Effects of US Quantitative Easing on Emerging Market Economies*

Saroj Bhattarai†
University of Texas at Austin

Arpita Chatterjee‡
University of New South Wales

Woong Yong Park§
Seoul National University and CAMA

Abstract

We estimate international spillover effects of US Quantitative Easing (QE) on emerging market economies (EMEs). Using a Bayesian VAR on monthly US macroeconomic and financial data, we first identify the US QE shock. The identified US QE shock is then used in a monthly Bayesian panel VAR for EMEs to infer spillover effects on these countries. We find that an expansionary US QE shock has significant effects on financial variables in EMEs. It leads to an exchange rate appreciation, a reduction in long-term bond yields, a stock market boom, and an increase in capital inflows to these countries. These effects on financial variables are stronger for the "Fragile Five" countries compared to other EMEs.

Keywords: US Quantitative Easing; Spillovers; Emerging Market Economies; Bayesian VAR; Panel VAR; Fragile Five Countries

JEL Classification: C31; E44; E52; E58; F32; F41; F42

---

*We thank Jim Bullard, Oli Coibion, Troy Davig, Taeyoung Doh, Charles Engel, Jonathan Eaton, Andrew Filardo, Jongrim Ha, Robert Kollmann, James Morley, Chris Neely, Paolo Pesenti, Alessandro Rebucci, John Rogers, Christie Smith, Minkee Song, Garima Vasishtha, James Yetman, and Tao Zha, seminar participants at Reserve Bank of New Zealand, University of Melbourne, University of New South Wales, and University of Texas-Austin, and conference participants at the 2015 ASSA meetings, Tsinghua University/St. Louis Fed Conference on Monetary Policy in a Global Setting, Bank of Canada/ECB Conference on the Underwhelming Global Post-Crisis Growth Performance, HKUST Conference on International Economics, the 2015 KIF-KAEA-KAFA Joint Conference, the 21st International Conference on Computing in Economics and Finance, the 11th Dynare Conference, the 2nd Conference of the Society of Economic Measurements, the Workshop on Empirical Monetary Economics, the 2016 Asia Economic Institutes Workshop at Peking University, and the 2017 Hong Kong Monetary Authority/Federal Reserve Board/Federal Reserve Bank of Atlanta joint conference on Unconventional Monetary Policy: Lessons Learned for valuable comments and suggestions. We thank Choongryul Yang for superb research assistance. Woong Yong Park gratefully acknowledges support by the Research Resettlement Fund for new faculty members and Creative-Pioneering Researchers Program through Seoul National University. First version: Dec 2014. This version: Sept 2017.

†2225 Speedway, Stop C3100, University of Texas at Austin, Austin, TX 78712, U.S.A. Email: saroj.bhattarai@austin.utexas.edu.

‡UNSW Business School, School of Economics, Sydney, NSW 2052, Australia. Email: arpita.chatterjee@unsw.edu.au.

§Department of Economics, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, South Korea. Email: woongyong.park@snu.ac.kr.

> *"Among the advanced economies, the mutual benefits of monetary easing are clear. The case of emerging market economies is more complicated ...Because many emerging market economies have financial sectors that are small or less developed by global standards but open to foreign investors, they may perceive themselves to be vulnerable to asset bubbles and financial imbalances caused by heavy and volatile capital inflows, including those arising from low interest rates in the advanced economies."* (Federal Reserve Chairman Ben Bernanke in a speech in 2013)

1 Introduction

As a countercyclical response to the onset of the Great Recession in 2007, the US Federal Reserve drastically cut its conventional monetary policy instrument - the federal funds rate. Once the federal funds rate effectively hit the zero lower bound (ZLB) at the end of 2008, the Federal Reserve engaged in unconventional monetary policies to provide further stimulus. In particular, through the large-scale asset purchase (LSAP) program, it purchased long-term Treasury and agency bonds and mortgage backed securities. The main goal of the program, often referred to as quantitative easing (QE), was to lower long-term interest rates and thus spur economic activities in a situation where the short-term interest rate was stuck at the ZLB.[1]

In this paper we evaluate the international spillover effects of the QE policy by the Federal Reserve on the emerging market (EM) economies. Massive capital has flowed into the EM economies since the Federal Reserve started its QE policy in 2008 and as a result, their local currencies appreciated substantially. These developments could have potentially significant financial and macroeconomic impacts on the EM economies. Our focus on the EM economies is also partly motivated by how popular media and policy-making circles around the world were rife with concerns about the spillover effects of the QE policy.[2]

Our empirical strategy is to first identify the US QE shock in a monthly structural vector autoregression (VAR) for the US economy and assess its international implications in a monthly panel VAR for the EM economies. This allows us to document three features of the US QE policy. First, we estimate the effects of QE policies on the US economy in a manner that is a close parallel to the approach in the conventional monetary policy VAR literature. Second, the panel VAR model for the EM economies that treats the US QE shock as an exogenous shock allows us to estimate macroeconomic and financial spillover effects of the US QE policy. Third, our panel VAR approach also allows us to assess heterogeneity in responses across different subgroups of the EM countries.

---

[1] We will use LSAP and QE interchangeably in the paper.

[2] One example of such attention in policy is the following quote from a speech by the then Governor of Central Bank of India:

> *"The question is are we now moving into the territory in trying to produce growth out of nowhere we are in fact shifting growth from each other, rather than creating growth. Of course, there is past history of this during the Great Depression when we got into competitive devaluation ...We have to become more aware of the spill-over effects of our actions and the rules of the game that we have — of what is allowed and what is not allowed — needs to be revisited."* (Governor of Reserve Bank of India Raghuram Rajan in a speech in 2015)

Such concerns were, at least partly, acknowledged by policy makers in advanced economies, as is evident in the quote above from a speech by Federal Reserve Governor Ben Bernanke.

We use the securities held outright on the balance sheet of the Federal Reserve, which consists of all outright asset purchases by the Federal Reserve, as our baseline measure for the QE policy instrument.[3] Then unanticipated exogenous changes in the QE policy instrument are isolated from endogenous adjustments of the same variable to the state of the economy using non-recursive restrictions on the short-run dynamics in the US VAR. The idea is analogous to the one in the structural VAR literature that identifies a conventional monetary policy shock from a monetary policy rule, in particular the identification approach of Sims and Zha (2006 a,b). Following that literature, we refer to the exogenous changes in the QE policy instrument as the US QE shock.[4]

In our baseline specification of the US VAR, we identify a strong impact of the QE shock on both output and consumer prices and find robust evidence of a reduction in long-term Treasury yields and an increase in stock prices.[5] Next, we estimate international spillover effects of the US QE shock on the following EM economies: Chile, Colombia, Brazil, India, Indonesia, Malaysia, Mexico, Peru, South Africa, South Korea, Taiwan, Thailand, and Turkey.[6] A panel VAR for macroeconomic and financial variables of the EM countries is estimated with the US QE shock included as an exogenous regressor. We use a random coefficients panel VAR approach that partially pools the cross-sectional information across the EM economies.

There are statistically and economically significant effects on exchange rates, long-term bond yields, and stock prices of these EM economies. In particular, an expansionary US QE shock appreciates the local currency against the US dollar, decreases long-term bond yields, and increases stock prices of these countries. The impact effects on the nominal exchange rate is around 25 bp, on stock prices around 100 bp, and on long-term bond yields around 3 bp. For the nominal exchange rate and stock prices, the peak effects are around three times as large as the initial effects and occur 5 months after impact. In addition, we find that more capital flows into the financial markets of these countries following an expansionary US QE shock. At its peak, capital inflows increase around 2%. This is a large effect. Using the average size of the capital flows in our data, this constitutes an average effect of 3.9 billion dollars on the aggregate and 300 million dollars per country.

On the contrary, we interestingly find no significant and robust effects on output and consumer prices of the EM countries. These results are not necessarily surprising as capital inflows and exchange rate appreciations can have opposite effects on production. Net exports also do not respond significantly on impact but, after several periods, respond positively. Given the exchange rate appreciation, this might be surprising, but other mechanisms, such as improved US financial conditions and a recovery of the US demand, can drive net exports in the opposite direction, thereby canceling

[3] This is our baseline approach throughout the paper. In a robustness check however, we also use a shadow interest rate as a QE policy instrument.

[4] As a theoretical justification for our framework, we simulate the Gertler and Karadi (2011) model of QE, which features a feedback rule for QE policy, with a QE shock. Like in our empirical exercise, this shock is an unanticipated exogenous change in the QE policy instrument, which is actual credit/securities purchases in the Gertler and Karadi (2011). The model implied impulse responses are qualitatively similar to our empirical results.

[5] The magnitude of the effects of the QE shock on US variables is also economically large, as we show later.

[6] 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 or are in the Euro zone (and hence are more vulnerable to the European debt crisis) as well as some other countries such as China and Russia that are known to manage their exchange rates.

the negative effect of the exchange rate appreciation.

Next, we investigate if there are meaningful differences in responses across some subgroups of the EM countries. Motivated by the attention that Brazil, India, Indonesia, Turkey, and South Africa, which came to be known as the "Fragile Five," received in the media due to the potential vulnerability of their economies to the US QE policy, we consider one group composed of these countries and another of the remaining eight countries. We indeed find that these Fragile Five countries respond more strongly and differently from the rest of the EM economies. This holds for all the financial variables that we consider, including capital flows. For example, the peak response of exchange rates and long-term bond yields is around four times larger for the Fragile Five countries and capital flows respond significantly only for the Fragile Five countries. However, we do not observe any significant heterogeneity in output and consumer price responses. Lastly, for net exports, the response is positive only for the Fragile Five group.

In a discussion of these heterogeneous effects across country groups, we document that the higher vulnerability of the Fragile Five countries is correlated with some important conditions and imbalances prior to the crisis. Specifically, prior to the crisis, these countries had a larger appreciation of exchange rates, a faster rise of stock prices, and higher interest rates as well as larger macroeconomic imbalances, measured by the current account, fiscal deficit, and debt to GDP ratio.

Overall, our estimates from the EM panel VAR suggest two main results. First, there is evidence of much stronger spillover effects of the US QE policy on financial variables compared to macroeconomic variables. This result on financial variables is consistent with the narrative of US investors "reaching for yield" in emerging financial markets. Second, the effects on the Fragile Five countries are larger compared to the other EM economies in our sample. This result is in turn consistent with the narrative of differential effects of US QE policy on the EM economies, which we relate to pre-crisis fundamentals.

This paper is related to several strands of the literature. There is an influential empirical literature, for example, Neely (2010), Gagnon et al (2011), Krishnamurthy and Vissing-Jorgensen (2011), trying to assess the effects of the US QE policy on interest rates, expected inflation, and other asset prices such as exchange rates.[7] A main approach in this literature is to assess the announcement effects of such policies - the response of high-frequency financial variables to the Federal Reserve's announcements of policy changes within a very narrow time frame. By isolating the changes in these variables due to the announcement of the QE policy, this literature has shown that it contributed to lowering long-term interest rates and depreciating the US dollar.

We contribute to this literature by taking an alternative approach. Our results for the impact of QE on financial variables are consistent with the findings of the announcement effect literature. We extend the results from the announcement effects literature by both assessing the impact on low-frequency macroeconomic variables that policy makers focus on, such as output and consumer prices, and ascertaining the dynamic effects of such policies beyond a narrow time frame around QE

[7] An incomplete list also includes Wright (2012), Hamilton and Wu (2012), and Bauer and Rudebusch (2013). Rogers et al (2014) is a cross-country empirical study while Fawley and Neely (2013) provides a narrative account of the LSAPs conducted by four major central banks.

policy announcements.

In taking a VAR-based approach to assess the effects of QE, our paper is related to Wright (2012), Baumeister and Benati (2013), and Gambacorta et al (2014). However, our identification approach is different so our evidence complements their findings. In particular, our approach is similar to that of Gambacorta et al (2014) who focused on domestic macroeconomic implications of QE by several advanced countries using a central bank balance sheet variable as an instrument of policy. We use a different identification method from theirs and focus on the effects of QE on the EM economies.[8]

Our empirical strategy is also close to the literature that assesses the purchase effects of the US QE policy. For example, D'Amico and King (2013) use a cross-sectional instrumental variables estimation, where Federal Reserve asset purchases are instrumented to avoid endogeneity concerns, to study the effects of large-scale Treasury purchases on high-frequency Treasury yields. Similar to D'Amico and King (2013) we estimate effects that arise when the actual operation of balance sheet policies by the Federal Reserve happens. We however use a different methodology to separate out unanticipated movements in the Federal Reserve's balance sheet variables. Our results on long-term interest rates are consistent with their findings.

There is important work assessing the international effects of the US QE policy, for example, Glick and Leduc (2012, 2013), and Bauer and Neely (2013). Our work is different from this research in that we focus on the EM economies. Chen et al (2016) investigate the international spillover effects of US unconventional monetary policies using the global vector error correction model. We instead use a panel VAR model to pool cross-sectional information about the international effects of US QE policy. Overall, our evidence on the effects on exchange rates and long-term interest rates for these countries is complementary to the international effects documented by these papers on advanced economies. With this focus, using different methods, we are also contributing in the same vein as Eichengreen and Gupta (2013), Aizenman et al (2014), Bowman et al (2014), and Tillmann (2014). Our approach is different with respect to identification and the way we pool cross-sectional responses by the EM countries. Our results on international capital flows are also related to Dahlhaus and Vasishtha (2014) and Lim et al (2014), who analyze the effects of the US unconventional monetary policy on capital flows to developing or EM economies. Finally, in using a VAR analysis to ascertain the effects of the US monetary policy on international capital flows and asset prices, this paper is also connected to Rey (2013) and Bruno and Shin (2015).

2 Empirical methodology

We proceed in two steps in our empirical study. A structural VAR for the US economy is first estimated to identify the QE shock. With this shock included as an external regressor, in the second step, a panel VAR for the EM countries (EM panel VAR) is estimated to assess the effects of the US QE shock on their economies. We use the Bayesian approach to estimate both the US VAR and the EM panel VAR, whose details including the prior distribution are provided in the appendix. We

[8] The robustness exercise where we use a shadow interest rate as an instrument of QE and identify a QE shock using a VAR is connected to papers such as Wu and Xia (2016). The shadow interest rate we use is from Krippner (2016).

start by describing briefly our data.

2.1 Data

We use macroeconomic and financial data at the monthly frequency from January 2008 to November 2014. All the US data is from FRED except for the House Price Index data from Core Logic. We employ the series of securities held outright by the Federal Reserve as a measure of QE. It consists of the holdings of US Treasury securities, Federal agency debt securities, and mortgage-backed securities by the Federal Reserve and thus is the most important measure of the size of the asset side of the Federal Reserve balance sheet for our purposes. In particular, these holdings are due to open market operations that constitute outright purchases by the Federal Reserve, which were a main component of QE. Figure A.1 in the appendix plots securities held outright along with 10-year Treasury yields, the S&P 500 index, nominal (trade-weighted) effective exchange rates, real GDP, and the private consumption expenditures (PCE) deflator over the sample period.

We assess international spillover effects of the US QE policy on the following important EM countries: Brazil, Chile, Colombia, India, Indonesia, Malaysia, Mexico, Peru, South Africa, South Korea, Taiwan, Thailand, and Turkey. We collect monthly output, prices, US dollar exchange rates, the stock market index, long-term and short-term interest rates, the bond index, and monetary aggregate data from Datastream and Bloomberg, trade flows data from Direction of Trade Statistics by IMF, and capital flows data from EPFR for the same sample period as the US data. The online data appendix contains a detailed description of data sources for the EM countries.

Figures A.2 and A.3 in the appendix document dynamics of long-term interest rates, stock prices, US dollar exchange rates, and cumulative capital flows for these countries. In addition, to demonstrate a pattern of heterogeneity among the EM countries evident in the data, we present the data in two subsets of countries in Figures A.2 and A.3: One for the "Fragile Five" countries including Brazil, India, Indonesia, South Africa, and Turkey, and the other for the rest of the EM countries. We will econometrically assess these differences across the two country groups in the paper.

2.2 Structural VAR for the US economy

We now describe the baseline specification for the US VAR and identification strategy and then discuss its various extensions.

2.2.1 Baseline specification

For the US economy, we consider a structural VAR (SVAR) model

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

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 A_j for $j = 0, \cdots, k$ is an $m_y \times m_y$ matrix.

