monetary policy. But, at the same time, note that capital inflows decrease and net exports increase. This presents the central banks with a trade-off if they care about limiting the volatility in external balance as increasing their policy rates can help them stem capital flowing out of their countries. This trade-off that arises when the EMEs are integrated in global financial markets motivates us to investigate heterogeneity in responses across sub-groups of EMEs, as different groups of countries might make different policy decisions in the face of such a trade-off.

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 of the emerging market countries.

[18] In terms of comparison with effects on the US economy, we show in the Appendix that, at peak, the negative effects on US consumption is around 0.1%. While roughly the same order of magnitude, the negative effects on output of EMEs is more pronounced.

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

Figure 3 shows clear and meaningful heterogeneity is present in responses of macroeconomic and financial variables. In particular, the negative effects on output and exchange rates are bigger and more persistent for the rest of the EMEs compared to South American countries. The effects on stock prices are similar, but they are more persistent and significant for longer for the rest of the EMEs. For instance, the peak effect on output is around double for the rest of the EMEs. For all these variables, the effects are significantly more persistent for the rest of the EMEs as well. Specifically, output drops around 0.08% in South American countries while it drops around 0.16% in the rest of the 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 the EMEs. In fact, the effects on net exports are significant only for South American countries. The peak effect on capital outflows of an exogenous one standard deviation increase in US short-term interest rate is estimated to be about 0.11% point relative to GDP in South American countries while it is about 0.08% in the rest of the countries. Also, net exports increase by about 0.012% point relative to GDP at its peak in South American countries, but only about 0.003% point in the rest of EMEs, with the latter effect not being significant at any horizon. 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 the EMEs not only does not decrease by more compared to South American countries, even though the countries are affected much more negatively in terms of output (with insignificant effects in terms of consumer prices), it is significantly positively affected. The positive response of the policy rate is statistically significant only for the rest of the EMEs. Therefore, the policy rates of the rest of the EMEs can be considered to be high and monetary policy tight, given the negative response of output.

This heterogeneity in outcomes and the short-term policy rates 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 worried about sharp reversals in capital flows, even independently of the effects on output. Then, if the rest of the EMEs are more concerned with capital outflows as a result of increased US interest rates than South American countries, the central banks of these countries might keep their policy rates high 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.[20]

3.2.3 Variance decomposition

So far we have assessed the transmission mechanism of the US monetary policy shock on EMEs. We have used impulse response analysis for this purpose. In an extension, we now conduct a complementary exercise, a variance decomposition analysis, to assess the economic significance of the effects on EMEs of a US monetary policy shock. The Appendix describes the method we use to compute the contribution of the US monetary policy shock at different horizons in explaining the forecast error variance in EME macroeconomic and financial variables.

Table 2 shows the results for all the EME countries. It is clear that the US monetary policy shock explains a non-trivial fraction of the variation of these variables, both in the short-term such as three months, as well as, at longer horizons such as 24 months. We start by discussing results for macroeconomic variables. For instance, it explains around 18% and 5% at the three-month horizon, and around 16% and 13% at the 24-month horizon, for output and net exports respectively. It also explains around 18% of the variation at 24 months for the policy instrument, the short-term interest rate. The monetary policy instrument of the EMEs is affected in an economically significant way by this external, US monetary policy shock.

For financial variables, the variance decomposition results are similarly non-trivial. For the long-term country spread and exchange rate, the US monetary policy shock explains around 12% and 15% at the three-month horizon and around 20% and 13% at the 24-month horizon respectively. Finally, for capital flows, while at the three-month horizon it explains relatively less, 3%, at the 24-month horizon, it rises to around 13%.

3.2.4 Extensions and robustness

We conduct several extensions and robustness exercises. These include specification checks, such

[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. We note, however, that in additional analysis, we have found that a sub-group estimation with Asian countries vs. the rest does not feature meaningful heterogeneity.

as different lags as well as using alternate variables compared to the baseline. In the Appendix, we present results from some important robustness exercises, such as those using four lags of the US monetary policy in the EME panel VAR (in Figures A.2 and A.3 respectively) and one that uses an alternate measure of capital inflows to the emerging market economies (in Figure A.4). The alternate capital flow measure is based on the bilateral net foreign asset position of the US, provided in Bertaut and Judson (2014), with the underlying data obtained from the US Treasury. Our results are robust to these extensions and alternate specifications.

4. Conclusion

Motivated by recentdiscussions on whether the open economy policy trilemma has morphed into a dilemma, we study spillover effects on emerging market economies (EMEs) of US monetary policy. We find there are non-trivial spillovers of US monetary policy actions on EMEs. These spillovers not only are prominent in the financial sector, but also transmit to the real economy of the EMEs. They then lead to a non-trivial policy trade-off for EME central banks.

We find that unanticipated US monetary policy changes have significant financial and macroeconomic spillover effects on EMEs. On average, following an exogenous increase in US short-term interest rates, EME short-term interest rates and, especially, EME long-term country spreads (EME long-term government yield compared to the 10-year US Treasury yield), increase persistently. In addition, stock prices decline and nominal exchange rates depreciate persistently. Finally, capital flows out of these countries. Importantly, we find that these financial effects are accompanied by significant contractionary macroeconomic effects. In particular, output of these countries drops while net exports increase.

The negative effects on output, together with positive effects on external balance, suggest that EME central banks face a trade-off. This is because while the negative effects on output can be limited by decreasing the policy rate, if EMEs care about limiting volatility in external balance, increasing the policy rate can help stem capital outflows. In this context, it is intriguing that, on average, the policy rate increases across EMEs. This trade-off that arises when EMEs are integrated in global financial markets motivates us to investigate heterogeneity in responses across EME sub-groups, as different country groups might make different policy decisions in the face of such a non-trivial trade-off.

