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Global Impact of US and Euro Area Unconventional Monetary Policies: A Comparison

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Global impact of US and euro area unconventional monetary policies: a comparison[1]

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Abstract

The paper analyses and compares the domestic and cross-border effects of US and euro area unconventional monetary policy measures on 24 major advanced and emerging economies, based on an estimated global vector error-correction model (GVECM). Unconventional monetary policies are measured using shadow interest rates developed by Lombardi and Zhu (2014) and Chen, Lombardi and Zhu (2015). Monetary policy shocks are identified using sign restrictions. The GVECM impulse responses suggest that US unconventional monetary policy generally has stronger domestic and cross-border impacts than euro area non-standard measures. Its spillovers to other economies are estimated to be more sizeable and persistent, especially in terms of output growth and inflation. There is evidence of diverse responses in the emerging economies in terms of exchange rate pressures, credit growth as well as monetary policy. In addition, the strength of cross-border transmission channels to the emerging economies appears to differ for US and euro area policies.

JEL Classification Numbers: E43, E44, E52, F42, F47

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I. INTRODUCTION

The Global Financial Crisis, which started in August 2007 and intensified following the bankruptcy of Lehman Brothers in September 2008, swept and deeply affected the financial markets in both advanced and emerging economies. The Crisis had two major components: the US subprime mortgage crisis; and the European sovereign debt crisis which exploded with the Greek debt crisis in May 2010. The virulence of market turbulences was soon translated into a major slowdown in the global real activity, as world exports collapsed and the Great Recession ensued. In response to mounting domestic difficulties, the US Federal Reserve cut rapidly its target for the federal funds rate, to a range between 0% and 0.25% in December 2008. Similarly, the European Central Bank (ECB) lowered its main refinancing and deposit facility rates to 1% and 0.25% in May 2009, from 4.25% and 3.25% in October 2008, respectively.

This proximity to the zero lower bound (ZLB) on nominal interest rates limited the scope for implementing additional monetary easing through further cuts to the policy rate. Consequently, the Federal Reserve and the ECB departed from the standard approach of reacting to inflation and output developments by changing the policy rate and have adopted a wide range of unconventional or non-standard measures. These measures, also known as quantitative easing (QE), include unprecedented money-market support measures, special loan programmes, large-scale asset purchases and forward guidance.[3] QE measures were considered to have provided significant stimulus to the domestic economy, and given the importance of the United States and euro area in the global economy, there are strong interests in better understanding how and to what extent such unconventional policy measures have affected the global economy.

QE actions taken by central banks in a number of major economies have led to a burgeoning literature on their impacts. Most work has focused on the domestic dimension and relied on event studies analysing QE announcement effects on asset prices, while some studies have also employed regression analysis. Among others, D'Amico and King (2010), Doh (2010), Gagnon, Raskin, Remache and Sack (2010, 2011), Joyce, Lasaosa, Stevens and Tong (2011), Krishnamurthy and Vissing Jorgensen (2011) and Meaning and Zhu (2011, 2012) provide estimates for the effects of the Federal Reserve's and the Bank of England's large-scale asset purchase programmes.

A better understanding of the monetary policy spillovers associated with QE measures may help policymakers to cope with the challenges posed by such policies and to assess the need for international policy coordination. Several studies examine the cross-border financial market impact of QE policies. Relying on event studies of US asset purchases, Neely (2010) finds that US QE lowered bond rates in the other advanced economies by 20-80 basis points and depreciated the US dollar by 4-11%. Glick and Leduc (2012) show that commodity prices on average fell upon the announcements of US asset purchases, despite a decline in

[3] Bernanke and Reinhart (2004) suggest three policy alternatives when central banks face the ZLB on nominal interest rates: first, shape public expectations about the future path of the policy rate; second, implement quantitative easing, i.e., increase the size of the central bank's balance sheet beyond the level needed to maintain a zero policy rate; third, change the composition of the central bank's balance sheet in order to affect the relative supply of securities held by the public.

long-term interest rates and US dollar depreciation. Chen, Filardo, He and Zhu (2012) and Rogers, Scotti and Wright (2014) provide evidence on the international spillovers of the unconventional measures implemented by the Bank of England, the European Central Bank, the Federal Reserve and the Bank of Japan. Fratzscher, Lo Duca and Straub (2013) find that earlier US QE measures were highly effective in lowering sovereign yields and raising equity prices. But since 2010 such measures have had a muted impact on yields across countries. Fratzscher, Lo Duca and Straub (2014) find that ECB non-standard measures had beneficial impact on euro area asset prices and lowered bond market fragmentation, with a positive cross-border impact on global equity markets and confidence. IMF (2013a, b) finds that unconventional monetary policies have successfully restored market functioning and intermediation in the early phase of the global financial crisis, but their continuation carries risks.