Table 1: Identifying restrictions on A_0

	Industrial production	PCE deflator	Securities held-outright	10-year Treasury yields	S&P500 index
Prod1	X				
Prod2	X	X			
I	X	X	X	X	X
F	X	X	a_1	a_2	
MP			a_3	a_4	

Notes: "X" indicates that the corresponding coefficient of A_0 is not restricted and blanks mean that the corresponding coefficient of A_0 is restricted to zero. Coefficient a_i $(i = 1, \cdots, 4)$ of A_0 is not restricted except that we impose $Corr\,(a_1, a_2) = 0.8$ and $Corr\,(a_3, a_4) = -0.8$ in the prior distribution.

In our baseline specification y_t includes five variables: the industrial production index, the PCE deflator, securities held outright on the balance sheet of the Federal Reserve, 10-year Treasury yields, and the S&P500 index. We include the long-term interest rate and the stock market price index, unlike much of the traditional VAR literature, as the outcomes and effects on the financial markets were an important aspect of policy making during the QE period.

As mentioned earlier, the size of the Federal Reserve balance sheet measured by the securities held outright is considered as the instrument of the QE program after the ZLB for nominal interest rates started binding in the US.[9] We choose this component of the balance sheet rather than total assets of the Federal Reserve as the baseline measure of QE since it is a direct measure of LSAP, which is the focus of our analysis.[10] Note that this measure is only about the asset size on the balance sheet and not its composition.[11]

We impose non-recursive short-run restrictions on SVAR (1) to identify exogenous variations in the securities held outright, which are referred to as the QE shock. Our identification approach is similar to that employed by, for example, Leeper, Sims, and Zha (1996) and Sims and Zha (2006a; 2006b) to identify conventional monetary policy shocks in the US.[12]

[9] During normal times, this component of the balance sheet does not vary much as it is only used to account for some secular changes in the currency demand. This measure is not a standard policy instrument as it constitutes what is often called "permanent open market operations." During such times, the Federal Reserve achieves its target for the federal funds rate via "temporary open market operations," using repurchase and reverse repurchase transactions.

[10] In addition to securities held outright, total assets of the Federal Reserve would contain some other components such as gold stock, foreign currency denominated assets, SDRs, and loans. These components are very minor and constant overall during the time period of our analysis, except for a period between Sept 2008 and June 2009 because of an increase in loans made by the Federal Reserve, mostly as primary credit and transactions in liquidity/auction facilities. These components would be distinct from LSAPs, which are our focus. Please see the Federal Reserve H.4.1 Release: Factors Affecting Reserve Balances for further details.

[11] One phase of the LSAPs, the Maturity Extension Program, only constituted a change in the composition and not the size of the balance sheet. Our baseline measure will not account for this phase and to the extent that it had important effects, our estimated effects will be a slight underestimate of the total possible effect of QE.

[12] In terms of the unconventional monetary policy, our empirical methodology is most related to Gambacorta et al (2014) but there are differences in the variables used, in the identification strategy, and in the time period used in the analysis. They used total assets of the Federal Reserve as the instrument of monetary policy and employed a mixture of sign and zero restrictions for identification. They did not include long-term yields and used data on the early part of the QE program only.

Table 1 describes the identifying restrictions on A_0 where the columns correspond to the variables while the rows correspond to the sectors in the US economy that each equation of SVAR (1) intends to describe.[13] The first two sectors (Prod1 and Prod2) in Table 1 are sectors related to the real economy, determining slow-moving variables like output and prices. The third equation (I) refers to the information sector and determines the fast-moving asset price variables which react contemporaneously to all the variables.

The last two equations (F and MP) in Table 1 are, respectively, the long-term interest rate determination and monetary policy equation. The former equation (F) embodies restrictions that the long-term interest rate adjusts contemporaneously to changes in output, prices, and asset purchases by the Federal Reserve.

For the monetary policy equation (MP), we assume that the monetary policy instrument reacts contemporaneously only to the long-term interest rate. The assumption that the Federal Reserve does not react contemporaneously to industrial production and prices is because the Federal Reserve cannot immediately observe these variables. We additionally posit no contemporaneous reaction of the monetary policy instrument to the stock price index on the grounds that the Federal Reserve would not respond instantaneously to temporary fluctuations in stock prices.[14] We thus postulate that the QE policy of the Federal Reserve is well approximated by a rule that determines the Federal Reserve's purchase of securities as a linear function of the contemporaneous long-term yield and the lags of macroeconomic and financial variables. Any unanticipated non-systematic variations in the securities held outright are then identified as a shock to the QE policy that is exogenous to the state of the US economy. This approach is analogous to that for the identification of monetary policy shocks in the conventional monetary policy analysis.

In order to identify the last two equations (F and MP) separately, we impose an extra prior restriction similar to the liquidity prior by Sims and Zha (2006b) on the otherwise mutually-uncorrelated coefficients of A_0. The liquidity prior expresses prior beliefs that in the interest rate determination equation (F), the long-term interest rate tends to decrease as the securities held outright increases (specifically, $Corr\,(a_1, a_2) = 0.8$), while in the monetary policy equation (MP), the securities held outright tends to increase as the long-term interest rate increases (specifically, $Corr\,(a_3, a_4) = -0.8$). The latter implies a natural restriction that policy makers would purchase more securities in response to a rise in long-term interest rates.[15] Sims and Zha (2006b) imposed this prior to separate out shifts in money demand from money supply in a framework that had both quantity (money) and price (interest rates) variables. We use them for similar reasons as we also have a specification with both quantity and price variables.[16]

[13] The identifying restrictions in Table 1 satisfies the sufficient condition for the global identification of the SVAR derived by Rubio-Ramirez et al. (2010). In fact, the identifying restrictions are numerically identical to those of a monetary SVAR which is given as an example in their paper.

[14] As we show in the appendix, allowing the securities held outright to respond to the stock price does not change our main results.

[15] Note that here the restrictions are on the correlation coefficients in the prior distribution, and hence, are weaker than the sign restrictions imposed directly on the impulse responses (for example, those imposed by Gambacorta et al, 2014).

[16] Thus, these prior specifications are useful for us to get meaningful inference on effects of purchases of securities by

For our identification approach to be valid, it is required that the policy measure, here the size of the Federal Reserve balance sheet, not be perfectly anticipated and forecastable by the private sector. In practice, the Federal Reserve announced components of the LSAP programs ahead of time. It is however reasonable that the entire path of the size of its balance sheet was not perfectly predictable by the private sector. First of all, the Federal Reserve provided only a tentative monthly schedule of operations with a range of the expected purchase size, not the exact purchase size. The Federal Reserve's asset purchases were conducted though competitive auctions, which further increased uncertainty around the actual path of the size of the Federal Reserve balance sheet. Finally, there can be limitations to perfectly forward looking behavior by the private sector due to information frictions. Our approach takes advantage of such forecast errors for identification. Our approach is thus similar to the approach by D'Amico and King (2013) who estimated the effects of the large-scale Treasury purchases in that both estimate the effects of actual security purchases by the QE policy.

2.2.2 Extensions and alternative specifications

We also estimate various extended specifications for the US VAR that include additional types of interest rates and asset prices. Because of the small sample size, we include one or two additional variables at a time to the baseline specification such as the nominal effective exchange rate, 20-year Treasury yields, corporate bond yields, 30-year mortgage yields, and house prices. Lastly, we experimented with recursive identifying restrictions on A_0 so as to check whether we indeed need our identifying restrictions described in Table 1 to correctly identify the QE shock and get results that are economically sensible and consistent with the findings of the related literature.

To further assess the robustness of our results, especially as they pertain to the spillover effects, we use an alternate measure of QE policy. Our baseline and focus is throughout on securities purchased as a measure of QE. In a sensitivity analysis, we use a shadow interest rate estimated by Krippner (2016) as a measure of QE policy and extract a US QE shock. For this exercise, we use a standard recursive identification in the US VAR with the shadow interest rate ordered last.

2.3 Panel VAR for the emerging market countries

In this subsection we explain the baseline specification and identification strategy of the EM panel VAR. Various extensions are also described.

2.3.1 Baseline specification

After identifying the QE shock from the US VAR, we assess its dynamic effects on the EM countries by feeding it into a joint system of equations for their economies. Suppose that our sample includes

the Federal Reserve on long-term interest rates. Without these priors results are unstable across specifications in terms of whether a positive QE shock decreases long-term interest rates. Note that in practice, as we show later, only one set of these prior restrictions (those on the long-term interest rate determination equation) are needed to get standard and stable impulse responses, but for the baseline specification we directly follow Sims and Zha (2006b) and use both set of prior restrictions.

N countries indexed by i. The dynamics of endogenous variables for country i are represented as

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

where $z_{i,t}$ is an $m_z \times 1$ vector of endogenous variables for country i, $\varepsilon_{QE,t}$ is the median of the US QE 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. 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 $\mathbf{u}_t = \left(u'_{1,t}, \cdots, u'_{N,t}\right)'$,

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

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 four variables: industrial production, CPI, M2, and nominal exchange rates of the local currency against the US dollar. M2 is included to control for endogenous monetary policy responses of the EM countries to the US QE shock. We opt to include M2 as a monetary policy instrument rather than the short-term interest rate mostly because of concerns about data quality and relevance.[17] M2 might also capture some broader monetary policy interventions carried out by central banks of these countries such as foreign exchange interventions. To the basic three-variable system with output, the price level, and the monetary aggregate, we add US dollar exchange rates to account for the open-economy features of the EM economies.

Many of the EM countries in our sample are commodity exporters. To take this fact into consideration, a proxy of the world demand for commodities and a price index of commodities are included in the vector of exogenous variables x_t.[18] In addition, we control for world demand proxied by overall industrial production of 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 x_t is exogenous in the system as the EM countries under study are a small open economy and thus the world variables can plausibly be considered exogenous. Nonetheless, it is likely that there are other common factors that influence the dynamics of these countries. We do not impose any restrictions on $\mathbf{\Sigma}$ in (3) except that it is positive definite so that the disturbance terms $u_{i,t}$'s are freely correlated across countries and could capture the effects, if any, of these other common factors.

Importantly, the coefficient matrices in (2) are allowed to be different across countries. Unlike a common approach for the panel model on micro data, we allow for such dynamic heterogeneities since

[17] Countries like Brazil and South Korea use the short-term interest rate as the monetary policy instrument and quality data is available for them. Later, in an extension, we use the short-term interest rate as a monetary policy instrument and show that our main results are robust.

[18] The measure of world demand for commodities is the index of global real economic activity in industrial commodity markets estimated by Lutz Kilian. The commodity price index is all commodity price index provided by IMF.

the economies of the EM countries in our sample have quite different characteristics and thus their dynamics are almost certainly not homogeneous. However, as Figures A.2 and A.3 suggest, during the crisis period, their major macroeconomic and financial variables exhibited large comovements. Even without any crisis going on in the US, they are small open economies and thus their economies are likely to be driven in a similar way by common world variables. To account for potential common dynamics, and especially effects of the US QE shock that are similar across those countries, we take the random coefficient approach and assume that the coefficient matrices in (2) are normally distributed 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 QE shock on the EM countries.

This random coefficient approach is implemented following Canova (2007) and Canova and Ciccarelli (2013). Let us collect the coefficient matrices in (2) as $B_i = \begin{pmatrix} B_{i,1} & \cdots & B_{i,p} \end{pmatrix}'$ and $D_i = \begin{pmatrix} D_{i,0} & \cdots & D_{i,q} \end{pmatrix}'$ and let $\gamma_i = \text{vec}\begin{pmatrix} B_i' & D_i' & C_i \end{pmatrix}'$. 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. We assume 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) is then 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 QE shock $\varepsilon_{QE,t}$ can be computed by tracing out the responses of $z_{i,t}$ to an increase in $\varepsilon_{QE,t}$ over time with γ_i replaced with $\bar{\gamma}$.

We note that since we use the median of the US QE shock estimated in the US VAR and its lags as regressors in (2), our estimation of its effects is subject to the generated regressor problem. As we show in Section 4, however, the US QE shock is very tightly estimated. Thus the uncertainty around the estimates of the shock is not big and the generated regressor problem is not likely severe. Ideally, we can estimate the effect of the US QE policy 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.[19] 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 try various alternative specifications and do robustness exercises.

[19] Cushman and Zha (1997) is a classic VAR based study of effects of monetary policy in small open economies under the block exclusion restriction. Our approach is similar, but not equivalent, since we do not include the US variables and their lags in the EM panel VAR. We choose not to include the US variables in the panel VAR because of the concern on the degrees of freedom. Instead, in the panel VAR, we control for world variables with the level of the world economic activities proxied by OECD industrial production and the demand for and price of commodities in the world market.

2.3.2 Heterogeneities across subgroups of countries

In addition to the baseline estimation above based on the random coefficient approach, in order to assess economically interesting heterogeneity across subgroups of the EM countries, we implement the following estimation method for two groups of the EM countries in our sample. The mean of the coefficients, $\bar{\gamma}$ in (4), is allowed to be different between two groups of the EM countries, denoted group 1 and 2. Specifically, the assumption for the random coefficient approach (4) is modified as follows: For $i = 1, \cdots, N$,

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

where $I_F(i)$ is an indicator function that takes on 1 if country i is in group 1 and 0 otherwise, and $v_i \sim \mathbb{N}\left(\mathbf{0}_{m_\gamma \times 1}, \Sigma_i \otimes \underline{\Sigma}_i\right)$. By comparing the impulse responses to the US QE shock across these two groups, using $\bar{\gamma}_1$ and $\bar{\gamma}_2$, respectively, we can study whether these two groups were differentially sensitive to the US QE shock. Our baseline sub-group estimation consists of the Fragile Five countries in one group and the rest of the EM countries in another.

2.3.3 Extensions and alternative specifications

We also assess the impact of the US QE shock on other important variables such as long-term interest rates, stock prices, capital flows, and trade flows in extensions to the baseline specification. Because our sample is not sufficiently large, we extend the four-variable baseline specification by including one additional variable at a time. In an alternative specification we also use the short-term interest rate as a measure of monetary policy instead of M2. Lastly, we also consider a different subgrouping of countries in which we include Mexico in the Fragile Five group of countries. Finally, we also report results when the US VAR includes uses a shadow interest rate as a measure of QE policy and identifies the US QE shock.

2.4 Estimation details

The frequency of our sample is monthly and it covers the period from 2008:1 through 20014:11. All the data except for interest rates and net exports to GDP ratios are used in logs.

The US VAR includes six lags of the endogenous variables, in the baseline specification and in specifications for robustness exercises, and we use the data in the period from 2008:1 through 2008:6 as initial conditions. The US VAR is estimated using the Bayesian approach with the Minnesota-type priors that are laid out in Sims and Zha (1998) and implemented, for example, in Sims and Zha (2006b). The Minnesota-type prior distribution combines a prior belief that a random-walk model is likely to describe well the dynamics of each variable in a VAR model and a belief that favors unit roots and cointegration of the variables. It is shown to improve macroeconomic forecasts across many different settings by effectively reducing the dimensionality (see, for example, a discussion in Canova, 2007) and widely used as the standard prior for a VAR model with variables that exhibit persistent dynamics like the data in our sample. We choose values for the hyperparameters of the prior distribution following Sims and Zha (2006b). However our results are robust to other values of the hyperparameters, as we report later.

We extract the QE shock as the posterior median of the identified QE shock. The EM panel VAR includes three lags for endogenous variables and six lags of the US QE shock. We include only three lags of endogenous variables because of the concern on the degrees of freedom of the panel VAR. Note that the estimated US QE shock is available only from 2008:7 and the first six observations from 2008:7 through 2008:12 are used as initial conditions. The panel VAR is also estimated using the Bayesian approach. A Minnesota-type prior similar to that for the US VAR is also employed for the EM panel VAR.

The Bayesian information criterion (BIC) favors a specification with one lag of the dependent variable for both the US VAR and the EM panel VAR. However our sample is quite small and the BIC is known to have poor small-sample properties. Moreover, we do not take the first difference of our data to remove potential unit roots in the data. So we choose to include more than one lag to capture persistent dynamics of the data for both the US VAR and the EM panel VAR. Our main results though hold with only one lag of the dependent variable included.

The Gibbs sampler is used to make draws from the posterior distribution of both the US VAR and the EM panel VAR. We diagnose convergence of the Markov chains of the Gibbs sampler by inspecting the trace plot and computing the Geweke diagnostic.[20] For further details about estimation, see the appendix.

3 Results

We now present our results on the effects of the US QE shock. We first start with our estimates of the domestic effects of the US QE shock as well as our inference of the shock series. The spillover effects of the US QE shock on the EM economies follow.