We find clear and meaningful heterogeneity across two EME sub-groups: South American countries vs. the rest of the EMEs. In particular, the negative effects on output and exchange rates are bigger and more persistent for the rest of the EMEs compared to South American countries. For instance, the peak effect on output is around double for the rest of the EMEs. For output and exchange rates, the effects are significantly more persistent for the rest of the EMEs as well. However, the effects are bigger and more persistent on capital flows and net exports for South American countries compared to the rest of the EMEs. In fact, the effects on net exports are significant only for South American countries. Strikingly, the short-term (policy) rate of the rest of the EMEs not only does not decrease by more compared to South American countries, it is significantly positively affected. The positive response of the policy rate is statistically significant only for the rest of the EMEs. In other words, faced with a non-trivial trade-off between output and external balance, South American countries appear to focus more on output stabilisation while the rest of the EMEs focus more on external balance stabilisation.

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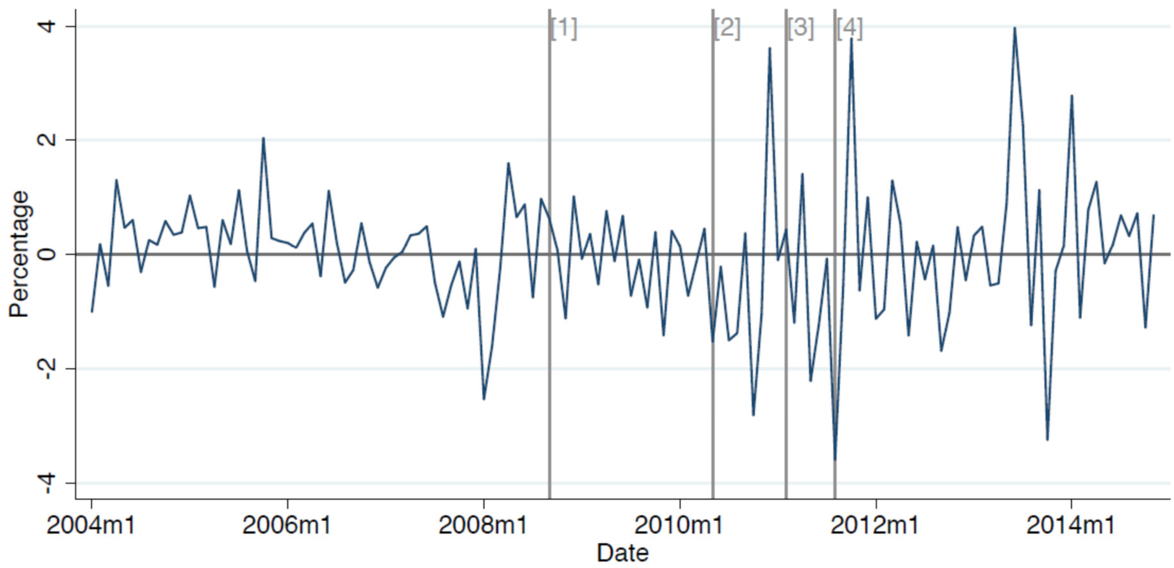
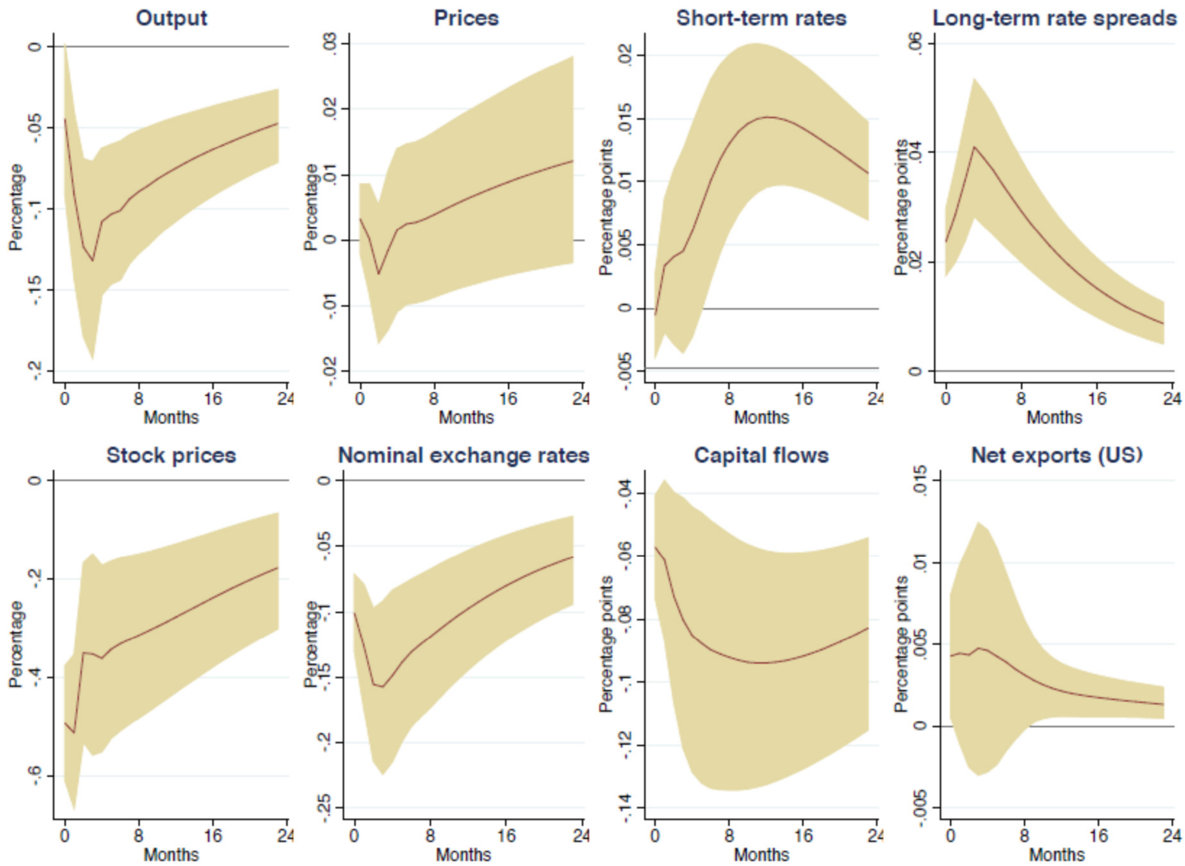
Figure 1. The estimated US monetary policy shock