Yet we know little about the impact on real activity of the unconventional policies, especially their cross-border spillovers to emerging economies. In this respect, Chen, Filardo, He and Zhu (2014) introduce estimated shadow federal funds rates in a global VAR to assess the domestic and global impact of US unconventional monetary policies. They find that US QE might not have only prevented US recessions but also had substantial global spillovers. Chen, Filardo, He and Zhu (2015) use US term and corporate spreads to study the impact of US QE, they find sizeable and diverse effects on the emerging economies, which are generally larger than those found for the United States and other advanced economies.

There are two major views on the spillovers of the unconventional monetary policies implemented in the major advanced economies. The first view considers that such policies are designed for domestic contingencies; any spillovers are unintended and primarily an issue for other policymakers to address. This echoes the Obstfeld-Rogoff (2002) proposition that there are only small gains from policy coordination once individual central banks implement policies optimised to achieve domestic macro stability. The second view argues that QE policies are less benign. Among other things, they depreciate domestic currencies and inflate risk-adjusted interest rate differentials vis-à-vis other economies, leading to potentially large capital inflows and consumer and asset price inflation pressures abroad. Taylor (2013) points out that, while the Obstfeld-Rogoff (2002) proposition may be true in normal times, sizeable cross-border spillovers seen in recent years have changed the cost-benefit analysis. This would particularly be the case if QE measures represent "deviations from rules-based policy" which create incentives for other central banks to deviate from rules-based policies. Besides some concerns with competitive devaluation as a result of QE policies, Rajan (2013) alerts us to the danger of "competitive asset price inflation". Yet Ostry and Ghosh (2013) consider uncertainties and disagreement about the cross-border effects of QE policies a major obstacle to policy coordination.

This paper studies macroeconomic effects of QE, both domestic and international, estimating a global vector error correction model (GVECM) covering 24 advanced and emerging economies, using monthly data spanning from October 2008 to June 2014. We use shadow interest rates, namely, the shadow policy rate recently developed by Lombardi and Zhu (2014) and Chen, Lombardi and Zhu (2015). These measures offer a new perspective on measuring monetary policy when the short-term policy rate effectively reaches the ZLB for nominal interest rates and central banks resort to non-standard policies. We also make use of

the consolidated bank lending statistics provided by the Bank for International Settlements (BIS), which along with bilateral trade data, allow us to incorporate both time-varying financial and trade linkages. In addition, we use a new BIS series of total credit to the non-financial private sector, which on average has a span of 45 years and is available for 40 advanced and emerging economies.

Our estimates suggest that the cross-border spillovers vary across economies. The impulse responses estimated from an estimated global vector error-correction model (GVECM) suggest that US unconventional monetary policy generally has stronger domestic and cross-border impacts than euro area non-standard measures. Its spillovers to other economies are estimated to be more sizeable and persistent, especially in terms of output growth and inflation. There is evidence of diverse responses in the emerging economies in terms of exchange rate pressures, credit growth as well as monetary policy. In addition, the strength of cross-border transmission channels to the emerging economies appears to differ for US and euro area policies. However, given the size of the GVECM and the limited data span, the elevated estimation uncertainty is reflected in the relatively large confidence bands. The diverse cross-border QE effects imply that the costs and benefits of US and euro area unconventional monetary policies have not been unevenly distributed between the advanced and emerging economies and have varied over time.

The rest of the paper is organised as follows. Section II provides an overview of the extraordinary monetary policy measures implemented by the Federal Reserve and ECB. In Section III, we describe our empirical methodology and data, highlighting the use of estimated shadow short-term interest rates to measure US and euro area monetary policy when nominal interest rates get close to the ZLB. Section IV provides and compares the impulse responses to US and euro area monetary policy shocks in both pre-crisis and crisis periods based on an estimated global VECM model. Section V concludes.

II. MEASURING US AND EURO AREA EXTRAORDINARY POLICIES

Large-scale asset purchases have been a major component of both US and euro area extraordinary monetary measures. The Federal Reserve announced its first Large-Scale Asset Purchase (LSAP) programme on 25 November 2008, with purchases of up to USD 600 billion in agency mortgage-backed securities (MBS) and agency debt (see Table 1). In March 2009, it expanded the LSAP with an additional USD 850 billion in purchases of agency securities and another USD 300 billion in purchases of longer-term Treasury securities. The operations (LSAP1) were extended to March 2010. As the recovery faltered, the Federal Reserve put in place LSAP2 in November 2010, which consisted of further purchases of USD 600 billion in longer-term Treasury securities until mid-2011.

In September 2011, the Federal Open Market Committee's (FOMC) announced a new maturity extension programme (MEP). Under the programme, by the end of June 2012 the Fed was expected to have bought USD 400 billion in Treasury securities with remaining maturities of six to 30 years, while selling an equal amount of Treasuries with remaining maturities of three months to three years. Against a background of slow and uncertain recovery, the FOMC extended the MEP in June 2012 to the end of that year. In September 2012, it added purchases of agency MBS at a pace of USD 40 billion per month in the latest

phase (LSAP3) of the LSAP programme. LSAP3 is open-ended. In December, when the MEP was due for completion, the Federal Reserve decided to continue to purchase longer-term Treasury bonds at a rate of USD 45 billion per month.