3.1 Domestic Effects of US QE Shock

Figure 1 shows the impulse responses to a positive shock to the securities held outright, which is identified as an expansionary QE shock, in the baseline specification. We estimate a positive response in industrial production after a lag of five months and an immediate positive effect on consumer prices. Moreover, the long term Treasury yield falls significantly on impact while the stock price increases significantly after some delay. Our results on the macro variables such as industrial production and consumer prices are similar to those in Gambacorta et al (2014) though the identification strategy is different. The results on long-term interest rates are consistent with the high-frequency data based announcement effects and the asset purchase effects estimated in the literature. We interestingly find quick effects of the QE policy on consumer prices. This is different from the delayed effects of the conventional monetary policy shock estimated in the VAR literature.

[20] For the US VAR estimation, we used the code made public by Tao Zha. Convergence diagnostics were computed using the *coda* package of R (Plummer et al, 2006). Detailed results of the convergence diagnostics are available on request.

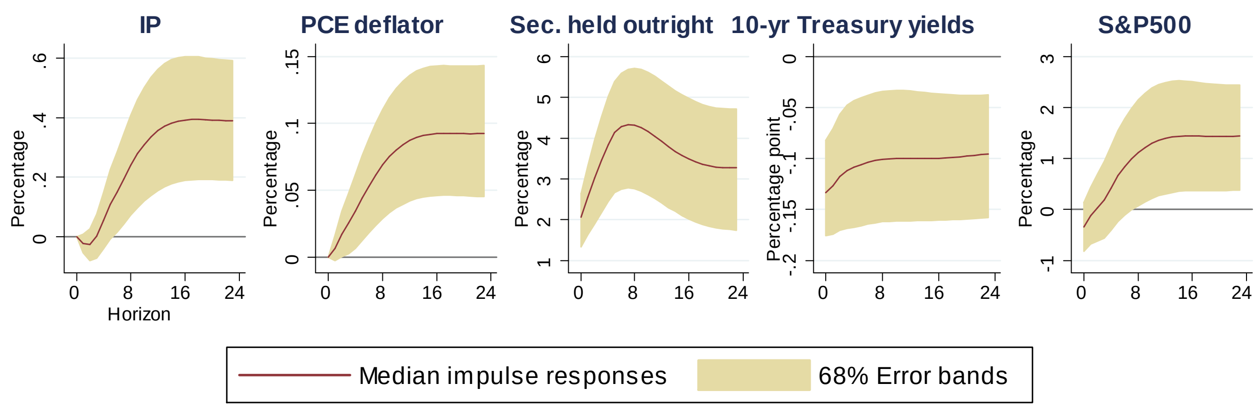


Figure 1: Impulse responses to the QE shock in the baseline specification for the US VAR

Notes: The shock is a one-standard deviation (unit) positive shock in the monetary policy (MP) equation.

How large are the effects of the QE shock? Here is a back-of-the-envelope calculation. A one-standard deviation shock in Figure 1 amounts to about a 2% increase in the securities held outright by the Federal Reserve on impact. This constitutes an increase, on average, of 40 billion dollars in the securities held outright by the Federal Reserve in our sample. In response to a shock of this size, the 10-year Treasury yield falls by around 10 bp on impact. In terms of magnitude, this effect is comparable to the estimated effect of QE2 announcement on long-term interest rates, as documented in Krishnamurthy and Vissing-Jorgensen (2011). It is also comparable to the estimated effect of QE1 purchases on long-term yields, as documented in D'Amico and King (2013). In addition, we find an immediate effect of around 50 bp on stock prices. Finally, we find a peak effect after around 10 months of 0.4% increase on output and 0.1% increase on consumer prices.

The posterior median of the identified QE shock from the baseline US VAR, along with the 68% error band, is presented in Figure 2. We rescaled the QE shock and its error bands so that the coefficient on the securities held outright in the monetary policy equation (MP) of the US VAR is one. Thus it is comparable to the monetary policy shock in the conventional Taylor-type monetary policy rule. The QE shock is quite precisely estimated as reflected in the tightness of the error band. The estimated QE shock presented in Figure 2 can be understood as the unanticipated deviation of the securities held outright from the QE policy rule, which is exogenous to the state of the US economy.

For comparison, in Figure 2 we also present the growth rate in securities held outright and the reduced form QE shock. Overall our identified QE shock series comoves with the growth rate of securities held outright but not perfectly. The growth rate of securities held outright partly reflects the endogenous response of the Federal Reserve's purchase of securities to the state of the US economy and thus is not appropriate to estimate the causal effect of the QE policy. Note that it would be potentially incorrect to use the growth rate of securities held outright as a measure of US QE in the EM panel VAR even if the EM economies do not influence the US economy. This is because the estimated effects of such endogenous responses in the growth rate of securities held outright can be

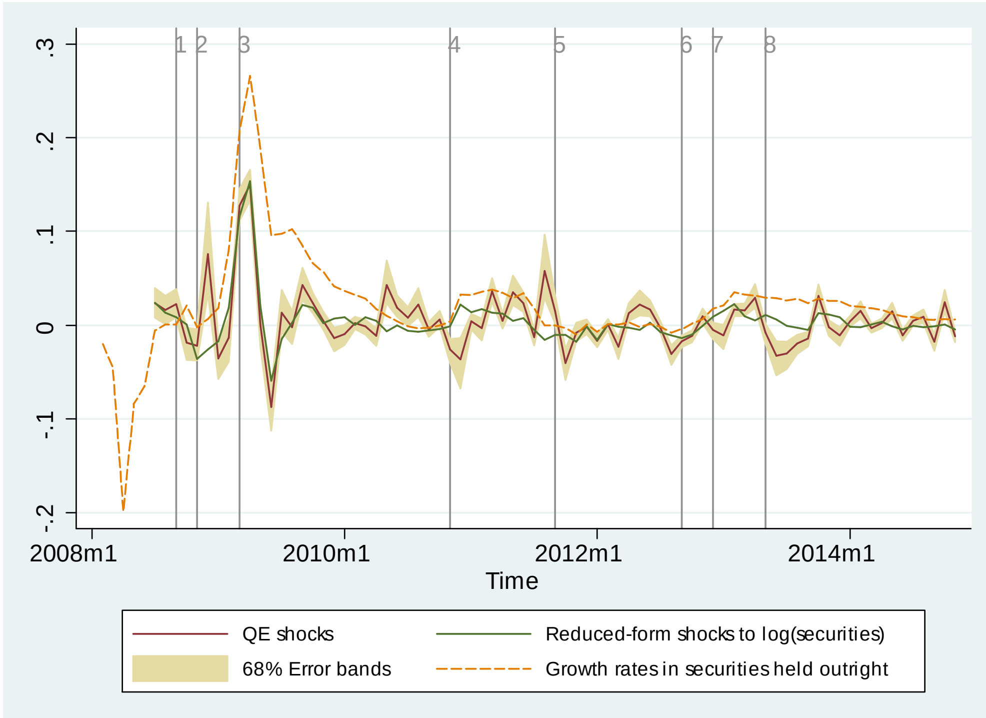


Figure 2: Identified US QE shocks, reduced form shocks to securities held outright, and the growth rate of securities held outright

Notes: The QE shock and the reduced-form shock are the posterior median. The QE shock was rescaled by the coefficient on the securities held outright in the monetary policy equation (MP) of the US VAR. The vertical lines mark dates of the major events: [1] September 2008 when the Lehman Brothers filed for bankruptcy; [2]-[3] November 2008 and March 2009 which are QE1 dates; [4] November 2010 which is a QE2 date; [5] September 2011 which is an MEP date; [6]-[7] September 2012 and December 2012 which are QE3 dates; and [8] May 2013 when Ben Bernanke discussed the possibility of withdrawal of the QE program at the US Congress.

attributed to changes in the US variables other than the QE policy.

Our shock series is not exactly aligned with important announcement dates of the QE program either. We believe that our econometric methodology that is based on a system of equations for macroeconomic and financial data and identifying restrictions for structural shocks allows us to separate out the dynamic effects of QE from its immediate announcement effects. One possible interpretation is that we are capturing effects coming from implementation of QE policies. Thus, the interpretation would be similar to the one in the purchase effects of QE in the literature.[21]

Finally, there is also a difference between the identified and the reduced-form shock, illustrating the role played by our identifying restrictions. Even after removing the predictable responses of the securities held outright to the lagged state of the US economy, there is an additional role played by explicit identification assumptions that isolate the unconventional monetary policy reaction function of the Federal Reserve. The reduced-form shock will be a combination of the QE shock and various

[21] Fratzscher et al (2012) also discuss this difference between announcement and actual implementation effects. For an empirical analysis that decomposes the effects of Federal Reserve asset purchases into “stock” vs. “flow” effects, see D’Amico and King (2013) and Meaning and Zhu (2011).

other shocks and cannot be interpreted exclusively as an unanticipated shock to the US QE policy. We present results on the importance of the identified US QE shock in explaining the forecast error variance and results of the alternative specifications to the baseline US VAR in the online robustness appendix.

3.2 Theoretical justification

While this paper is empirical and we do not attempt to tease out the precise theoretical reasons for which QE, as given by actual purchases by the central bank, might have effects on the macroeconomy, we do one exercise using the well-known Gertler and Karadi (2011) model. Gertler and Karadi (2011)'s framework features a QE policy reaction function and is therefore an ideal set-up for us to use. Our goal is to illustrate the transmission mechanism of a QE shock in that model and to provide some theoretical grounding for our paper. In particular, using the exact specification and calibration as in their paper, and with various versions of the feedback rule for QE policy, we show how a QE shock, which is an unanticipated shock to the feedback rule, affects macroeconomic variables and interest rates in the model. The only change we make to the Gertler and Karadi (2011) set-up is to add a QE shock to the QE feedback rule, and to consider a more general version of the feedback rule such that policy might respond to lagged output growth and inflation and there might be a smoothing component to QE policy. Such a feedback rule is close to the QE reaction function we identify in the US VAR.[22]

In particular, we consider the following QE reaction function

$$\psi_t = \rho_\psi \psi_{t-1} + \left(1 - \rho_\psi\right) \left[\left(\kappa E_t \left(R_{k,t+1} - R_{t+1}\right) - \kappa_\pi \pi_{t-1} - \kappa_y \left(y_{t-1} - y_{t-2}\right)\right)\right] + \varepsilon_{\psi,t}$$

where ψ_t reflects asset purchases/credit intermediation by the central bank, $E_t\left(R_{k,t+1} - R_{t+1}\right)$ is the expected interest rate spread (between returns to capital and a safe interest rate) in the model, π_t is inflation, and $y_t - y_{t-1}$ is output growth. The exact feedback rule in Gertler and Karadi (2011) is one with no smoothing and no response to inflation and output $(\rho_\psi = 0, \kappa_\pi = 0, \kappa_y = 0)$ and where QE purchases only respond to expected interest rate spread.[23] Here we make the specification more general and perhaps most importantly, assess the transmission of the QE shock $\varepsilon_{\psi,t}$.

It is shown that a positive shock to asset purchase by the central bank in that model leads to a positive effect on output, inflation, and a negative effect on interest rate spreads.[24] This holds for the various QE policy reaction functions that we consider, both variants that respond only to spread and those that are more consistent with empirical applications such as with smoothing terms and feedback also to output and inflation. These response are, at least qualitatively, consistent with our

[22] In Gertler and Karadi (2011), the interpretation of QE policy is directly in terms of credit easing. This framework can also however be extended to consider asset purchases in terms of long-term government bonds, as in Gertler and Karadi (2012).

[23] We use a long-term interest rate and not a long-term spread in our empirical exercise, but with the zero lower bound binding on the short-rate, these will be comparable.

[24] Figures B.4 and B.5 in the appendix present the impulse responses. It will be possible to change the timing on the information set of agents to also generate model implied impulse responses such that output and prices do not respond on impact to the QE shock. We do not do so here to avoid changing the Gertler and Karadi (2011) model.

empirical findings.

3.3 Spillover Effects of US QE Shock

We now report the spillover effects of the US QE shock on the EM economies.

3.3.1 Overall effects

We are first interested in the overall dynamic effects of the US QE shock across all the EM countries as given by the pooled estimates of the effects computed with $\bar{\gamma}$ in (4). Figure 3 reports the posterior median and 68% error bands of the impulse responses. As we mentioned before, we first estimate the baseline specification with output, prices, the monetary aggregate, and US dollar exchange rates and then estimate extended specifications that include one additional variable at a time. Only the impulse responses of the additional variables, including the stock price, the long-term interest rate, the EMBI index, capital flows and net exports to the US, from these extended specifications are presented in the second row of Figure 3. Our inference on the baseline four variables are robust to which additional variable we include in the extended EM panel VAR.

Figure 3 shows that in response to an expansionary QE shock, the currencies of these EM countries appreciate significantly against the US dollar and long-term bond yields decrease. The impact effects on the US dollar exchange rate is around 25 bp and on long-term yields around 3 bp. For the exchange rate, the peak effects are around four times as large as the impact effects and occur after about 5 months. This result confirms anecdotal evidence on the behavior of exchange rates of these EM economies.

The effect on stock prices is also positive and is accompanied by an increase in capital inflows to these countries. The impact effect on the stock price is around 100 bp, with a peak effect of around 200 bp. This is a large effect, comparable to the effect of the QE shock on US stock prices themselves. Capital inflows also increase by a fairly substantial amount, around 2% at its peak. This is also a large (peak) effect. Using the average size of the capital flows in our data, this constitutes an average effect of 3.9 billion dollars on the aggregate and 300 million dollars per country. Finally, there are no statistically significant effects on important macroeconomic variables such as output and consumer prices. The only exception is net exports, for which, while the effect is not significant for the first few periods, it eventually increases.[25]

Our results on the financial variables is consistent with the narrative of U.S. investors "reaching for yield" in emerging financial markets during the QE period. That is, as a positive US QE shock brought down long-term yields in the US, investors sought higher yielding assets, among which were the assets of the EM economies. Thus, capital flows accelerated to the EM economies, bidding up asset prices such as exchange rates of the local currencies and stock prices and decreasing long-term yields in those countries. In this sense, there was an "asset market boom" in these EM countries following a positive US QE shock.[26]

[25] Mackowiak (2007) finds significant effects of the conventional monetary policy shock on output and prices, which is not the case for our unconventional US monetary policy shock.

[26] Rapid capital inflows often lead to these developments in small open economies generally. This was true for example

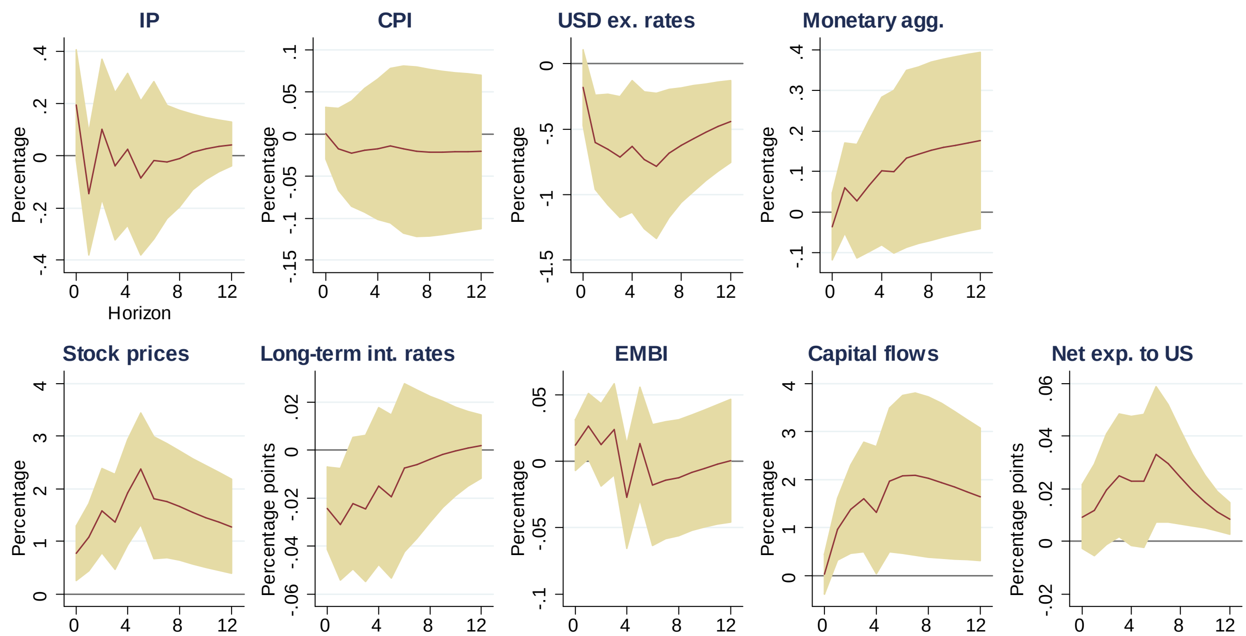


Figure 3: Impulse responses of the panel VAR on emerging market economies

Notes: Each plot displays the posterior median of the impulse responses to a one-standard deviation (unit) increase in the US QE shock identified in the baseline VAR for the US, along with 68% error bands. The first row presents the impulse responses from the baseline specification. The second row presents the impulse responses of each variable from the extended specification that includes the corresponding variable as well as the baseline four variables. USD ex. rates are the domestic currency price of a US dollar for each country. Net exports to the US are the ratio of net exports to the US to GDP of each country. For the description of other variables, see the main text and the online data appendix.