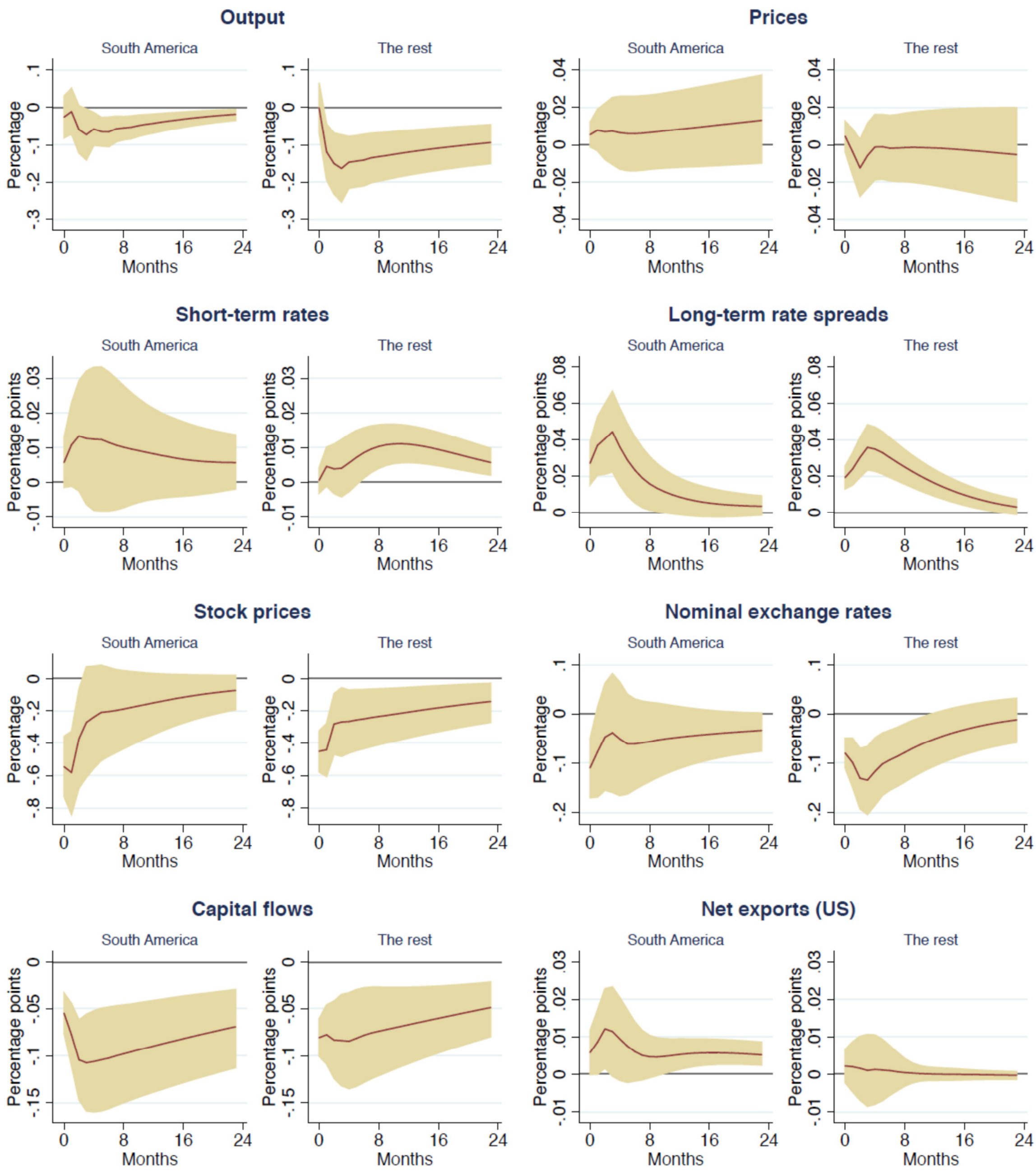
Notes: The figure displays the posterior median of the US monetary policy shock identified in US VAR (1). The shock series is shown over the time period that is used in the EME panel VAR as an external regressor to assess spillover effects. The vertical lines mark the financial crisis and the three major events of the Euro debt crisis: [1] September 2008, when Lehman filed for bankruptcy, [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 European Commission President Jose Manuel Barroso warned that the sovereign debt crisis was spreading beyond the periphery of the Eurozone.

Figure 2. Impulse responses of the EM panel VAR to the US monetary policy shock: macroeconomic and financial variables



Notes: Each plot presents the posterior median of the impulse responses to a one standard deviation (contractionary) US monetary policy shock along with the 68% error band in the baseline specification that includes macroeconomic and financial variables. A one standard deviation increase constitutes an increase of 0.262% points in the US short-term interest rate. 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. US and EM interest rates are nominal. The stock price is the MSCI. The nominal exchange rate is the nominal effective exchange rate of the local currency so a decrease in the exchange rate suggests 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.