The Federal Reserve's large-scale asset purchase (LSAP) programmes Table 1

	Announcement	Termination	Assets purchased	Amount[1]
LSAP1	November 2008		Agency mortgage-backed securities (MBS) and agency debt	$600 billion
	March 2009		Agency securities	$850 billion
		March 2010	Longer-term US Treasury securities	$300 billion
LSAP2	November 2010	June 2011	Longer-term US Treasury securities	$600 billion
Maturity extension programme (MEP)	September 2011		US Treasury securities with remaining maturities of six to 30 years	$400 billion
	June 2012	December 2012	US Treasury securities with remaining maturities of six to 30 years	
LSAP3	September 2012	October 2014	Agency MBS	$40 billion per month[2]
	December 2012	October 2014	Longer-term US Treasury securities	$45 billion per month[2]

[1] Initially announced amount of asset purchases for each programme or programme expansion. In US dollar. [2] The purchases were open-ended when they were announced. The Federal Reserve started to taper the asset purchases in January 2014, and eventually halted the purchases altogether in October 2014.

Source: US Federal Reserve.

As a consequence, the balance sheet and asset holdings of the Federal Reserve have experienced an unprecedented expansion since the second half of 2008. As the recovery appeared to become more broad-based, the Federal Reserve began to publicly raise the possibility of tapering the pace of its asset purchases and reduced its purchases in early 2014 at a rate of USD 10 billion per month. As the US economy continued to improve and the labour market recovery sped up, the FOMC ended its large-scale asset purchases in October 2014. Yet the overall size of its asset holdings has been maintained through the reinvestment of principal payments in agency MBS.

In the early phase of the Global Financial Crisis, the ECB intervened with "enhanced credit support", directly providing liquidity to banks through fixed-rate instead of variable-rate tenders, with full allotment. The ECB extended the list of eligible collaterals, adjusting the quality thresholds for particular asset classes. In addition, the ECB lengthened the maturity of its longer-term refinancing operations (LTROs), implementing three- and six-month full-allotment LTROs of EUR 300 billion in November 2008 and 12-month LTROs of EUR 442 billion in June 2009 (see Table 2). The Eurosystem provided liquidity in foreign currencies, at various maturities and against EUR-denominated collateral, using reciprocal currency swaps with the Federal Reserve, the Bank of England, the Swiss National Bank, and the Bank of Japan.

In May 2009, the ECB announced its first covered bond purchase programme (CBPP1) of EUR 60 billion, implemented between July 2009 and June 2010. It was intended to support

"a specific financial market segment that is important for the funding of banks and that had been particularly affected by the financial crisis". The CBPP2 was implemented between November 2011 and October 2012, which reached EUR 16.4 billion.

The European Central Bank's main non-standard measures

Table 2

	Start	Termination	Programme	Amount[1]
LTRO1	November 2008		Longer-term refinancing operations, three- and six-month full-allotment	EUR 300 billion
	June 2009		12-month full-allotment	442 billion
CBPP1	July 2009	June 2010	Covered bond purchase programme	60 billion
SMP	May 2010	June 2012	Securities markets programme	>200 billion
CBPP2	November 2011	October 2012	Covered bond purchase programme	16.4 billion
LTRO2	December 2011 February 2012		Longer-term refinancing operations, three-year full-allotment	529 billion
OMT	September 2012		Outright monetary transactions, government bonds of one to three years	Open-ended[2]
TLTRO	September 2014	June 2016	Targeted longer-term refinancing operations	
CBPP3	October 2014	At least 2 years	Covered bond purchase programme	Billion
ABSPP	November 2014	At least 2 years	Longer-term US Treasury securities	Billion
EAPP PSPP	March 2015	September 2016	expanded asset purchase programme, public sector purchase programme	60 billion per month[2]

[1] Amount for each programme or programme expansion. In euros. [2] The purchases were supposed to be open-ended and unlimited in size when they were announced, but the facility has never been activated.

Source: European Central Bank (ECB).

From May 2010 to June 2012, the ECB made bond purchases of over EUR 200 billion via its securities markets programme (SMP) to address the malfunctioning of securities markets and restore monetary transmission. The purchases were then fully sterilised through "fixed term deposits". In September 2012, the ECB terminated the SMP and announced details of an outright monetary transactions (OMT) programme, which has yet to be activated, to address euro area redenomination risks and to repair monetary transmission. Focusing on purchases of government bonds with maturities of one to three years, the OMT had no ex-ante time or size limit. Like the SMP, the OMT purchases would be fully sterilised. In addition, the ECB offered three-year long-term refinancing operations (LTRO), LTROs in December 2011 and February 2012, with an amount of EUR 529 billion, in order to support bank lending and counteract risks of a disorderly deleveraging process. The sum of all these measures led to a peak in the balance sheet of about 3.1 trillion euros in mid-2012.