In spite of these large effects on the financial variables, we do not however find robust and significant effects on the macroeconomic variables. This is not fully surprising and is actually in line with possible opposing effects of increased capital inflows on the EM economies, as argued for example recently in Blanchard et al (2015). The result on net exports might be more surprising, as we estimate an appreciation of these currencies, but improved financial and macroeconomic conditions

for the southern European countries following the introduction of the Euro. For some recent evidence using quarterly data on large effects on house prices and consumption in emerging economies of a global shock, see Cesa-Bianchi et al (2015).

in the US following the QE policy can play a role in the reverse direction.[27]

3.3.2 Fragile Five vs. Others

Next, we investigate the heterogeneity in the spillover effects of the US QE shock across different subgroups of the EM countries. Specifically, the mean of the coefficients, $\bar{\gamma}$ in (4), is now allowed to be different between the Fragile Five countries and the rest of the EM countries in our sample. In our notation in (5), let $\bar{\gamma}_1$ be the mean of the coefficients for the Fragile Five countries and $\bar{\gamma}_2$ be the mean for the rest. By comparing the impulse responses to the US QE shock across these two groups, using $\bar{\gamma}_1$ and $\bar{\gamma}_2$, respectively, we can study if these two groups were differentially responsive to the US QE shock. We can thereby empirically assess if the Fragile Five countries were particularly vulnerable to the spillover effects of US QE policy.

The results in Figure 4 show that the effects on the financial variables such as US dollar exchange rates, long-term interest rates, the EMBI, and capital inflows are stronger for the Fragile Five countries compared to the rest of the EM countries. The effects on stock prices are similar. In fact, note that for the non-Fragile Five countries the response of US dollar exchange rates, long-term yields, and capital inflows have little statistical significance. In terms of the magnitude, the effects on US dollar exchange rates and long-term yields are at least double both on impact and at peak for the Fragile Five compared to the rest. For output and consumer prices however, there are no significant effects on both groups. Moreover, net exports increases for the Fragile Five countries after a delay, and it is not significant for the other countries. Our conclusions regarding the heterogeneity in responses between the Fragile Five countries and the rest remain robust if we instead estimate a panel VAR on the financial variables only. The results for the specification with financial variables only are reported in the online robustness appendix.

[27] Stanley Fischer recently made a similar argument:

> "*There is little doubt that the aggressive actions the Federal Reserve took to mitigate the effects of the global financial crisis significantly affected asset prices at home and abroad as well as international capital flows ...An easing of monetary policy in the United States benefits foreign economies from both stronger U.S. activity and improved global financial conditions. It also has an offsetting contractionary effect on foreign economies because their currencies appreciate against the dollar.*" (Federal Reserve Vice Chairman Stanley Fischer in a speech in 2014)

Moreover, note that our findings of capital flowing in with net exports also increasing are not inconsistent, per se, on purely statistical/accounting grounds. There is some disconnect in these two measures, as our data is on gross capital inflows while we use a net exports measure, and moreover, the capital flows data is at a global level while the trade data is at the bilateral level with the US (we make this choice with the trade data as our external shock is US specific).

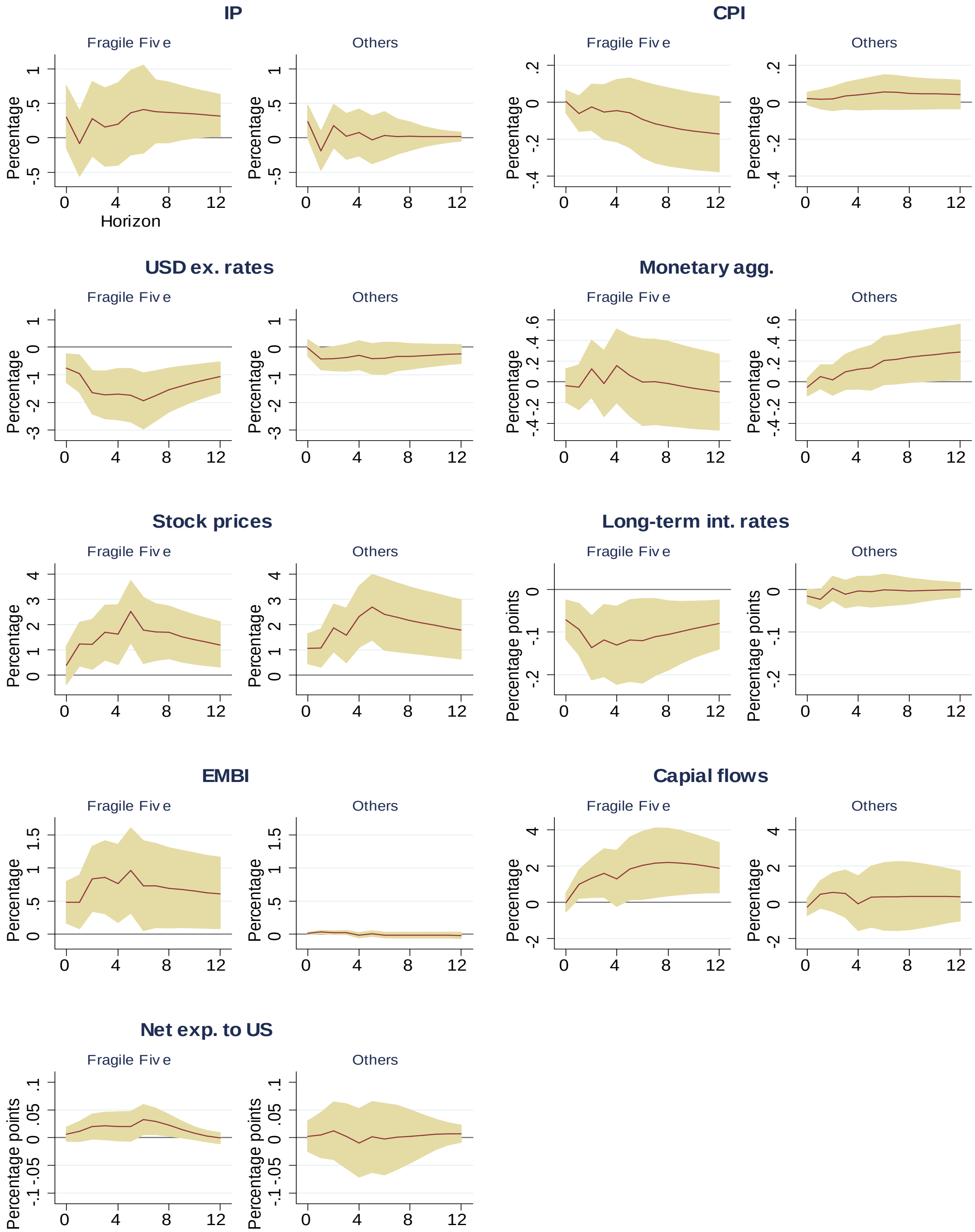


Figure 4: Impulse responses of the panel VAR on Fragile Five and others

Notes: Subplots are arranged by variables and shown for two groups of countries: the Fragile Five countries including Brazil, India, Indonesia, South Africa and Turkey and the rest of the EM economies. See the notes in Figure 3.

Table 2: Averages of key financial variables in the period of 2000-2007

	Fragile Five Countries	Rest of Emerging Markets
US Dollar Exchange Rates	-0.37	-0.21
Long-term Interest Rates	15.02	4.96
Stock Prices	2.15	1.73

Notes: The monthly data source is the same as in the panel VAR analysis. The average monthly growth rate for exchange rates and stock prices and the monthly average of long-term interest rates are presented. All the numbers are in percentage.

Table 3: Averages of key imbalance variables in the period of 2000-2007

	Fragile Five Countries	Rest of Emerging Markets
Current Account	-0.57	2.58
Fiscal Balance	-3.66	-1.05
Structural Fiscal Balance	-3.53	-1.35
Government Debt	59.7	34.5

Notes: We take the average of annual data for the two groups. The current account, fiscal balance, and government debt are presented as ratios of GDP while structural fiscal balance is presented as ratio of potential GDP, all in percentage. Government debt is gross government debt. Net government debt is not available for all countries but the average for those available countries follows a similar pattern as gross government debt. The datasource is the World Economic Outlook (WEO) by IMF.

3.3.3 Discussion

We now assess what might be underlying fundamental reasons that led the Fragile Five countries to be more sensitive and respond more strongly to the US QE shock. To provide such a narrative, we look at some key data from the pre-QE period, in particular from years 2000-2007, for these two groups of countries. Our objective here is to present a picture of the ex-ante state of the economy of these countries such that it can be related to the effect of the US QE shock.

In Table 2, we present the average growth rates of the nominal US dollar exchange rate and stock prices and the level of long-term interest rates for the period from 2000 through 2007. While the difference among the two groups of countries is not very stark in the foreign exchange and stock market, long-term interest rates are much higher in the Fragile Five countries than in the other EM countries. Thus, it seems natural that as the Federal Reserve embarked on QE, these countries saw stronger capital inflows as they were more attractive to investors who were going after higher yields with abundant liquidity.

Next, in Table 3, we present some statistics about key external and fiscal imbalances for the same period. The objective here is to assess if these imbalances were more pronounced in the Fragile Five countries, which would then help provide an explanation for why they were more vulnerable to an external shock such as the US QE shock. Indeed, Table 3 shows that the Fragile Five countries had a greater level of current account deficits and fiscal deficits, as well as a higher level of government debt, relative to GDP.[28]

4 Robustness and Extensions

We now present results of a series of robustness exercises and extensions to the baseline specifications that we have implemented.

4.1 Domestic Effects of US QE Shock

We first consider an extension of our baseline five-variable US VAR that is economically interesting. It is to assess the empirical evidence on one of the stated goals of QE by the Federal Reserve:[29] "Thus, the overall effect of the Fed's LSAPs was to put downward pressure on yields of a wide range of longer-term securities, support mortgage markets, and promote a stronger economic recovery." This exercise may help us identify the QE shock better by considering the goal of QE explicitly.

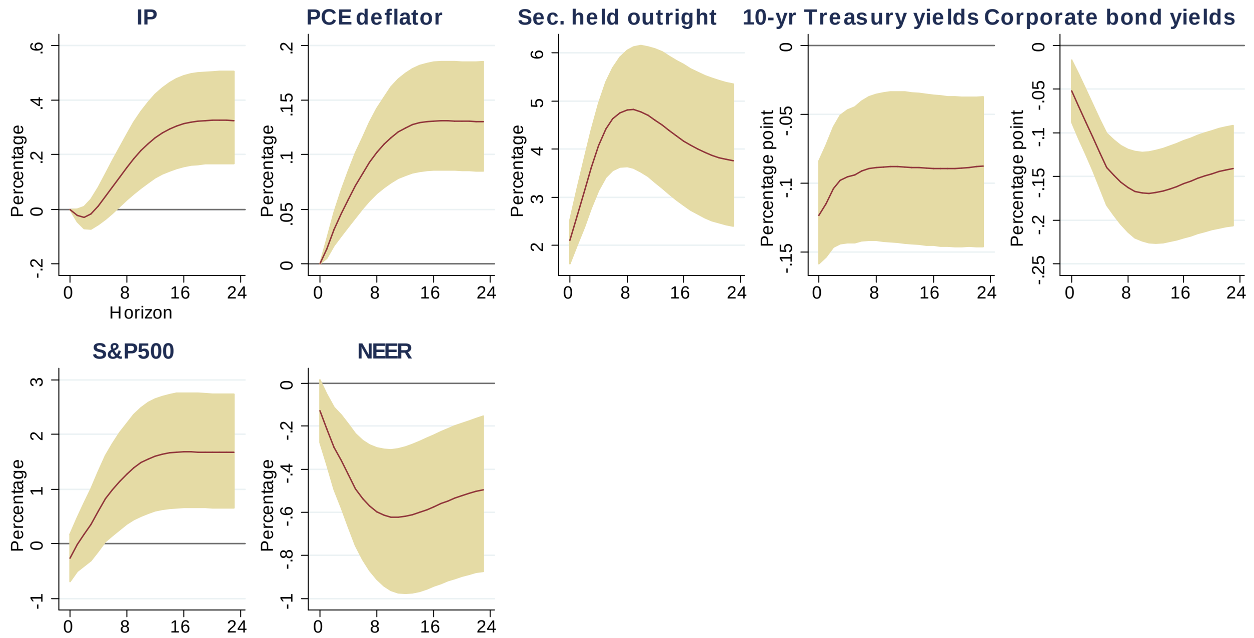
We proceed by adding in the US VAR a private-sector yield and an additional asset price. For private-sector yields, we use a corporate bond yield and a mortgage yield. The corporate bond yield measure, the effective yield of the BofA Merrill Lynch US Corporate 10-15 Year Index, includes a subset of the BofA Merrill Lynch US Corporate Master Index tracking the performance of US dollar denominated investment grade rated corporate debt publicly issued in the US domestic market. The mortgage yield measure, the 30-year Conventional Mortgage Rate, is the contract interest rates on commitments for 30-year fixed-rate first mortgages. These variables will help assess whether the QE policy had effects generally on financial markets by lowering a wide-range of yields rather than just lowering yields on US Treasuries. For the additional asset price, we consider the nominal exchange rate of US Dollars and a house price index. Specifically, the US nominal effective exchange rate and the Core Logic house price index are used. The effects on the nominal exchange rate will help connect the results with the bilateral exchange rate results we have already established through the EM panel VAR, while the exercise on house prices is a logical extension given the attention the housing sector received in policy making during this period.

In terms of identification, we now include a private-sector yield in the interest rate determination (F) equation in an extension and an additional asset price in the information (I) equation in another extension. Moreover, we impose that the Federal Reserve does not respond to the private-sector yield or the additional asset price contemporaneously.

[28] Our results are similar to Ahmed et al (2015) who also find that the EM economies that had relatively better fundamentals to begin with— as measured by a host of individual variables such as current account deficits and government debt— were less sensitive to developments in the US QE policy. Our results are also consistent with those in Mishra et al. (2014).

[29] Quoted from the answer to the question "What are the Federal Reserve's large-scale asset purchases?" on the Federal Reserve's website: https://www.federalreserve.gov/faqs/what-were-the-federal-reserves-large-scale-asset-purchases.htm

(a) Extension with corporate bond yields and the nominal effective exchange rate (NEER)



(b) Extension with mortgage yields and the nominal effective exchange rate (NEER)

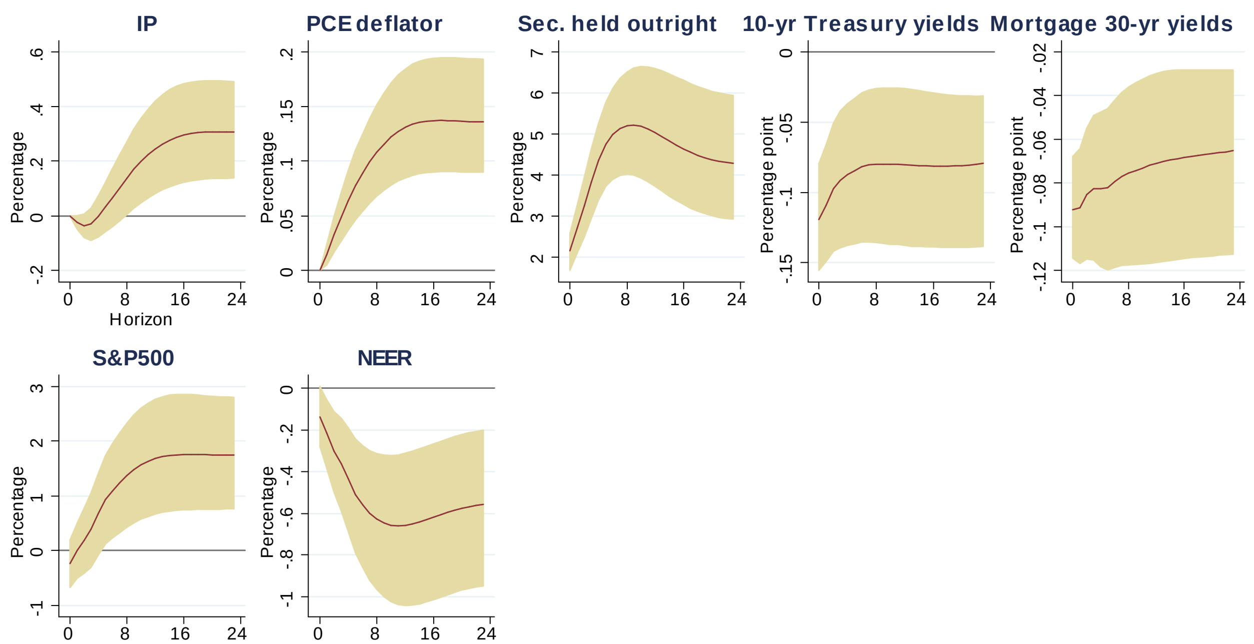


Figure 5: Impulse responses to the QE shock in the seven-variable extended specifications for the US VAR

Notes: Each plot displays the posterior median of the impulse responses to a one-standard deviation (unit) shock in the monetary policy ("MP") equation, along with 68% error bands.