Figure 3. Impulse responses of the EM panel VAR to the US monetary policy shock: macroeconomic and financial variables; South America vs. The rest



Notes: Each plot presents the posterior median of the impulse responses to a one standard deviation (contractionary) US monetary policy shock along with the 68% error bands in the specification for subgroup analysis that includes 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.

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	Long-term interest rate spread is replaced with long-term real interest rate spread
	2	Net exports to the US is replaced with net foreign asset position with the US
	3	Capital inflows from world replaced with capital inflows from the US

Notes: For each of the EMEs in the EM panel VAR the endogenous variables listed above, the US monetary policy 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.

Table 2. Baseline and alternative specifications of the EM panel VAR

Horizon	Output	Short rate	LR spread	Exch Rate	Cap Flows	Stock Prices	Net exports
1	1.4	1.2	9.3	10.4	2.70	13.2	2
3	18.4	3	12.2	15	3.39	14.7	4.9
6	17.2	5	16.9	18.8	9.7	12.7	12.9
12	16.8	10.3	21	18.3	8.63	13.5	13.6
24	15.9	18.1	19.8	12.43	12.76	12.4	15

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

Appendix

A Data description

See the data Appendix for the complete list of 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 emerging market countries. For the latter countries, monthly GDP is used to normalise 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 Panel VAR for a single group

Assume 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

$$z_{i,t}^{o} = \sum_{j=1}^{p} B_{i,j} z_{i,t-j}^{o} + \sum_{j=0}^{q} D_{i,j} \varepsilon_{MP,t-j} + C_i x_{i,t}^{o} + u_{i,t}^{o}, \tag{A.6}$$

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.6) in $w_{i,t}^{o}$ as

$$w_{i,t}^{o} = \begin{bmatrix} z_{i,t-1}^{o\prime} & \cdots & z_{i,t-p}^{o\prime} & \varepsilon_{MP,t-0} & \cdots & \varepsilon_{MP,t-q} & x_{i,t}^{o\prime} \end{bmatrix},$$

and write (A.6) as

$$z_{i,t}^{o\prime} = w_{i,t}^{o\prime}\Gamma_i + u_{i,t}^{o\prime}, \tag{A.7}$$

where Γ_i collects the coefficient matrices on the right hand side of (A.6)

$$\Gamma_i = \begin{bmatrix} B_{i,1} & \cdots & B_{i,p} & D_{i,0} & \cdots & D_{i,q} & C_i \end{bmatrix}'.$$

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 vectorise equation (A.7) as

$$z_{i,t}^{o} = \left(I_{m_z} \otimes w_{i,t}^{o\prime}\right)\gamma_i + u_{i,t}^{o}, \tag{A.8}$$

where $\gamma_i = \mathrm{vec}(\Gamma_i)$, and stack (A.8) for $i = 1, \cdots, N$ as

$$\boldsymbol{z}_t^{o} = \boldsymbol{W}_t^{o}\boldsymbol{\gamma} + \boldsymbol{u}_t^{o}, \tag{A.9}$$

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 $\boldsymbol{u}_t^{o} \sim \mathrm{N}(\boldsymbol{0}, \boldsymbol{\Sigma})$ 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) and $\boldsymbol{\Sigma}$ next.

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

$$\gamma_i = \bar{\gamma} + v_i, \tag{A.10}$$

for $i=1,\cdots,N$, where $\bar{\gamma}$ is an $m_\gamma \times 1$ vector and $v_i \sim \mathrm{N}(0, \Sigma_i \otimes \underline{\Sigma}_i)$. Note that Σ_i is an $m_z \times m_z$ matrix that is the ith block on the diagonal of $\boldsymbol{\Sigma}$ and $\underline{\Sigma}_i$ is an $m_w \times m_w$ positive definite matrix. Equation (A.10) can be written as

$$\gamma_i \mid \bar{\gamma}, \boldsymbol{\Sigma} \sim \mathrm{N}(\bar{\gamma}, \Sigma_i \otimes \underline{\Sigma}_i).$$

We assume that γ_i is independent of each other conditional on $\bar{\gamma}$ and $\boldsymbol{\Sigma}$. That is, $E(v_i v_j')=0$ 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

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

where $\underline{\nu} > Nm_z + 1$ and $\underline{S}$ is $Nm_z \times Nm_z$ and positive definite. We set $\bar{\nu} = Nm_z + 2$, which 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) conditional on $\boldsymbol{\Sigma}$ and $\bar{\gamma}$ and the posterior distribution of $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$ and $\bar{\gamma}$. Let

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

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

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

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

$$\boldsymbol{\gamma} \mid \bar{\gamma}, \boldsymbol{\Sigma}, z_T^o, \cdots, z_1^o, z_0^o, \cdots, z_{-p+1}^o \sim \mathbb{N}\left[\tilde{\boldsymbol{\gamma}}, \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o'} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\boldsymbol{\Sigma}}_{\gamma}^{-1}\right)^{-1}\right], \tag{A.11}$$

and

$$\boldsymbol{\Sigma}^{-1} \mid \boldsymbol{\gamma}, \bar{\gamma}, z_T^o, \cdots, z_1^o, z_0^o, \cdots, z_{-p+1}^o \sim \mathbb{W}\left(T + \underline{\nu}, \tilde{S}^{-1}\right),$$

where

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

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 vectorised OLS estimator of γ_i 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 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 $\{\lambda \boldsymbol{z}_1^d, \lambda \boldsymbol{W}_1^d\}$ 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.9), it would suggest

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

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 favour 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 $\{\mu \boldsymbol{z}_t^d, \mu \boldsymbol{W}_t^d\}_{t=2}^{m_z+1}$ such that