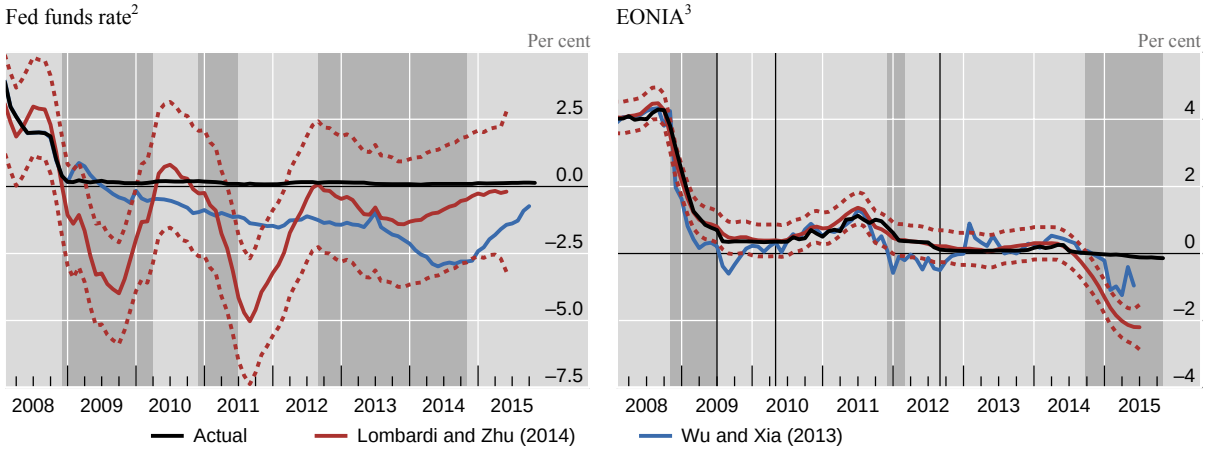
After introducing an asymmetric corridor of the standing facility rates around the main-refinancing operations in November 2013, the ECB lowered the rate applied to the deposit facility to –0.10% in June 2014, and by a further 20 basis points in September 2014. In June 2014, the ECB announced a series of targeted LTROs (TLTROs), to be conducted between September 2014 and June 2016, all maturing in September 2018. In September 2014, the ECB announced the CBPP3 which started in October 2014, and an asset-backed securities

purchase programme (ABSPP) which started in November 2014, both programmes were expected to last for at least two years. To provide better access to credit for firms and households and further ease financial conditions, in January 2015, the ECB announced an expanded asset purchase programme (EAPP) with the public sector purchase programme (PSPP). The PSPP, to be carried out between March 2015 and September 2016, allows the Eurosystem to purchase bonds issued by euro area central governments, agencies and European and supranational institutions in the secondary market, at a rate of EUR 60 billion per month. It will continue until inflation is consistent with the "below, but close to, 2%" target over the medium term.

A. Shadow interest rates

The large and growing variety of unconventional policy measures has made it difficult to accurately measure monetary policy, key to our goal of estimating the domestic and cross-border effects of US and euro area monetary policy. Instead of relying on financial market proxies such as term and corporate spreads, as in Chen, Filardo, He and Zhu (2012, 2015), we use estimated shadow interest rates instead. There are two main approaches to obtain shadow rate estimates: the first is based on Black's (1995) idea to treat nominal interest rates as options and back out the implied values of the segment of the term structure which turns zero at the ZLB from the part which is assumed to be still driven by market forces. Christensen and Rudebusch (2013), Krippner (2013) and Wu and Xia (2013) provide estimates building on this framework. Yet such estimates are criticised for being sensitive to the underlying term structure model. In addition, they likely include elements that reflect market expectations of short nominal interest rates, especially in turbulent times when uncertainties and volatility are high, and market sentiment shifts frequently.

Actual and shadow interest rates[1] Graph II.1



[1] Dashed lines are the respective confidence bands. [2] Grey areas indicate the implementation periods of LSAP1, LSAP2 and LSAP3. [3] Grey areas indicate the initial implementations of LTRO1 (November 2008 – June 2009) and LTRO2 (December 2011 – February 2012) and Targeted LTRO (September 2014 –December 2016). Vertical lines indicate the start of CBPP1 (July 2009), SMP (May 2010) and OMT (September 2012), respectively.

Source: Chen, Lombardi and Zhu (2015); Lombardi and Zhu (2014); Wu and Xia (2013); Datastream.

An alternative approach proposed by Lombardi and Zhu (2014) is to construct a shadow federal funds rate, estimating a dynamic factor model on a large set of variables – the yield curve, monetary aggregates, reserves and the size and the composition of the Federal Reserve's asset holdings – which reflect different facets of US monetary policy actions. They use the estimated factors to back out the implied policy rate, which is not constrained by the ZLB. While the yield curve plays an important role, it is one among several factors which determine the shadow rate dynamics. Chen, Lombardi and Zhu (2015) extend this work and construct a shadow policy rate for the euro area. Unlike the term structure model based shadow rates derived from Black (1995), the shadow policy rate approach is model-free in the sense that it does not depend on any specific term structure model and have more room to let the data speak. In fact, the shadow policy rates appear to have successfully captured the successive major waves of US and euro area unconventional monetary measures, especially the significant easing effects of US LSAP1, LSAP2 and LSAP (see Graph II.1).