(c) Extension with mortgage yields and house prices

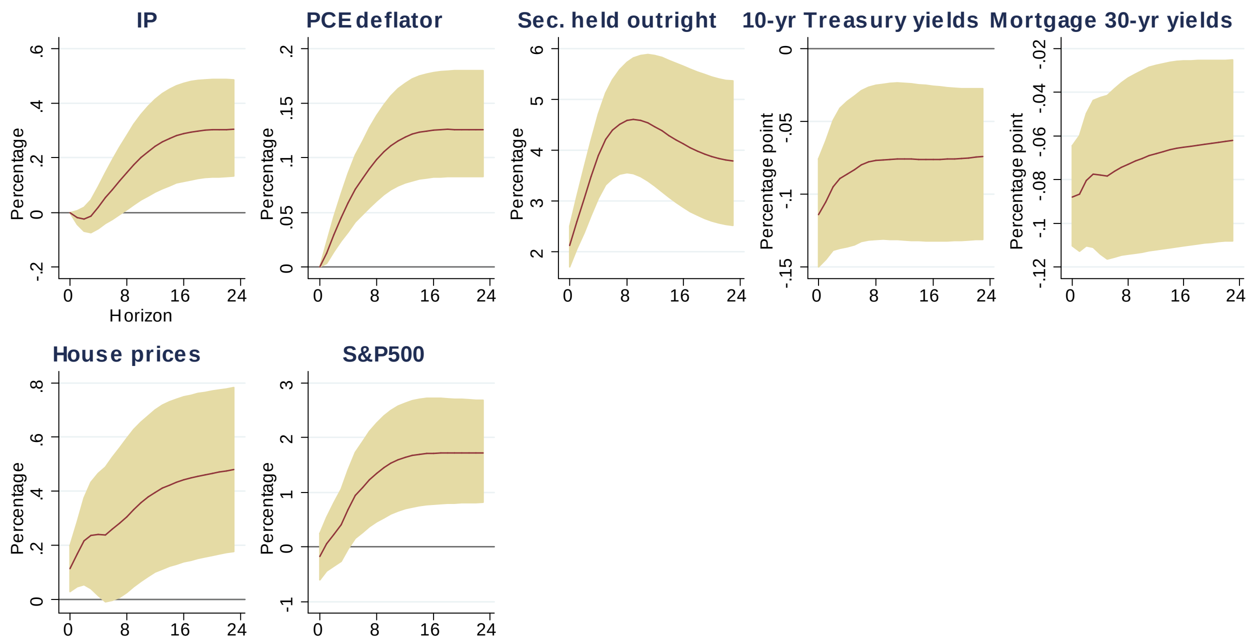


Figure 5: (continued) Impulse responses to the QE shock in the seven-variable extended specifications for the US VAR

Notes: Each plot displays the posterior median of the impulse responses to a one-standard deviation (unit) shock in the monetary policy ("MP") equation, along with 68% error bands.

Figure 5 shows the impulse responses in the extended specifications. Panel (a) shows the results where we include a measure of corporate bond yields and the US nominal effective exchange rate. It is clear that the US QE shock decreases the corporate bond yield and depreciates the US nominal effective exchange rate.[30] The announcement effect literature that generally focused on the US dollar exchange rate also has established that QE policies led to a depreciation. We thus have a similar result here, which is in turn consistent with the bilateral appreciation of the EM currencies against the US dollar that we established in the EM panel VAR.

Panel (b) of Figure 5 shows the impulse responses when we extend the baseline VAR by including both a measure of mortgage yield and the US nominal effective exchange rate. It shows clearly that the US QE shock decreases the mortgage yield and depreciates the US nominal effective exchange rate. Thus we find that an unanticipated shock to asset purchases by the Federal Reserve reduces both Treasury and mortgage yields. Finally, Panel (c) of Figure 5 presents our results when we include the mortgage yield and the house price index. By focusing on the housing sector, this allows a direct comparison of how the dynamics of mortgage yields and house prices were affected by the US QE shock and whether the results are economically sensible. As to be expected, the US QE shock decreases the mortgage yield and increases the house price index.

[30]Unlike for the bilateral exchange rates, for the effective exchange rate, a decrease constitutes a depreciation.

Lastly, we identify a conventional monetary shock in the US before the Great Recession (from 1965 to 2007) using non-recursive restrictions and a set of variables that are similar to those in the baseline specification described above. This helps us assess whether our identification scheme as well as inclusion of variables like stock prices (which do not always appear in monetary VAR studies) leads to non-standard results during the conventional time period. The results show that applying our empirical strategy to identify the QE shock to the conventional time period would still lead to inference for the conventional monetary policy shock that is consistent with the findings in the related literature. The results are provided in the online robustness appendix.

4.1.1 Other robustness exercises

We also estimate various extended specifications for the US VAR. We consider monthly GDP and the coincidence index in place of industrial production and CPI in place of the PCE deflator to see whether our results are robust to the choice of the activity measure (including one that contains labor market information) and the price measure. We find that our key empirical results remain robust to these alternative measures and we also provide additional insights into effect of QE on inflation expectations. All the identification restrictions and results in these extensions are detailed later in the online robustness appendix. Lastly, we try to identify the QE shock using recursive identifying restrictions on A_0 and confirm that we need our identifying restrictions described in Table 1 to correctly identify the QE shock and obtain empirical results that are economically sensible and consistent with the findings of the related literature.

4.2 Spillover Effects of US QE Shock

We now provide three sets of important additional results on the EM panel VAR. First, we use the short-term interest rate instead of the monetary aggregate; second, we consider an alternative sub-grouping of countries; and third, we use a shadow interest rate based measure of a US QE shock. Robustness exercises where we consider only financial variables, vary lag length, and include dummies for announcement dates are in the online robustness appendix.

4.2.1 Short-term interest rate as a monetary policy instrument

In the baseline EM panel VAR a measure of the monetary aggregate was included to capture and control for monetary policy responses in the EM countries. While this is our preferred specification, we now instead use a measure of short-term interest rates and repeat the EM panel VAR analysis. This is because some of the EM countries in our sample, such as Brazil and South Korea, implement monetary policy by adjusting short-term interest rates rather than monetary aggregates. We start first with the baseline results that use all countries. We then move on to the sub-group analysis where the Fragile Five countries constitute one group and the rest of the EM countries another.

Figure 6 presents the results based on the estimated average effects across all the EM economies in our sample. As is clear, our inference is the same as that from Figure 3 for financial variables: an expansionary US QE shock leads to an appreciation of the currencies of these countries against US

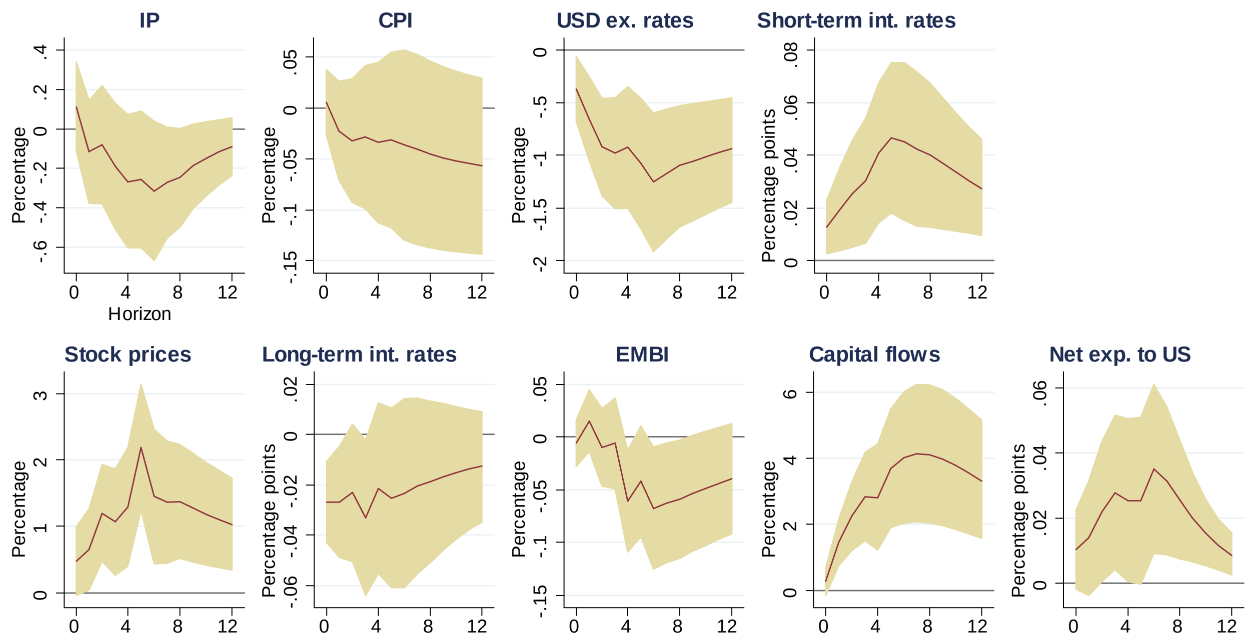


Figure 6: Impulse responses of the panel VAR on emerging market economies that includes the short-term interest rate

Notes: Results are from a specification that uses the short-term interest rate instead of the monetary aggregate in the panel VAR. See also notes in Figure 3.

Dollar, an increase in stock prices, a decrease in long-term interest rates, as well as an increase in capital inflows. Moreover, on the macroeconomic front, there are no significant effects on output and consumer prices, but net exports to the US increase. In addition, even in terms of the magnitude, the results are very similar as in Figure 3, except with stronger estimated effects on capital flows. These conclusions are also confirmed in the financial-variable only EM panel VAR.

Using the short-term interest rate instead of the monetary aggregate, we now present results based on subgroup estimation where the Fragile Five countries constitute one group and the rest of emerging markets constitute another. Figure 7 shows that the Fragile Five countries respond more strongly, in particular their exchange rate appreciates more and long-term interest rates fall by a larger amount. Moreover, capital inflows increase significantly more for them, with an imprecise and weak response of the non-Fragile Five countries. The response of stock prices is comparable across the groups and the rise of net exports is only a feature of the Fragile Five. Thus, these results are both qualitatively and quantitatively similar to the results in Figure 4 that were estimated with the monetary aggregate included.

Overall, this comparison leads us to conclude that the substantive aspects of our results do not change if we use the short-term interest rate instead to control for monetary policy actions by the EM countries despite our concern on the poor quality of the data on short-term interest rates and relevance.

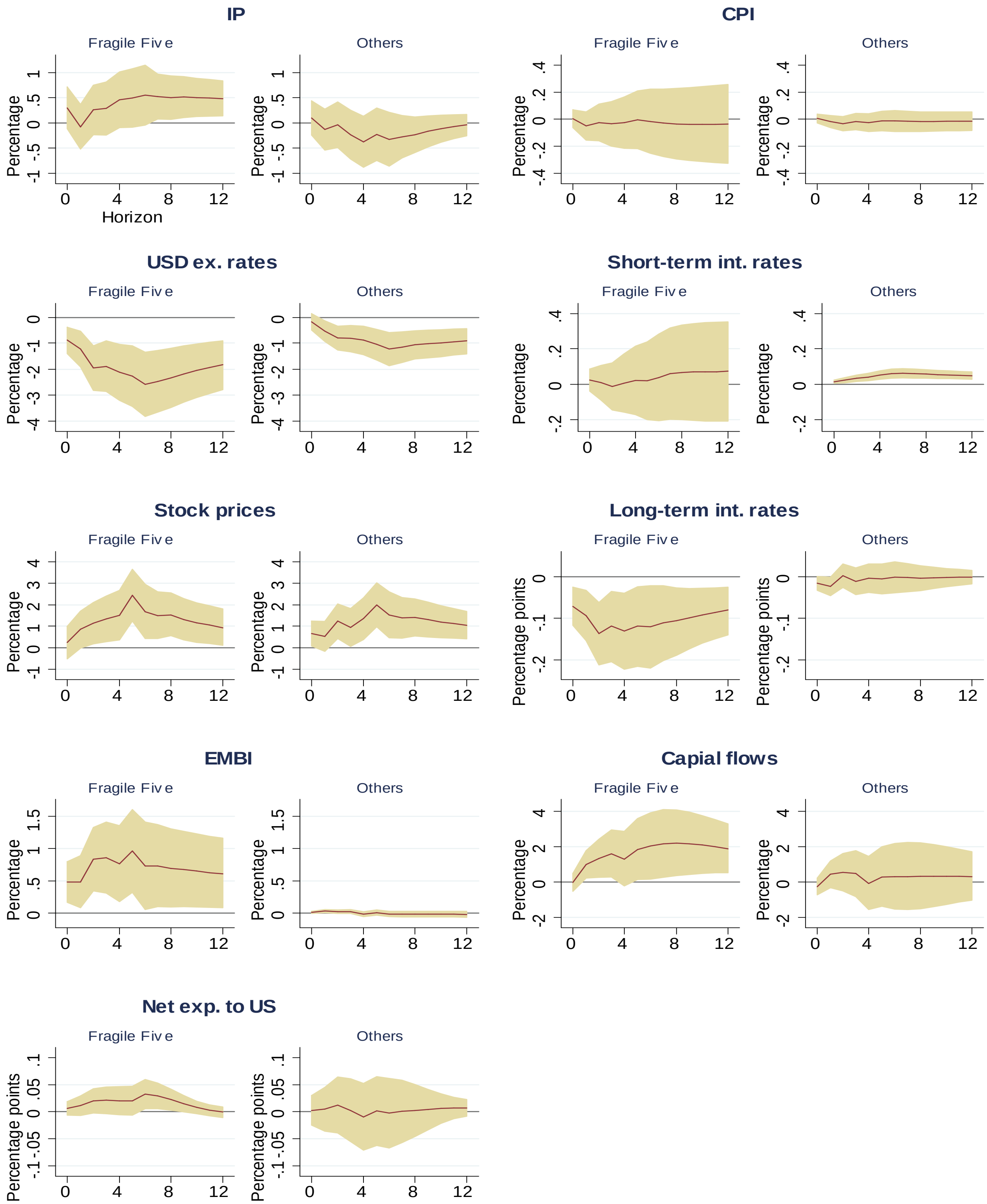


Figure 7: Impulse responses of the panel VAR on Fragile Five and others that includes the short term interest rate

Notes: Results are from a specification that uses the short-term interest rate instead of the monetary aggregate in the panel VAR. Subplots are arranged by variables and shown for two groups of countries: the fragile five countries including Brazil, India, Indonesia, South Africa and Turkey and the rest of emerging markets. See also the notes in Figure 4.

4.2.2 Alternative country groups in the EM panel VAR

So far, we considered two subgroups of countries in an extension of the panel VAR analysis: the Fragile Five and the rest. Arguably, this grouping is somewhat ad-hoc. We here consider an alternative country group where we add Mexico to the group of the Fragile Five countries as it has strong linkages with the US. In Figure 8 we present the results. Comparing with Figure 4, it is noticeable that the responses of the financial variables to the US QE shock, in particular, the exchange rate, long-term interest rates, and capital inflows are stronger and more precisely estimated for this group that includes Fragile Five countries as well as Mexico. Even so, for output and consumer prices, there are no significant effects of the US QE shock. For conciseness, we present the results of the financial panel VAR for this sub-grouping in the online robustness appendix. The results are similar as here in that the financial variables of the group that includes the Fragile Five and Mexico get affected more strongly by the US QE shock.