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

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 $w_{i,t}^d = \left[\left(\overline{z}_{i,0}^o\right)_{(t-1)}' \quad \cdots \quad \left(\overline{z}_{i,0}^o\right)_{(t-1)}' \quad 0 \quad \cdots \quad 0 \quad 0_{m_x \times 1}' \right]'$ for $i = 1, 2, \cdots, N$ and $\left(\overline{z}_{i,0}^o\right)_{(t-1)}$ 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 $\overline{z}_{i,0}^o$. The second type suggests that the jth equation of the ith unit implies there is a unit root for the jth 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

$$\overline{\gamma} \mid \boldsymbol{\gamma}, \boldsymbol{\Sigma}, z_T^o, \cdots, z_1^o, z_0^o, \cdots, z_{-p+1}^o \sim \mathrm{N}\left[\tilde{\overline{\gamma}}, \left(\sum_{i=1}^N \left(\Sigma_i \otimes \underline{\Sigma}_i\right)^{-1} + \underline{\Sigma}_{\overline{\gamma}}^{-1} \right)^{-1} \right], \tag{A.13}$$

where

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

B.1.3 Posterior simulation

We use the Gibbs sampler to alternatively draw $\boldsymbol{\gamma}$ conditional on $\boldsymbol{\Sigma}$ and $\overline{\gamma}$ from (A.11), $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$ and $\overline{\gamma}$ from (A.12), and $\overline{\gamma}$ conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ from (A.13). We make 200,000 draws and use only the last 100,000 draws to make posterior inferences.

B.2 Panel VAR 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, $v_i\sim\mathrm{N}(0,\Sigma_i\otimes\underline{\Sigma}_i)$. Independence between α_i is assumed within each group and across groups: $E(v_i v_j^{\prime})=0$ 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

$$\boldsymbol{\gamma}\mid\bar{\gamma}_1,\bar{\gamma}_2,\boldsymbol{\Sigma},z_T^o,\cdots,z_1^o,z_0^o,\cdots,z_{-p+1}^o\sim\mathrm{N}\left[\tilde{\boldsymbol{\gamma}},\left(\sum_{t=1}^{T}\boldsymbol{W}_t^{o\prime}\boldsymbol{\Sigma}^{-1}\boldsymbol{W}_t^{o}+\underline{\boldsymbol{\Sigma}}_{\gamma}^{-1}\right)^{-1}\right], \tag{A.14}$$

where

$$\begin{aligned}
\bar{\boldsymbol{\gamma}}&=\left(I_F(1)\ \cdots\ I_F(N)\right)^{\prime}\otimes\bar{\gamma}_1+\left(1-I_F(1)\ \cdots\ 1-I_F(N)\right)^{\prime}\otimes\bar{\gamma}_2,\\
\hat{\boldsymbol{\gamma}}&=\left(\sum_{t=1}^{T}\boldsymbol{W}_t^{o\prime}\boldsymbol{\Sigma}^{-1}\boldsymbol{W}_t^{o}\right)^{-1}\left(\sum_{t=1}^{T}\boldsymbol{W}_t^{o\prime}\boldsymbol{\Sigma}^{-1}z_t^{o}\right),\\
\tilde{\boldsymbol{\gamma}}&=\left(\sum_{t=1}^{T}\boldsymbol{W}_t^{o\prime}\boldsymbol{\Sigma}^{-1}\boldsymbol{W}_t^{o}+\underline{\boldsymbol{\Sigma}}_{\gamma}^{-1}\right)^{-1}\left[\left(\sum_{t=1}^{T}\boldsymbol{X}_t^{o\prime}\boldsymbol{\Sigma}^{-1}\boldsymbol{X}_t^{o}\right)\hat{\boldsymbol{\gamma}}+\left(\underline{\Sigma}_{\gamma}^{-1}\right)\bar{\boldsymbol{\gamma}}\right],
\end{aligned}$$

and that is common in business cycle studies.

$$\boldsymbol{\Sigma}^{-1}\mid\boldsymbol{\gamma},\bar{\gamma}_1,\bar{\gamma}_2,z_T^o,\cdots,z_1^o,z_0^o,\cdots,z_{-p+1}^o\sim\mathrm{W}\left(T+\underline{\nu},\tilde{S}^{-1}\right), \tag{A.15}$$

where

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

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

A priori, we assume that

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

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

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

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

$$\bar{\gamma}_1 \mid \boldsymbol{\gamma}, \boldsymbol{\Sigma}, z_T^o, \cdots, z_1^o, z_0^o, \cdots, z_{-p+1}^o \sim \mathrm{N}\left[\tilde{\bar{\gamma}}_1, \left(\sum_{i=1}^{N_1} \left(\Sigma_i \otimes \underline{\Sigma}_i\right)^{-1} + \Sigma_{\bar{\gamma}}^{-1}\right)^{-1}\right],$$

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

$$\bar{\gamma}_2 \mid \boldsymbol{\gamma}, \boldsymbol{\Sigma}, z_T^o, \cdots, z_1^o, z_0^o, \cdots, z_{-p+1}^o \sim \mathrm{N}\left[\tilde{\bar{\gamma}}_2, \left(\sum_{i=N_1+1}^{N} \left(\Sigma_i \otimes \underline{\Sigma}_i\right)^{-1} + \Sigma_{\bar{\gamma}}^{-1}\right)^{-1}\right],$$

where

$$\tilde{\bar{\gamma}}_1 = \left(\sum_{i=1}^{N_1} \left(\Sigma_i \otimes \underline{\Sigma}_i\right)^{-1} + \Sigma_{\bar{\gamma}}^{-1}\right)^{-1} \left[\left(\sum_{i=1}^{N_1} \left(\Sigma_i \otimes \underline{\Sigma}_i\right)^{-1}\right)\gamma_i + \left(\Sigma_{\bar{\gamma}}^{-1}\right)\hat{\bar{\gamma}}_1\right],$$

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

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.14), $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$, $\bar{\gamma}_1$ and $\bar{\gamma}_2$ from (A.15), and $\bar{\gamma}_1$ and $\bar{\gamma}_2$ conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ from (A.16) and (A.17). We make 200,000 draws and use only the last 100,000 draws to make posterior inferences.