III. METHODOLOGY AND DATA

We study both the domestic and cross-border effects of the Federal Reserve's and the European Central Bank's (ECB) balance sheet policies, taking into account the international interdependences and feedbacks manifested in the growing macro-financial linkages among 24 economies. The sample includes six advanced economies: the United States, euro area, Japan, Sweden, Switzerland and the United Kingdom; nine emerging economies in Asia: China, Hong Kong SAR, India, Indonesia, Korea, Malaysia, the Philippines, Singapore, and Thailand; four economies in Latin America: Argentina, Chile, Brazil, and Mexico; three emerging European economies: Czech Republic, Poland and Russia; and Saudi Arabia and South Africa. We focus on the period which started with the rapid cuts in US and euro area policy rates to close to the zero lower bound on nominal interest rates in October 2008, to June 2014 when calls for US policy normalisation gradually increased.

A. Estimating a GVECM Model

To assess the domestic and cross-border impact of US and euro area's unconventional monetary policy, we estimate a Global Vector Error Correction Macroeconometric (GVECM) model first proposed by Pesaran, Schuermann and Weiner (2004). First, we estimate vector error-correcting models for each country, linking domestic variables to foreign variables. Then the country models are combined in a consistent manner to generate impulse responses for all variables in the GVECM model. The model provides a convenient dynamic framework for the analysis of the international transmission of country-specific shocks among a large number of economies.

Our GVECM model is structured as follows.[4] First, we characterise the macro-financial structure of each economy using a set of six domestic endogenous variables: real GDP growth, CPI inflation rate, a monetary policy indicator, credit growth, equity price inflation and an exchange rate pressure index. Second, the foreign variables include foreign real GDP growth, CPI inflation rate, a monetary policy indicator, credit growth, equity price inflation,

[4] We provide technical details on the structure of the GVECM in Appendix I.

exchange rate pressure index, the VIX index of market volatility, and oil prices. For each economy, the foreign variables are constructed as weighted averages of the corresponding variables in all other economies and are treated as being weakly exogenous.[5] A notable exception to these assumptions is the specification for the US model block, which does not treat foreign financial variables as exogenous, including the VIX index. This reflects the dominant role that the US plays in global trade and financial markets.

A few differences in the country specifications deserve mention. First and most importantly, we use shadow short-term interest rates to represent monetary policy for the US, euro area, and UK economies. We estimate a GVAR models based on the Lombardi-Zhu (2014) shadow federal funds rate for the United States and the Chen-Lombardi-Zhu (2015) shadow Eonia rate for euro area. For the United Kingdom, we use the Wu-Xia (2013) rate.

For monetary policy indicators in the emerging economies, we use short-term interest rate for Poland and Russia, and the year-on-year growth rates of a broad monetary aggregate for the other emerging economies. This choice reflects a pragmatic choice to use a consistent and valid indicator across a broad range of economies. During the sample period, many emerging economies combined the use of multiple policy instruments and operational targets, and the relative importance of each instrument differed across economies as well as over time. Growth in a broad monetary aggregate turns out to be a solid measure for monetary policy for this group of rather distinct economies.

For the United States, we exclude foreign financial variables in the US VECM model. Given its relative size and importance, foreign financial variables are less likely to have a large impact on US domestic variables. We assume that the VIX index and the growth of oil price are endogenous in the US model and its evolution depends on the dynamics of US domestic variables. For all other economies, the VIX index and growth of oil price are treated as a weakly exogenous global common factor.

Our exchange rate pressure index is computed as a weighted average of changes in the nominal effective exchange rates and the foreign exchange reserves, in such a way that an increase in the index implies currency appreciation pressure, and vice versa.[6] The index is a variant of the index proposed by Eichengreen, Ross, and Wyplosz (1995) and it takes into account different exchange rate regimes as well policy interventions by the respective governments.

Identification of shocks

We construct impulse response functions following the approach of Eickmeier and Ng (2015), which combines the generalized impulse responses widely used in the GVAR literature with the sign restrictions approach to the identification of structural shocks.

[5] See Appendix II for information on the time-varying weights..

[6] See Appendix III.

In particular, we use explicit sign restrictions to identify the shocks in the GVECM model, based on economic theory and commonly accepted empirical regularities. To identify a structural monetary policy shock on the loosening side, we follow the literature and restrict the domestic responses of the country where shock originates. In particular, responses in the US and euro area shadow interest rates are restricted to be non-positive for six months following the one-time shock; responses in domestic inflation are non-negative for six months; and euro area real GDP growth is non-negative for six months. In addition to this, we also assume that the changes in domestic equity prices are non-negative for two periods after a monetary policy easing shock.

We start with a Cholesky decomposition of the covariance matrix of the vector of the residual in the specific country block, then randomly draw 1000 rotation matrices that satisfy restrictions regarding the domestic impact of the monetary policy shock in the US and the euro area respectively. The sign restrictions used in this paper only restricts signs of impulse responses in the short run and imposes no restriction on the impact of shocks other than monetary policy shocks.