4.2.3 Spillover effects of the shadow interest rate shock

For the sensitivity analysis using the QE shock from a US VAR we use a shadow interest rate estimated by Krippner (2016) as a measure of QE. To conserve space, we do not show the impulse responses of US variables. But we note that the US QE shocks from our baseline case and from this measure are positively correlated, though not perfectly so (the correlation is -0.31). Thus, there is some independent variation based on these two approaches. At the same time, as we show in Figure B.6 in the appendix, the spillover results based on a QE shock that is obtained using a shadow interest rate as a measure of QE policy in the US VAR is similar to our baseline results. We nevertheless still prefer the securities held outright on the balance sheet of the Federal Reserve as our baseline measure over the shadow rate since it is a more direct measure of QE policy.

4.2.4 Other robustness exercises

We also show that our empirical pattern of spillover effects are robust to controlling for announcement effect dates via dummy variables in the panel VAR and also are not sensitive to choice of lag length. In order to check the latter, we re-estimate the EM panel VAR for the Bayesian Information Criterion suggested lag length. Moreover, to highlight the strong effect on the financial variables of the EM countries, and to possibly mitigate some concerns of the small sample bias, we also estimate an alternative specification of the EM panel VAR with monetary aggregate and only four important financial variables: stock prices, US dollar exchange rates, long-term interest rates, and capital flows. This specification arguably allows an even more direct comparison with the announcement effect literature which mostly focuses on the effects of QE on the financial market variables. The estimates of this specification are somewhat more precise, and overall qualitatively and quantitatively, consistent with the specification that includes both macroeconomic and financial variables. In order to save space, we relegate all these results to the online robustness appendix.

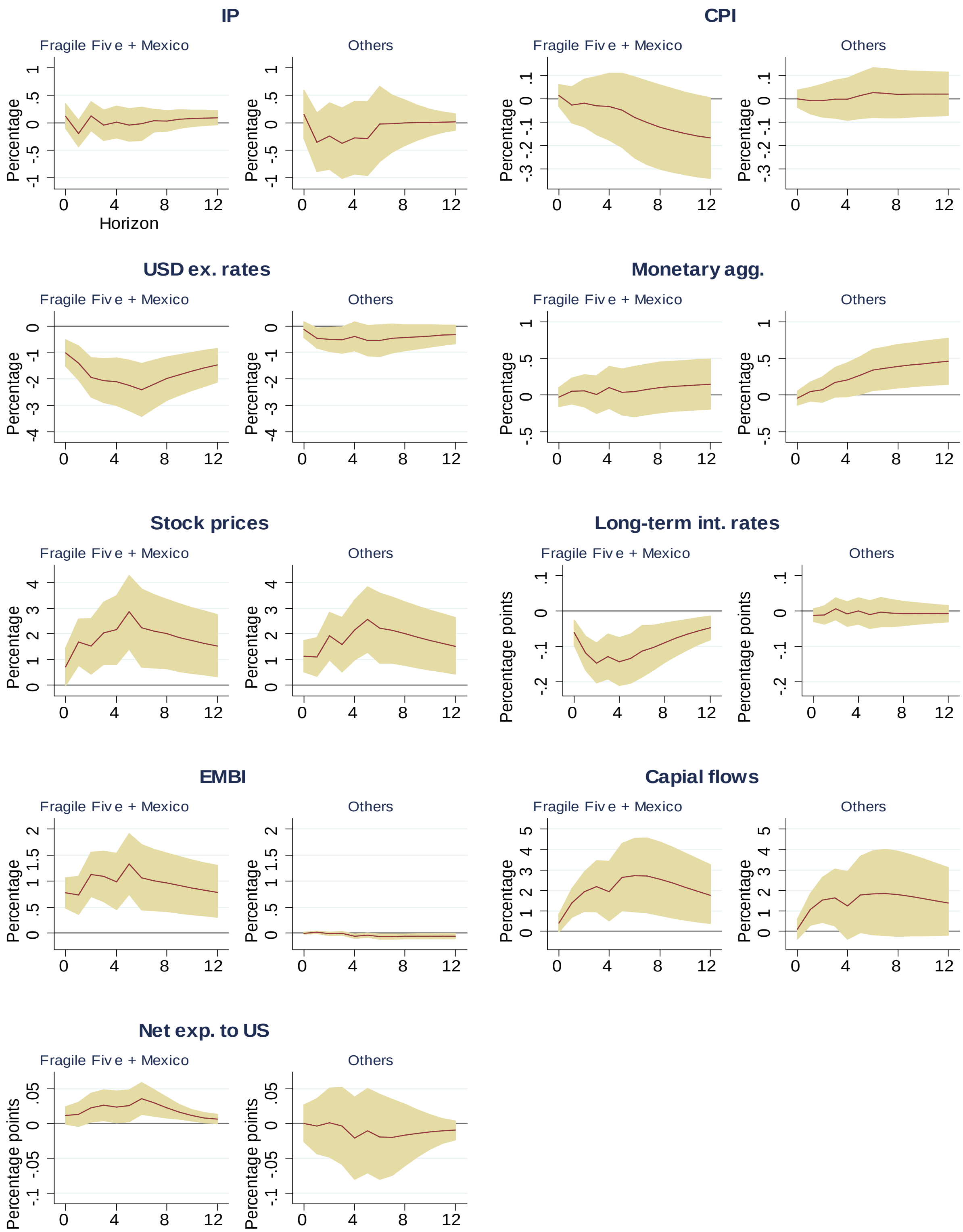


Figure 8: Impulse responses of the panel VAR on Fragile Five plus Mexico and others

Notes: Sub-plots are arranged by variables and shown for two groups of countries: the fragile five countries plus Mexico and the rest of emerging markets. See also the notes in Figure 3.

5 Conclusion

In this paper we estimate the spillover effects of US quantitative easing (QE) on the emerging market (EM) economies. Using a VAR with a non-recursive identification method on monthly US macroeconomic and financial data, we first estimate the US QE shock and infer its effects on the US variables. The effects on US financial and macroeconomic variables are remarkably robust and strong. We then use this identified US QE shock to infer the spillover effects on the EM economies in a panel VAR framework. We find that an expansionary US QE shock leads to an exchange rate appreciation, a reduction in long-term bond yields, and a stock market boom for these EM countries. These effects are bigger for the Fragile Five countries that include Brazil, India, Indonesia, South Africa and Turkey, but are also present for the other EM economies. We also find significant positive effects on capital flows to these countries following a positive US QE shock. We however do not find consistent and significant effects of the US QE shock on output and consumer prices of the EM countries, with net exports as the only real variable that gets affected significantly.

Our empirical results are helpful in establishing a set of empirical facts that can guide open economy models of unconventional monetary policy transmission mechanisms and spillovers. In doing so, various mechanisms proposed in the closed-economy literature for why QE policies have domestic macroeconomic effects can be extended to an open economy setting. Closed-economy mechanisms that generate domestic effects of QE are for example, those that work through credit intermediation (Gertler and Karadi (2011)) and which we indeed used to provide theoretical justification of our approach to identification of the US QE shock, portfolio balance effects (Chen et al (2012)), provision of scarce collateral (Williamson (2012)), or signalling of future lower interest rates (Bhattarai, Eggertssson, and Gafarov (2015)).

References

[1] Aizenman, Joshua, Mahir Binici, and Michael M. Hutchison (2014), "The Transmission of Federal Reserve Tapering News to Emerging Financial Markets," working paper.

[2] Ahmed, Shaghil, Brahima Coulibaly, and Andrei Zlate (2015), "International Financial Spillovers to Emerging Market Economies: How Important Are Economic Fundamentals?" working paper.

[3] Bauer, Michael D., and Glenn D. Rudebusch (2013), "The Signaling Channel for Federal Reserve Bond Purchases," working paper.

[4] Bauer, Michael D., and Christopher J. Neely (2014), "International Channels of the Fed's Unconventional Monetary Policy," *Journal of International Money and Finance*, 44, 24-46.

[5] Beraja, Martin, Andreas Fuster, Erik Hurst, and Joseph Vavra (2015), "Regional Heterogeneity and Monetary Policy," working paper.

[6] Bhattarai, Saroj, Gauti B. Eggertsson, and Bulat Gafarov (2015), "Time-Consistency and the Duration of Government Debt: A Signalling Theory of Quantitative Easing," working paper.

[7] Blanchard, Olivier, Jonathan D. Ostry, Atish R. Ghosh, and Marcos Chamon (2015), "Are Capital Inflows Expansionary or Contractionary? Theory, Policy Implications, and Some Evidence," working paper.

[8] Bowman, David, Juan M. Londono, and Horacio Sapriza (2014), "U.S. Unconventional Monetary Policy and Transmission to Emerging Market Economies," working paper.

[9] Bruno, Valentina, and Hyun Song Shin (2015), "Capital Flows and the Risk-taking Channel of Monetary Policy," *Journal of Monetary Economics*, 71, 119-132.

[10] Canova, Fabio (2005), "The Transmission of US Shocks to Latin America," *Journal of Applied Econometrics,* 20, 229-251.

[11] Canova, Fabio (2007), *Methods for Applied Macroeconomic Research*, Princeton, NJ: Princeton University Press.

[12] Canova, Fabio, and Matteo Ciccarelli (2013), "Panel Vector Autoregressive Models: A Survey," working paper.

[13] Cesa-Bianchi, Ambrogio, Luis, Cespedes, and Alessandro, Rebucci (2015), "Global Liquidity, House Prices and the Macroeconomy: Evidence from Advanced and Emerging Economies," *Journal of Money, Credit, and Banking*, 47, 301-335.

[14] Christiane Baumeister, and Luca Benati (2013), "Unconventional Monetary Policy and the Great Recession: Estimating the Macroeconomic Effects of a Spread Compression at the Zero Lower Bound," *International Journal of Central Banking*, 9, 165-212.

[15] Chen, Han, Vasco Curdia, and Andrea Ferrero (2012), "The Macroeconomic Effects of Large-scale Asset Purchase Programmes," *Economic Journal,* 122, 289-315.

[16] Chen, Qianying, Andrew Filardo, Dong He, and Feng Zhu (2016), "Financial Crisis, US Unconventional Monetary Policy and International Spillovers," *Journal of International Money and Finance,* 67, 62-81.

[17] Cushman, David O., and Tao Zha (1997), "Identifying Monetary Policy in a Small Open Economy Under Flexible Exchange Rates," *Journal of Monetary Economics*, 39, 433-448.

[18] Dahlhaus, Tatjana, and Garima Vasishtha (2014), "The Impact of U.S. Monetary Policy Normalization on Capital Flows to Emerging-Market Economies," working paper.

[19] D'Amico, Stefania, and Thomas B. King (2013), "Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply," *Journal of Financial Economics*, 108, 425-448.

[20] Eichengreeen, Barry, and Poonam Gupta (2014), "Tapering Talk: The Impact of Expectations of Reduced Federal Reserve Purchases on Emerging Markets," working paper.

[21] Fawley, Brett W., and Christopher J. Neely (2013), "Four Stories of Quantitative Easing," *Federal Reserve Bank of St. Louis Review,* Jan/Feb, 51-88.

[22] Fratzscher, Marcel, Marco Lo Duca, and Roland Straub (2012), "A Global Monetary Tsunami? On the Spillovers of US Quantitative Easing," working paper.

[23] Gambacorta, Leonardo, Boris Hofmann, and Gert Peersman (2014), "The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis," *Journal of Money, Credit and Banking*, 46, 615–642.

[24] Gagnon, Joseph, Matthew Raskin, Julie Ramache, and Brian Sack (2011), "The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases," *International Journal of Central Banking,* 7, 3-43.

[25] Gertler, Mark, and Peter Karadi (2011), "A Model of Unconventional Monetary Policy," *Journal of Monetary Economics*, 58, 17-34.

[26] Gertler, Mark and Peter Karadi (2012), "QE1 vs. 2 vs. 3...: A Framework For Analyzing Large Scale Asset Purchases as a Monetary Policy Tool," working paper.

[27] Glick, Reuven, and Sylvain Leduc (2012), "Central Bank Announcements of Asset Purchases and the Impact on Global Financial and Commodity Markets," *Journal of International Money and Finance,* 31, 2078–2101.

[28] Glick, Reuven, and Sylvain Leduc (2013), "The Effects of Unconventional and Conventional U.S. Monetary Policy on the Dollar," working paper.

[29] Hamilton, James D., and Cynthia Wu (2012), "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment," *Journal of Money, Credit, and Banking,* 44, 3-46.

[30] Kim, Soyoung (2001), "International Transmission of U.S. Monetary Policy Shocks: Evidence from VAR's," *Journal of Monetary Economics,* 48, 339-372.

[31] Krishnamurthy, Arvind, and Annette Vissing-Jorgensen (2011), "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity,* 43, 215-287.

[32] Krippner, Leo (2016), "Measures of Monetary Policy," working paper.

[33] Lavigne, Robert, Subrata Sarker, and Garima Vasishtha (2014), "Spillover Effects of Quantitative Easing on Emerging Market Economies," *Bank of Canada Review,* Autumn, 23-33.

[34] Leeper, Eric M., Christopher A. Sims, and Tao Zha (1996), "What Does Monetary Policy Do?" *Brookings Papers on Economic Activity,* 2, 1-78.

[35] Lim, Jamus Jerome, Sanket Mohapatra, and Marc Stoker (2014),"Tinker, Taper, QE, Bye? The Effect of Quantitative Easing on Financial Flows to Developing Countries," working paper.

[36] Litterman, Robert (1986), "Forecasting With Bayesian Vector Autoregressions-Five Years of Experience," *Journal of Business & Economic Statistics,* 4, 25-38.

[37] Mackowiak, Bartosz (2007), "External Shocks, U.S. Monetary Policy and Macroeconomic Fluctuations in Emerging Markets," *Journal of Monetary Economics,* 54, 2512-2520.

[38] Meaning, Jack, and Feng Zhu (2011), "The Impact of Recent Central Bank Asset Purchase Programmes," *BIS Quarterly Review*, Dec, 73-83.

[39] Mishra, Prachi, Kenji Moriyama, Papa N'Diaye, and Lam Nguyen (2014), "Impact of Fed Tapering Announcements on Emerging Markets," working paper.

[40] Neely, Christopher J. (2010), "The Large-Scale Asset Purchases Had Large International Effects," working paper.

[41] Plummer, Martyn, Nicky Best, Kate Cowles, and Karen Vines (2006), "CODA: Convergence Diagnosis and Output Analysis for MCMC," *R News*, 6, 7-11.

[42] Rey, Helene (2013), "Dilemma not Trilemma: The Global Financial Cycle and Monetary Policy Independence," *Proceedings of the Jackson Hole Economic Policy Symposium.*

[43] Rogers, John H., Chiara Scotti, and Jonathan H. Wright (2014), "Evaluating Asset-Market Effects of Unconventional Monetary Policy: A Cross-Country Comparison," working paper.

[44] Rubio-Ramirez, Juan, Daniel Waggoner, and Tao Zha (2010), "Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference," *Review of Economic Studies*, 77, 665-696.

[45] Sims, Christopher A., and Tao Zha (1998), "Bayesian Methods for Dynamic Multivariate Models," *International Economic Review* 39, 949-968.

[46] Sims, Christopher A., and Tao Zha (2006a), "Does Monetary Policy Generate Recessions?" *Macroeconomic Dynamics,* 10*,* 231-272.

[47] Sims, Christopher A., and Tao Zha (2006b), "Were There Regime Switches in U.S. Monetary Policy?" *American Economic Review,* 96*, 54-81.*

[48] Tillmann, Peter (2014), "Unconventional Monetary Policy Shocks and the Spillovers to Emerging Markets," working paper.

[49] Waggoner, Daniel F., and Tao Zha (2003a), "A Gibbs Sampler for Structural Vector Autoregressions," *Journal of Economic Dynamics and Control*, 28, 349–366.

[50] Waggoner, Daniel F., and Tao Zha (2003b), "Likelihood Preserving Normalization in Multiple Equation Models," *Journal of Econometrics*, 114, 329–347.

[51] Williamson, Steve (2012), "Scare Collateral, the Term Premium, and Quantitative Easing," working paper.

[52] Wright, Jonathan (2012), "What does Monetary Policy do to Long-term Interest Rates at the Zero Lower Bound?" *Economic Journal*, 122, F447-F466.

[53] Wu, Cynthia J., and Fan Dora Xia (2016), "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound," *Journal of Money, Credit, and Banking*, 48, 253-291.

Appendices

A Data description and sources

See the online data appendix for the complete list of the data with detailed descriptions and their sources. It also explains how quarterly GDP series are interpolated to monthly series for the US and the emerging market (EM) countries. For the EM countries, monthly GDP is used to normalize net exports to the US. Here, we show and discuss briefly the data we use in the baseline analysis.