B.3 Contribution of the US MP shock

We compute the contribution of the US MP shock to the dynamics of the endogenous variables in $z_{i,t}^o$ as follows. Here we treat the US MP 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

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

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 $\Phi_{h,h17-j}^{MP}$ is the impulse response of $z_{i,t+h}^o$ to a shock to $\varepsilon_{MP,t+h-j}$ and an

$m_z \times m_z$ matrix $\Phi^{u}_{h,h-j}$ is the impulse response of $z^{o}_{i,t+h}$ to a shock to $u^{o}_{i,t+h-j}$. The impulse responses can be easily computed using a recursive algorithm. The US MP 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^2_{MP}. It follows that

$$E_t\left[\left(z^{o}_{i,t+h} - E_t z^{o}_{i,t+h}\right)^2\right] = \sum_{j=0}^{h-1}\left[\Phi^{MP}_{h,h-j}\left(\Phi^{MP}_{h,h-j}\right)'\sigma^2_{MP} + \Phi^{u}_{h,h-j}\Sigma_i\left(\Phi^{u}_{h,h-j}\right)'\right].$$

Let us denote

$$\Sigma_{i,(t+h,t)} = E_t\left[\left(z^{o}_{i,t+h} - E_t z^{o}_{i,t+h}\right)^2\right] = \Sigma^{MP}_{i,(t+h,t)} + \Sigma^{u}_{i,(t+h,t)},$$

where

$$\Sigma^{MP}_{i,(t+h,t)} = \sum_{j=0}^{h-1}\left[\Phi^{MP}_{h,h-j}\left(\Phi^{MP}_{h,h-j}\right)'\sigma^2_{MP}\right],$$
$$\Sigma^{u}_{i,(t+h,t)} = \sum_{j=0}^{h-1}\left[\Phi^{u}_{h,h-j}\Sigma_i\left(\Phi^{u}_{h,h-j}\right)'\right].$$

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

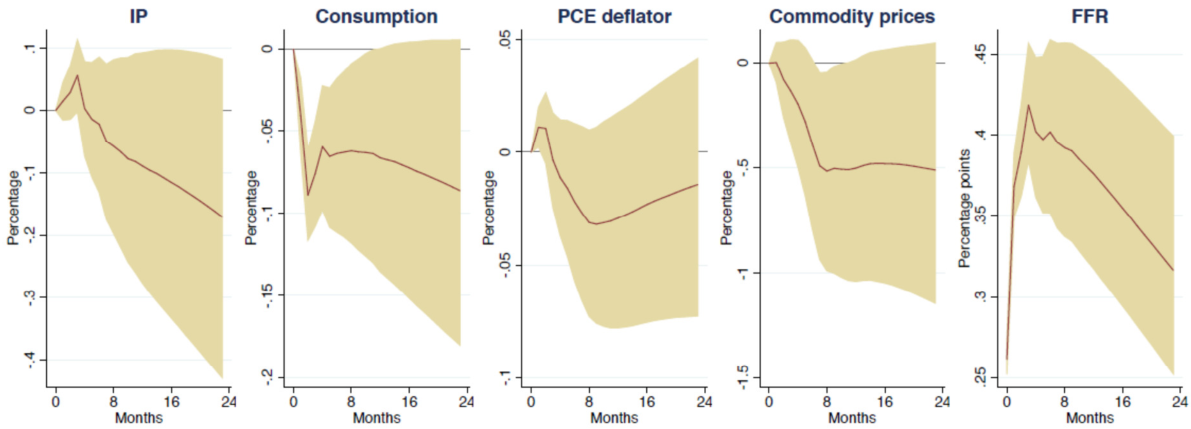
C Extensions and robustness

We now discuss the results from the various extensions and robustness exercises. We start with the results from the estimation of the US monetary policy shock and then present those from the spillover effects of the US monetary policy shock on EMEs.

C.1 US VAR

We present in Figure A.1 the impulse responses of US variables to the US monetary policy. This is based on our baseline specification of a five-variable VAR. The estimate of the effects on output is imprecise, but is mostly due to the sample period we use, which is the post-Volcker period.