We consider the rotation matrix that produces results closest to the median of the impulse responses generated by the 1000 rotation matrices as the appropriate rotation matrix, and derived the identified shock. Once the shock is identified, the responses of endogenous variables in shock-originating countries and other countries can be obtained using the generalized impulse response approach. Error bands are calculated by generating 500 bootstraps with the selected rotation matrix. We regard this as a relatively agnostic approach that lets the data speak, as we impose fewer restrictions compared to the existing work using sign restrictions (Uhlig 2005, Scholl and Uhlig 2008).

B. Data

Estimation of the GVECM model is based on monthly macroeconomic and financial data for the period ranging from February October 2008 to June 2014. The details on data sources and data transformations are provided in Appendix IV. The variables that are expressed as growth rates are calculated as annual (year-on-year) changes. For data of quarterly or lower frequencies, we use the Chow-Lin (1971) procedure to interpolate them into monthly data series using an appropriate reference series that is available at monthly frequency. For example, to obtain monthly real GDP data, we typically rely on the monthly series of industrial production or employment, assuming that these series have similar seasonal or cyclical patterns.

There are three important aspects to our choice of the underlying data. First, as mentioned above, we use shadow interest rates for the United States and euro area developed by Wu and Xia (2013) and the shadow policy rates proposed by Lombardi and Zhu (2014) and Chen, Lombardi and Zhu (2015).

Second, we use a new BIS dataset of total credit to the private, non-financial sector. The "private non-financial sector" includes non-financial corporations (both private and public-owned), households and non-profit institutions serving households as defined in the System

of National Accounts. In terms of financial instruments, credit covers both loans and debt securities.[7]

Third, we use data on both bilateral trade and cross-border bank lending for the weights used to construct the foreign variables. These data account for bilateral financial and real linkages.[8] The weights are time-varying so as to take account of significant changes in such linkages. In the past, cross-country linkages have been measured largely on bilateral trade data alone; our time-varying trade weights also capture sizeable changes in the global and regional trade patterns via bilateral export and import data. The recent literature has begun to take financial linkages into account but has largely ignored the temporal changes associated with globalisation, financial liberalisation, and a significant rise in capital flows in the last two decades. We use the BIS consolidated cross-border bank lending statistics to approximate and incorporate the time-varying strength of the cross-border financial linkages in the model estimation.[9]

The GVECM model is estimated for the period from October 2008 to June 2014, after the peak of the collapse of Lehman Brothers in September 2008 and before the announcement of LSAP1 in November 2008, when the federal funds rate became effectively zero. We focus on the sample period when the ZLB became binding and unconventional monetary measures were taken.

IV. The Impact of US and Euro Area Unconventional Policies

A. Impulse Response Analysis

We focus on the impact of shocks to US and euro area monetary policy, in a period when the zero lower bound on the short-term policy interest rates has become practically binding. Assessing the estimated impulse responses to shocks to the Lombardi-Zhu (2014) and Chen-Lombardi-Zhu (2015) shadow policy rates provide a way to gauge the impact of unconventional monetary measures implemented by the US Federal Reserve and the European Central Bank. As a robustness check, we also estimate the impulse responses to shocks to the Wu-Xia (2013) shadow federal funds and eonia rates, which is comforting given the existing differences between the two different sets of shadow interest rates. We find that the results are broadly similar, although some variables in some economies do respond differently. The corresponding graphs are provided in Appendix V.

Domestic effects

We first examine the domestic impacts of shocks to US and euro area monetary policies. In Graph IV.1, we report the responses of key domestic variables in the US and the euro area to

[7] Details of the new BIS credit series can be found at: www.bis.org/statistics/credtopriv.htm. Also see Dembiermont et al (2013) for a discussion of the international comparability and consistency across time.