Figure A.1 plots securities held outright along with 10-year Treasury yields, the S&P 500 index, nominal (trade-weighted) effective exchange rates, real GDP, and the private consumption expenditures (PCE) deflator. The vertical lines represent the dates of major events including the onset of the Lehman crisis, several phases of QE by the Federal Reserve, and the taper talk. The decision to purchase large volumes of assets by the Federal Reserve came in three steps, known as QE1, QE2 and QE3 respectively. On November 2008, the Federal Reserve announced purchases of housing agency debt and agency mortgage-backed securities (MBS) of up to $600 billion. On March 2009, the FOMC decided to substantially expand its purchases of agency-related securities and to purchase longer-term Treasury securities as well, with total asset purchases of up to $1.75 trillion, an amount twice the magnitude of total Federal Reserve assets prior to 2008. On September 2011, the Federal Reserve announced a new program on Operation Twist that involved purchasing $400 billion of long-term treasury bonds by selling short-term treasury bonds. This program was further extended in June 2012 till the end of the year. On September 2012, the last round of quantitative easing was announced, which consisted of an open ended commitment to purchase $40 billion mortgage backed securities per month. On December 2012, this program was expanded further by adding the purchase of $45 billion of long-term treasury bonds per month. Quantitative easing officially ended on October 2014.

It is clear that QE was initiated in an environment where a large negative shock drove down output and prices. Figure A.1 also suggests that after some lag, these interventions likely contributed to driving down long-term interest rates, a stock market boom, and depreciation of the US dollar. The observed comovements of the securities held outright with the other variables, however, do not necessarily imply the causal effects of QE. We aim to isolate and identify such causal effects by careful econometric analysis.

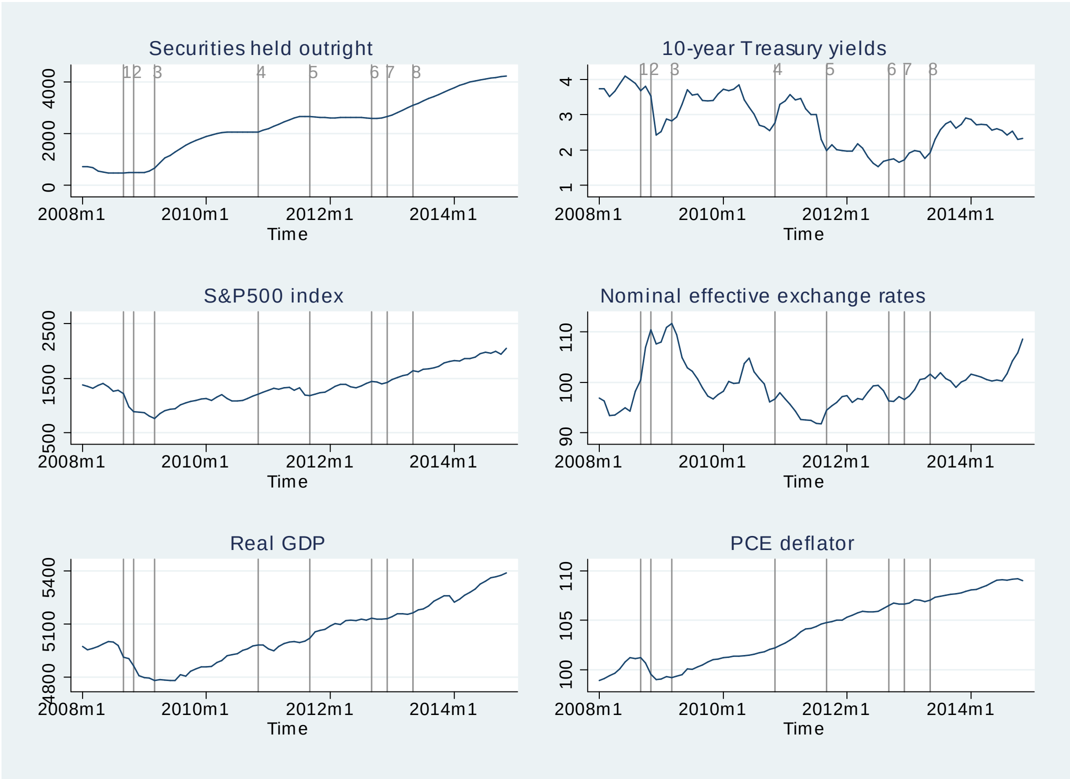
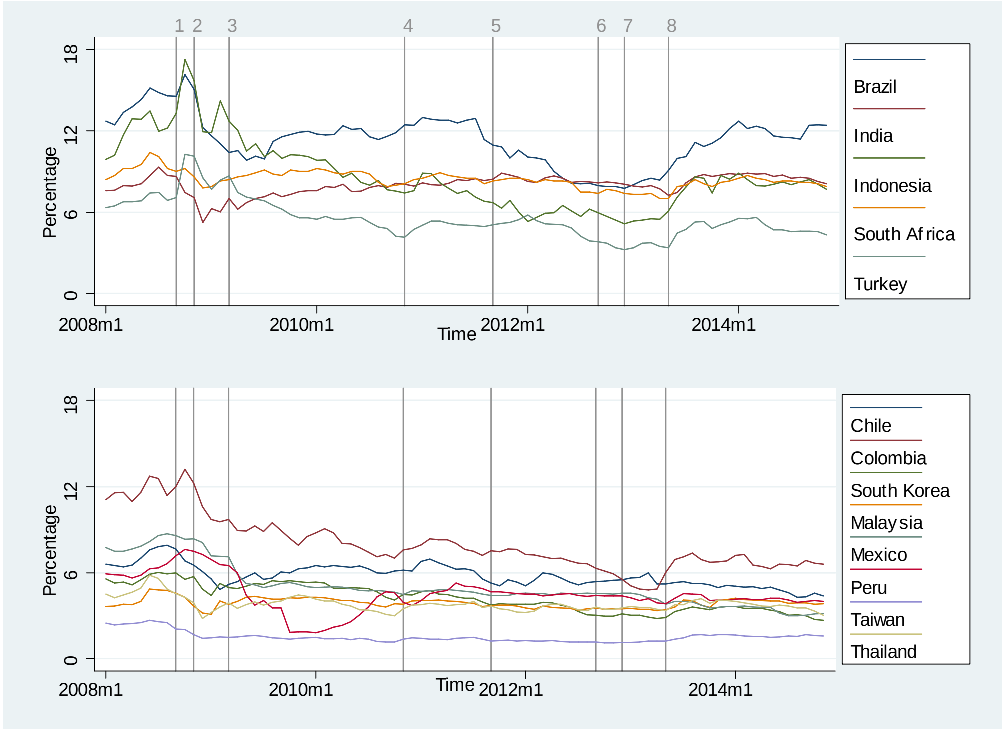


Figure A.1: Selected US macroeconomic and financial data

Notes: The vertical lines mark dates of the major events: [1] September 2008 when the Lehman Brothers filed for bankruptcy; [2]-[3] November 2008 and March 2009 which are QE1 dates; [4] November 2010 which is a QE2 date; [5] September 2011 which is an MEP date; [6]-[7] September 2012 and December 2012 which are QE3 dates; and [8] May 2013 when Ben Bernanke discussed the possibility of withdrawal of the QE program at the US Congress. The units are billions of dollars for securities held outright, percentages for 10-year Treasury yields, a 2010=100 index for nominal effective exchange rates, billions of chained 2009 dollars for real GDP, and an 2009=100 index for the PCE deflator, respectively. A decrease in the effective exchange rate means depreciation of the US dollar against a basket of currencies. Real GDP is an interpolated measure. For further details of data, see the online data appendix.

(a) Long-term interest rates



(b) Stock market indices

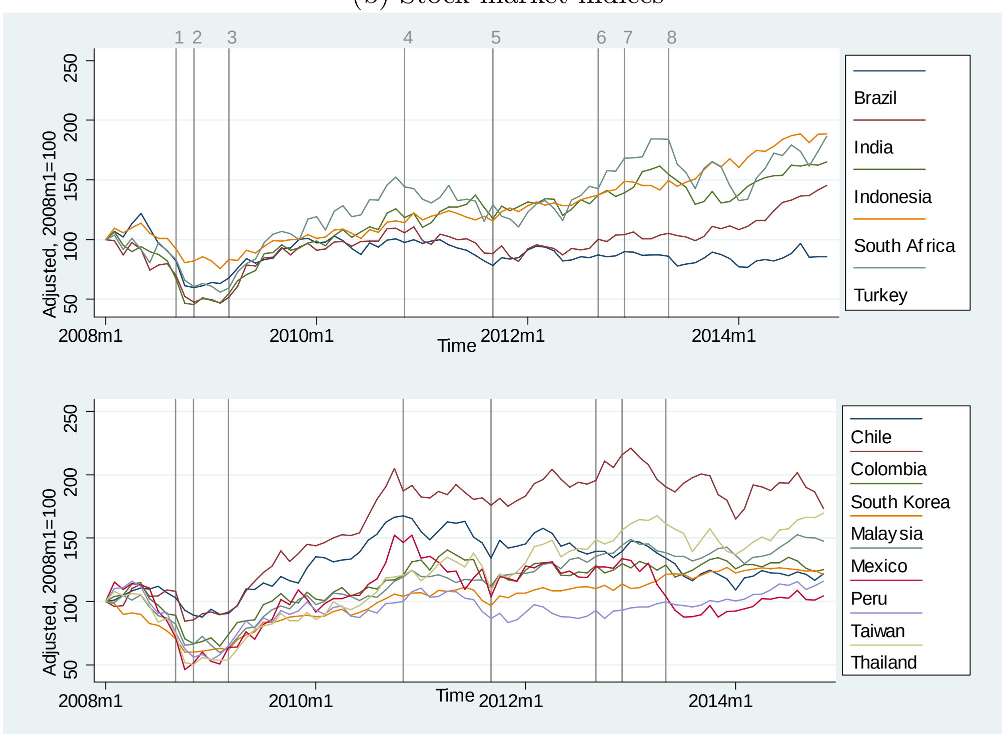


Figure A.2: Long-term interest rates and stock market indices in emerging market economies

Notes: Panel (a) presents the long-term interest rates and Panel (b) displays the Morgan Stanley Capital International (MSCI) index for each country, adjusted so that it is equal to 100 in January 2008. For the details of data, see the online data appendix. The vertical lines mark the dates of the major events. For the details, see the notes in Figure A.1.

(a) Nominal exchange rates against US dollar

(b) Cumulative capital flows

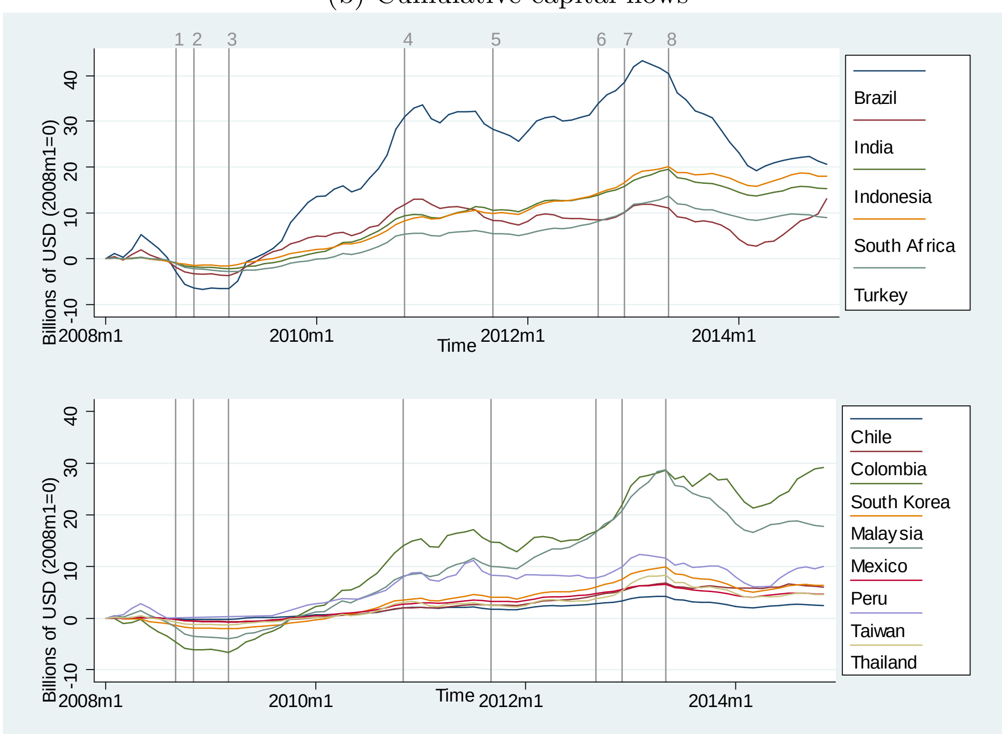


Figure A.3: Nominal exchange rates and cumulative capital inflows in emerging market economies

Notes: Panel (a) presents nominal exchange rates against US dollar, the domestic currency price of a US dollar, adjusted so that the exchange rate is equal to 100 in January 2008. Panel (b) shows the cumulative capital flows into each country since January 2008. For the details of data, see the online data appendix. The vertical lines mark the dates of the major events. For the details, see the notes in Figure A.1.

B Additional results from extensions and robustness exercises

We have estimated a large number of extensions to the baseline specification of the US VAR and the EM panel VAR and also an extensive set of robustness exercises. See the online robustness appendix for all those results.

Here, we present results from two important exercises. First, we present results from the theoretical exercise based on the Gertler and Karadi (2011) model of QE. Second, we present spillover results based on using a US QE shock that is estimated from a US VAR that contains a shadow rate as a measure of US QE.

Figure B.4 shows the responses of variables to a QE shock in the Gertler and Karadi (2011) model where we use the exact paramterization of the model as in Gertler and Karadi (2011). We refer the reader to the Gertler and Karadi (2011) paper for details on the model. We show results for both the QE reaction function that features only spread, as in Gertler and Karadi (2011), as well as one that includes also lagged inflation and output growth. This latter specification is more in line with our empirical one and we therefore show those results as well. In terms of parameterization of the feedback coefficients, we follow the baseline calibration of Gertler and Karadi (2011) that uses $\kappa = 10$ and impose for simplicity $\kappa = \kappa_\pi = \kappa_y$. Figure B.5 shows the responses of variables to a QE shock in the Gertler and Karadi (2011) model where additionally, we allow for smoothing in the QE reaction function, as that is a standard assumption in the conventional monetary policy literature. We use a standard value of $\psi = 0.8$.

Figure B.6 present results from a panel VAR specification that uses as a QE shock a shock to the shadow rate as estimated and identified in a US VAR.

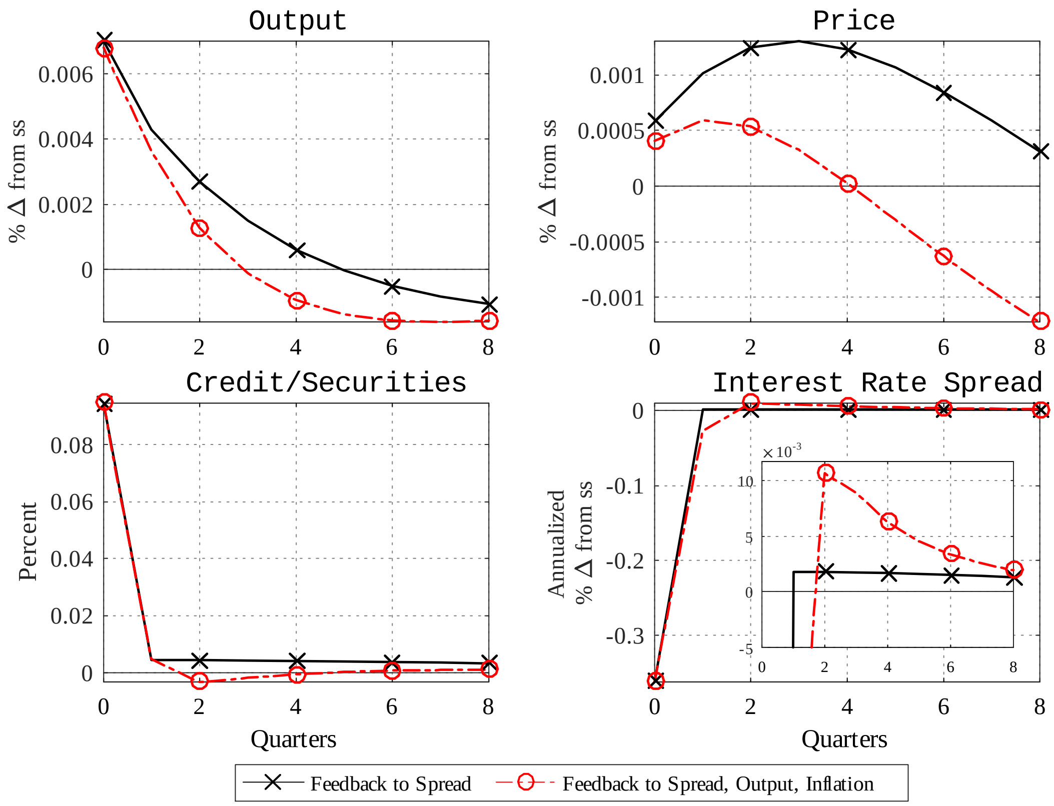


Figure B.4: Impulse responses to a 1 percent QE shock in the Gertler and Karadi (2011) model

Notes: The parameterization of the model and the QE reaction function is exactly the same as in Gertler and Karadi (2011).