Figure A.1: Impulse responses of US variables to the US monetary policy shock

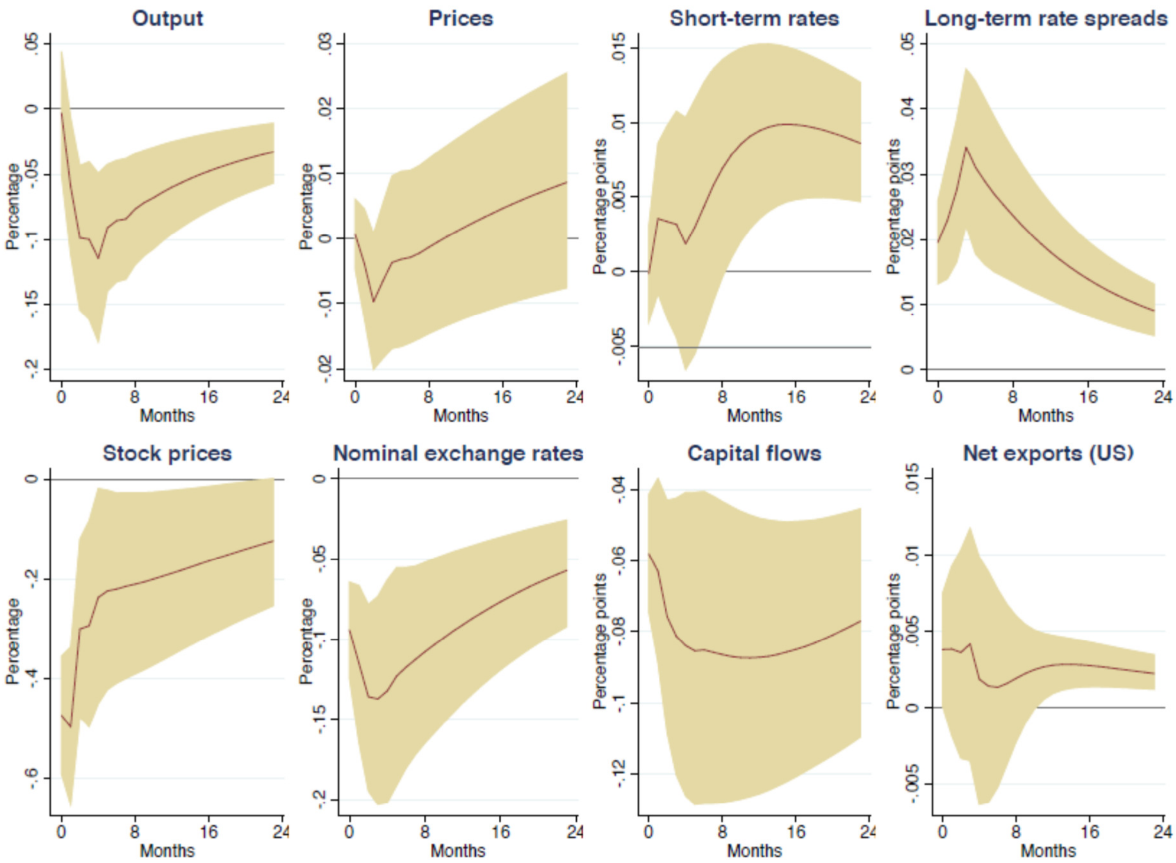


Notes: Each plot presents the posterior median of the impulse responses to a one standard deviation (contractionary) US monetary policy shock along with the 68% error band in the baseline specification for US VAR. Output is the industrial production and consumption is personal consumption expenditures index. Commodity prices is the CRB BLS spot price index. During the periods when the ZLB is binding, rather than the FFR, we use the shadow rate of Krippner (2015).

C.2 EME panel VAR

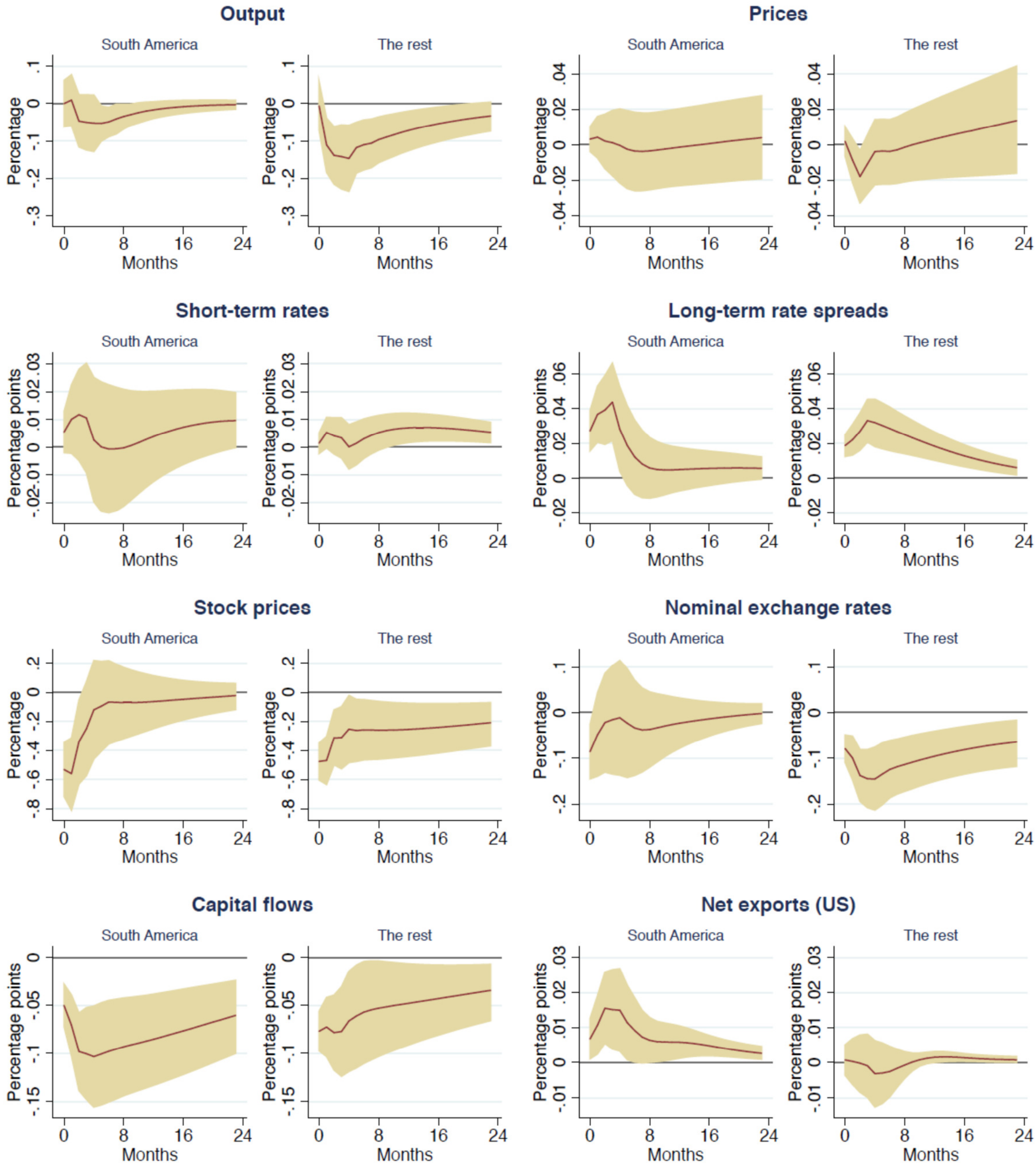
We conduct several robustness checks on the baseline EME panel VAR results. We first use four lags of the US monetary policy in the panel VAR. Figures A.2 and A.3 present the results based on this specification for the baseline and sub-group analysis respectively.