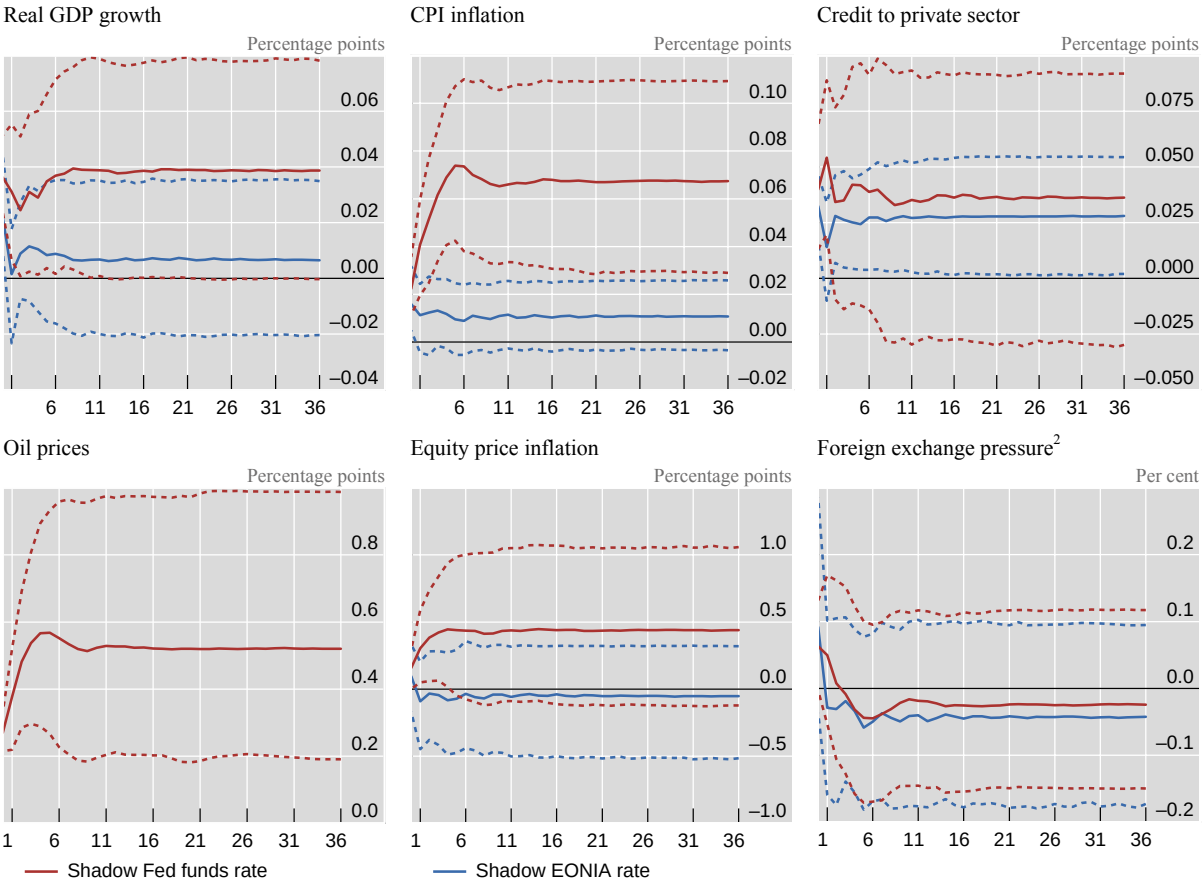
[8] The foreign variables are constructed to match the international patterns of trade and financial flows for each country. Details of weight construction are provided in Appendix III.

[9] We calculate the flows based on cross-border claims, which include loans and securities against all counterparties and of all maturities. For details of the BIS consolidated international banking statistics, see McGuire and Wooldridge (2005).

a 25-basis-point reduction in the shadow federal funds rate and shadow eonia rate, respectively. Several points stand out. First, the impact on real GDP growth and CPI inflation of a monetary stimulus is generally positive, as predicted by the theory. The magnitude of the responses are apparently much larger and more persistent in the United States, as the increases in real GDP growth and inflation reach near 0.04 and above 0.07 percentage points in eight and five months, respectively. In addition, US output and inflation responses are statistically significant, while euro area output and inflation responses, though positive, are rather small and only significant in the first period on impact.

Impulse responses to US and Euro area policy shocks[1]

Domestic impacts — Graph IV.1



[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Lombard-Zhu (2014) shadow federal funds and Chen-Lombard-Zhu (2015) shadow Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Second, the impact of a monetary loosening on credit is broadly similar in the two economies, so is the impact on exchange rate pressure. A 25-basis-point easing leads to greater credit expansion of more than 0.025 percentage points in both economies, and the effects are statistically significant in euro area. This suggests that the domestic credit

channels does work for unconventional monetary policy, although the transmission is weak. In addition, a monetary easing leads to a temporary appreciation in both the US dollar and euro initially, soon followed by a sustained depreciation.

Third, unsurprisingly, easing US monetary policy appears to be much more effective in boosting investor confidence and supporting equity prices. This may be attributed to the special role that the US capital markets play in domestic credit intermediation. The US effect is statistically significant in the first four months. In contrast, easing euro area monetary policy has little impact on its equity prices. In addition, US monetary easing apparently has a sizeable and statistically significant impact on oil prices.

Overall, monetary easing through unconventional monetary measures seem to have had positive effects on output growth, inflation and credit growth in both the United States and euro area. The domestic effects tend to be large and significant in the US economy, where both credit and confidence channels seem to have played a role. This could be partly due to the fact that much of US QE consisted in large-scale purchases of both sovereign and private assets, which are considered by some as a more effective means of easing.

B. Impact of the US and Euro Area Monetary Policy

US and euro area unconventional monetary measures apparently have some intended effects on the respective domestic economies, both in terms of real activity and financial markets, and such effects can be persistent. But these policy measures are also expected to have a non-negligible international dimension. To assess and compare the cross-border spillovers of US and euro area QE measures, we first examine the impulse responses of a 25-basis-point monetary policy shock from one economy on the other; we then look at the cross-border spillovers in terms of the impulse responses in the major emerging economies, namely the larger four BRICS economies: Brazil, Russia, India and China.