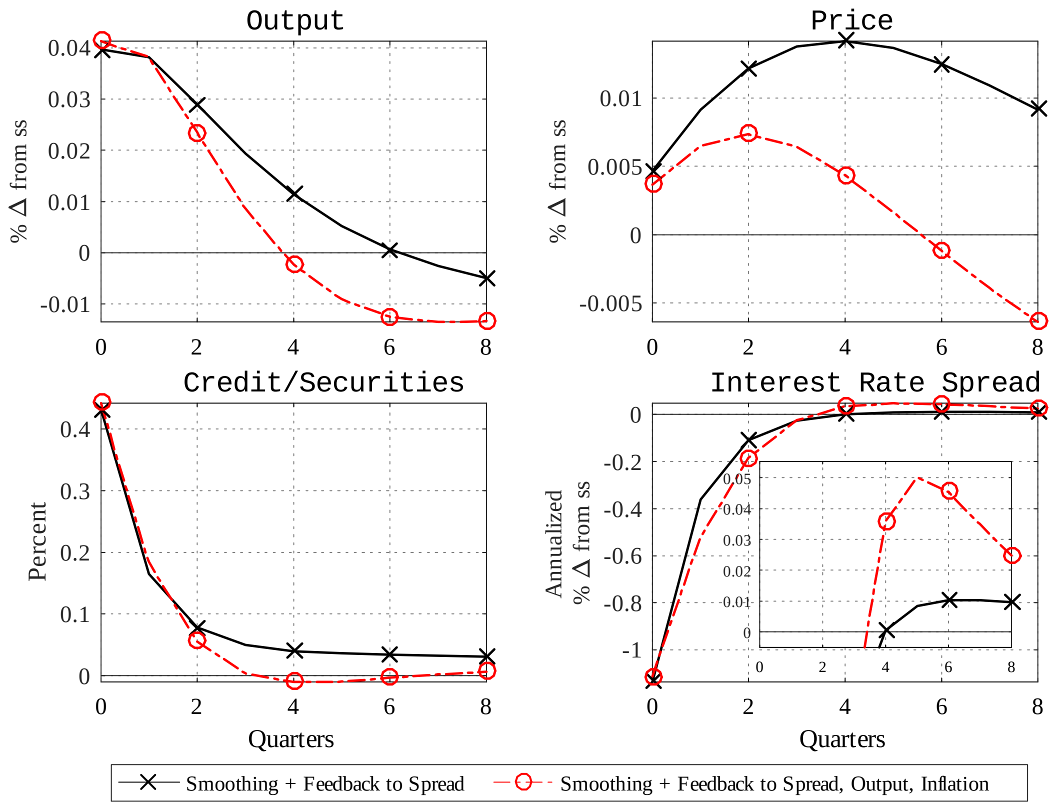


Figure B.5: Impulse responses to a 1 percent QE shock in the Gertler and Karadi (2011) model

Notes: The parameterization of the model and the QE reaction function is exactly the same as in Gertler and Karadi (2011), with the addition of a smoothing term.

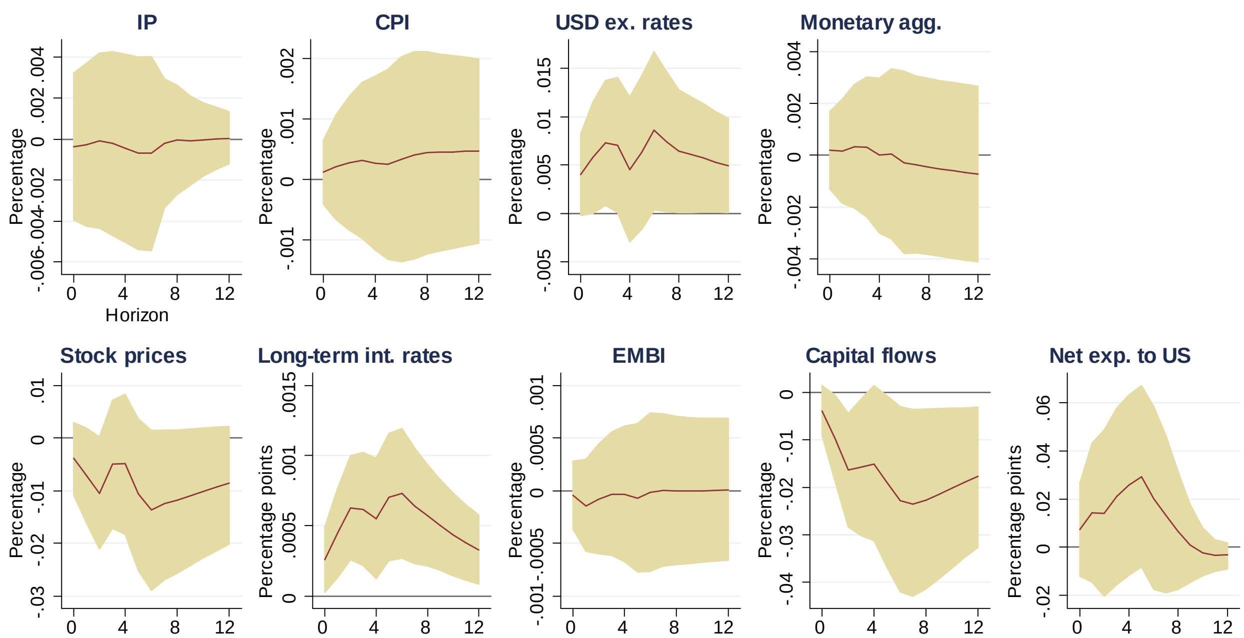


Figure B.6: Impulse responses of the panel VAR on emerging market economies that uses as QE shock a shock to the US shadow rate

Notes: Results are from a panel VAR specification that uses as the QE shock a shock from US VAR with the shadow interest rate as an instrument of QE.

C Econometric methodology

C.1 Structural VAR for the US

As the methods for the Bayesian structural VAR are well described in Sims and Zha (1998), Waggoner and Zha (2003a; 2003b) and Sims and Zha (2006b), we refer readers to these papers for details of estimation methods. Here we only explain the hyperparameters for the Minesota-type prior distribution of the US VAR proposed by Sims and Zha (1998).

The Minnesota-type prior distribution is implemented by three types of dummy observations and there are six hyperparameters. The first type of the dummy observations expresses a prior belief that the dynamics of each variable in the US VAR is centered around a random walk behavior and has four hyperparameters μ_0, μ_1, μ_2, and μ_3. Hyperparameter μ_0 determines the overall tightness of prior beliefs, μ_1 the tightness of prior beliefs around a random walk process, and μ_3 the rate at which the prior variance shrinks as the lag order increases.[31] The second and third type of the dummy observations expresses a prior belief that each variable is likely to contain a unit root and a prior belief that the endogenous variables are likely to be cointegrated, respectively. The tightness of these two types of the dummy observations are determined by μ_4 and μ_5, respectively. As we use the monthly data, we set $\mu_0 = 0.6$, $\mu_1 = 0.1$, $\mu_3 = 1.2$, $\mu_4 = 5$ and $\mu_5 = 5$ in the baseline specification following Sims and Zha (2006b).

C.1.1 Posterior simulation

We use the Matlab code made public by Tao Zha to do Gibbs sampling from the posterior distribution of the US VAR: 60,000 draws are made, but the first 10,000 draws are discarded and the last 50,000 draws are used to make posterior inferences.

C.2 Panel VAR for the emerging market countries

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.

C.2.1 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 $t = 0, -1, \cdots, -(p-1)$.

[31] Another hyperparameter, μ_2, is always set to 1 to keep the simultaneous equation framework in Sims and Zha (1998) contrary to the original equation-by-equation approach by Litterman (1986).

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

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

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 (C.1) in $w_{i,t}^o$ as

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

and write (C.1) as

$$z_{i,t}^{o\prime} = w_{i,t}^{o\prime} \Gamma_i + u_{i,t}^{o\prime}, \tag{C.2}$$

where Γ_i collects the coefficient matrices on the right hand side of (C.1)

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

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 (C.2) as

$$z_{i,t}^o = \left(I_{m_z} \otimes w_{i,t}^{o\prime} \right) \gamma_i + u_{i,t}^o, \tag{C.3}$$

where $\gamma_i = \text{vec}(\Gamma_i)$, and stack (C.3) for $i = 1, \cdots, N$ as

$$\boldsymbol{z}_t^o = \mathbf{W}_t^o \boldsymbol{\gamma} + \boldsymbol{u}_t^o, \tag{C.4}$$

where

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

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

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

$$\gamma_i = \bar{\gamma} + v_i, \tag{C.5}$$

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 (C.5) 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 $\underline{\nu} > N m_z + 1$ and $\underline{S}$ is $N m_z \times N m_z$ and positive definite. We set $\bar{\nu} = N m_z + 2$ 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

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

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

$$\boldsymbol{\gamma} | \bar{\gamma}, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N}\left[\tilde{\gamma}, \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^{o} + \underline{\boldsymbol{\Sigma}}_\gamma^{-1}\right)^{-1}\right], \tag{C.6}$$

and

$$\boldsymbol{\Sigma}^{-1}|\boldsymbol{\gamma}, \bar{\gamma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}^o_{-p+1} \sim \mathbb{W}\left(T + \underline{\nu}, \tilde{S}^{-1}\right), \tag{C.7}$$

where

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

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,

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

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 $\boldsymbol{z}_1^d = \left[\begin{array}{ccc} \bar{z}_{1,0}^{o\prime} & \cdots & \bar{z}_{N,0}^{o\prime} \end{array}\right]'$, and

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

with $w_{i,1}^d = \left[\begin{array}{cccccccc} \bar{z}_{i,0}^{o\prime} & \cdots & \bar{z}_{i,0}^{o\prime} & 0 & \cdots & 0 & \bar{x}_0^{o\prime} \end{array}\right]'$ for $i = 1, 2, \cdots, N$. When it is substituted in (C.4), 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 $\bar{Z}^o_{i,0}$ 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 $\left\{\mu \boldsymbol{z}^d_t, \mu \boldsymbol{W}^d_t\right\}_{t=2}^{m_z+1}$ such that

$$\begin{pmatrix} \boldsymbol{z}^d_2 \\ \vdots \\ \boldsymbol{z}^d_{m_z+1} \end{pmatrix} = \text{vec} \begin{pmatrix} \bar{Z}^o_{1,0} \\ \vdots \\ Z^o_{N,0} \end{pmatrix},$$

and

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

for $t = 2, \cdots, m_z + 1$ where $w^d_{i,t} = \begin{bmatrix} \left(\bar{z}^o_{i,0}\right)'_{(t-1)} & \cdots & \left(\bar{z}^o_{i,0}\right)'_{(t-1)} & 0 & \cdots & 0 & 0'_{m_x \times 1} \end{bmatrix}'$ for $i = 1, 2, \cdots, N$ and $\left(\bar{z}^o_{i,0}\right)_{(t-1)}$ 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 $\bar{z}^o_{i,0}$. 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

$$\bar{\gamma}|\boldsymbol{\gamma}, \boldsymbol{\Sigma}, \boldsymbol{z}^o_T, \cdots, \boldsymbol{z}^o_1, \boldsymbol{z}^o_0, \cdots, \boldsymbol{z}^o_{-p+1} \sim \mathbb{N}\left[\tilde{\bar{\gamma}}, \left(\sum_{i=1}^{N} \left(\Sigma_i \otimes \underline{\Sigma}_i\right)^{-1} + \underline{\Sigma}_{\bar{\gamma}}^{-1}\right)^{-1}\right], \tag{C.8}$$

where

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

Posterior simulation We use the Gibbs sampler to alternatingly draw $\boldsymbol{\gamma}$ conditional on $\boldsymbol{\Sigma}$ and $\bar{\gamma}$ from (C.6), $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$ and $\bar{\gamma}$ from (C.7), and $\bar{\gamma}$ conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ from (C.8). We make 200,000 draws and use only the last 100,000 draws to make posterior inferences.

C.2.2 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 $i \neq j$.

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

$$\boldsymbol{\gamma}|\bar{\gamma}_1, \bar{\gamma}_2, \boldsymbol{\Sigma}, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{N}\left[\tilde{\boldsymbol{\gamma}}, \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\boldsymbol{\Sigma}}_\gamma^{-1}\right)^{-1}\right], \tag{C.9}$$

where

$$\begin{aligned}
\bar{\boldsymbol{\gamma}} &= \begin{pmatrix} I_F(1) & \cdots & I_F(N) \end{pmatrix}' \otimes \bar{\gamma}_1 + \begin{pmatrix} 1 - I_F(1) & \cdots & 1 - I_F(N) \end{pmatrix}' \otimes \bar{\gamma}_2, \\
\hat{\boldsymbol{\gamma}} &= \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o\right)^{-1} \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{z}_t^o\right), \\
\tilde{\boldsymbol{\gamma}} &= \left(\sum_{t=1}^{T} \boldsymbol{W}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{W}_t^o + \underline{\boldsymbol{\Sigma}}_\gamma^{-1}\right)^{-1} \left[\left(\sum_{t=1}^{T} \boldsymbol{X}_t^{o\prime} \boldsymbol{\Sigma}^{-1} \boldsymbol{X}_t^o\right) \hat{\gamma} + \left(\underline{\Sigma}_\gamma^{-1}\right) \bar{\boldsymbol{\gamma}}\right],
\end{aligned}$$

and

$$\boldsymbol{\Sigma}^{-1}|\boldsymbol{\gamma}, \bar{\gamma}_1, \bar{\gamma}_2, \boldsymbol{z}_T^o, \cdots, \boldsymbol{z}_1^o, \boldsymbol{z}_0^o, \cdots, \boldsymbol{z}_{-p+1}^o \sim \mathbb{W}\left(T + \underline{\nu}, \tilde{S}^{-1}\right), \tag{C.10}$$

where

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

Prior and posterior distribution for $\bar{\gamma}_1$ and $\bar{\gamma}_2$ A priori, we assume that

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

where $\bar{\bar{\gamma}}_1$ and $\bar{\bar{\gamma}}_2$ 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

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

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

$$\bar{\gamma}_1|\boldsymbol{\gamma},\boldsymbol{\Sigma},\boldsymbol{z}_T^o,\cdots,\boldsymbol{z}_1^o,\boldsymbol{z}_0^o,\cdots,\boldsymbol{z}_{-p+1}^o \sim \mathbb{N}\left[\tilde{\bar{\gamma}}_1,\left(\sum_{i=1}^{N_1}(\Sigma_i\otimes\underline{\Sigma}_i)^{-1}+\Sigma_{\bar{\gamma}}^{-1}\right)^{-1}\right], \tag{C.11}$$

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

$$\bar{\gamma}_2|\boldsymbol{\gamma},\boldsymbol{\Sigma},\boldsymbol{z}_T^o,\cdots,\boldsymbol{z}_1^o,\boldsymbol{z}_0^o,\cdots,\boldsymbol{z}_{-p+1}^o \sim \mathbb{N}\left[\tilde{\bar{\gamma}}_2,\left(\sum_{i=N_1+1}^{N}(\Sigma_i\otimes\underline{\Sigma}_i)^{-1}+\Sigma_{\bar{\gamma}}^{-1}\right)^{-1}\right], \tag{C.12}$$

where

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

Posterior simulation We use the Gibbs sampler to alternatingly draw $\boldsymbol{\gamma}$ conditional on $\boldsymbol{\Sigma}$, $\bar{\gamma}_1$ and $\bar{\gamma}_2$ from (C.9), $\boldsymbol{\Sigma}$ conditional on $\boldsymbol{\gamma}$, $\bar{\gamma}_1$ and $\bar{\gamma}_2$ from (C.10), and $\bar{\gamma}_1$ and $\bar{\gamma}_2$ conditional on $\boldsymbol{\gamma}$ and $\boldsymbol{\Sigma}$ from (C.11) and (C.12). We make 200,000 draws and use only the last 100,000 draws to make posterior inferences.