Figure A.2: Impulse responses of the EM panel VAR to the US monetary policy shock: macroeconomic and financial variables



Notes: Each plot presents the posterior median of the impulse responses to a one standard deviation (contractionary) US monetary policy shock along with the 68% error band in the baseline specification that includes macroeconomic and financial variables. A one standard deviation increase constitutes an increase of 0.262% points in the US short-term interest rate. 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. US and EM interest rates are nominal. The stock price is the MSCI. The nominal exchange rate is the nominal effective exchange rate of the local currency so a decrease in the exchange rate suggests 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. Four lags of the US monetary policy shock are used in the panel VAR. See the notes in Figure 2.

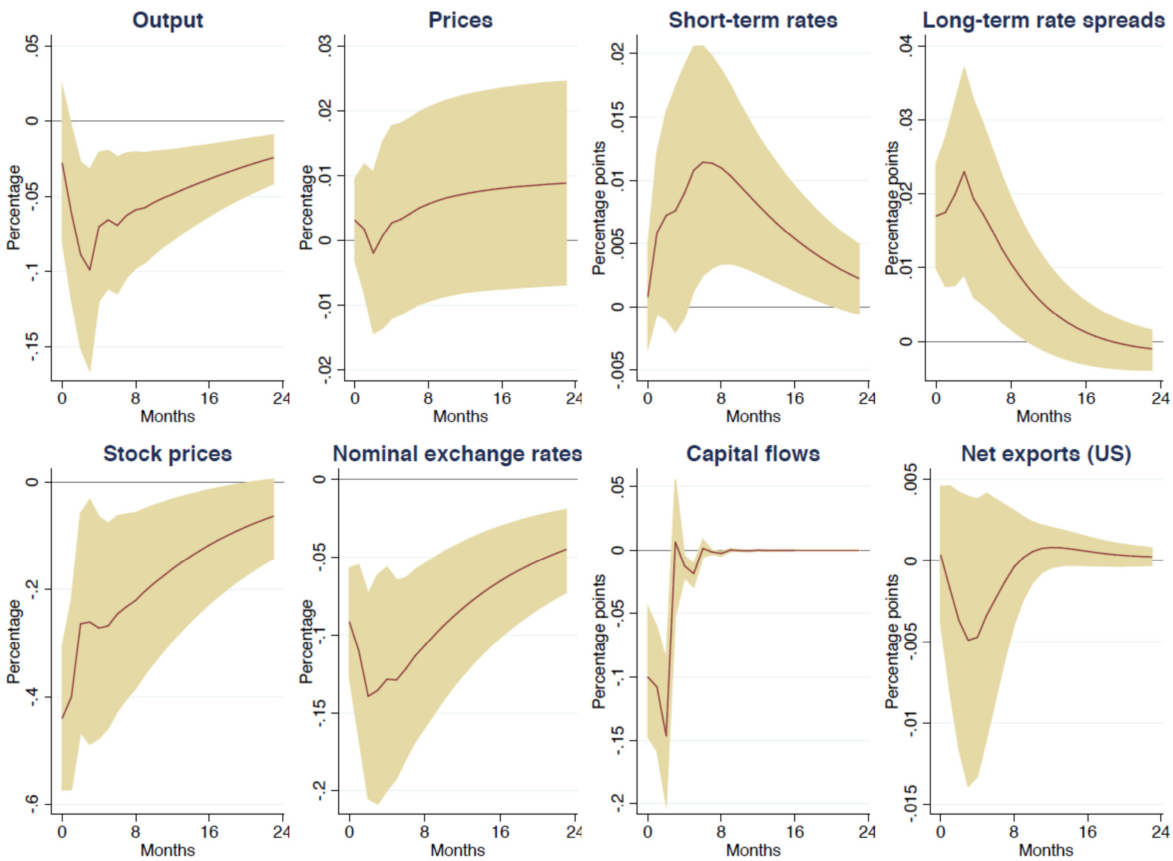
Figure A.3: Impulse responses of the EM panel VAR to the US monetary policy shock: macroeconomic and financial variables; South America vs. The rest



Notes: Each plot presents the posterior median of the impulse responses to a one standard deviation (contractionary) US monetary policy shock along with the 68% 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. Four lags of the US monetary policy shock are used in the panel VAR. See the notes in Figure 2.

We next use alternate variables in the EME panel VAR. For illustration, in Figure A.4, we present results where we use an alternate measure of capital inflows to the EME, based on bilateral net foreign asset position of the US.

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



Notes: Each plot presents the posterior median of the impulse responses to a one standard deviation (contractionary) US monetary policy shock along with the 68% 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. US and EM interest rates are nominal. The stock price is the MSCI. The nominal exchange rate is the nominal effective exchange rate of the local currency so a decrease in the exchange rate suggests depreciation of the local currency. The capital flow is a measure of NFA to GDP ratio of the US to these EM countries. See the notes in Figure 2.