Trans-Atlantic spillovers

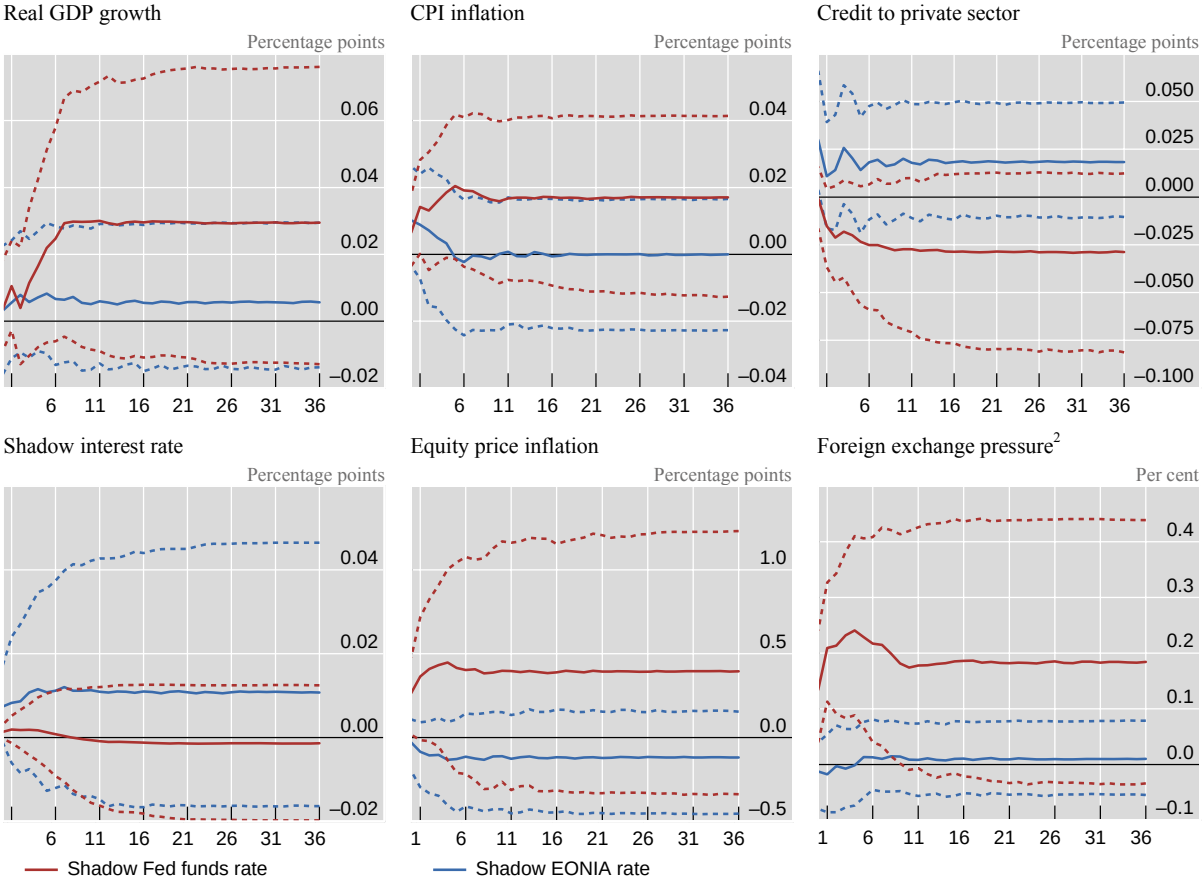
As a consequence of close trade and financial linkages between the two largest economies in the world, monetary policies in the United States and euro area are expected to have sizeable impact on each other. In the sub-section, we examine in detail such trans-Atlantic spillovers.

In Graph IV.2, we plot the impulse responses of euro area real and financial variables to a US shadow federal funds rate shock (red lines) and those of US variables to a euro area shadow eonia rate shock (blue lines). We reach the following conclusions: first, consistent with our findings on their domestic effects, in terms of their trans-Atlantic impact, US monetary policy turns out to be rather more potent. In fact, a one-time 25-basis-point monetary loosening in the United States provides a boost to euro area equity prices of over 0.4 percentage points, it leads to a statistically significant euro appreciation in the first nine months subsequently euro appreciation at about 0.2%. In addition, it provides a boost to euro area real GDP growth of 0.03 percentage points six months after the shock, which is larger than the domestic output impact of a euro area monetary easing of the same size. Similarly, the impact of a US monetary policy shock on euro area HICP inflation is close to 0.02

percentage points, much larger that the impact of a comparable euro area monetary policy shock.

Impulse responses to US and Euro area policy shocks[1]

Trans-Atlantic impacts Graph IV.2



[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Lombard-Zhu (2014) shadow federal funds and Chen-Lombard-Zhu (2015) shadow Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

However, in the opposite direction, the impact of a euro area monetary stimulus has relatively muted effects on the US economy, especially in terms of real GDP growth, CPI inflation and foreign exchange pressure index. Interestingly, the ECB seems not to respond to US monetary measures while the Federal Reserve tightens in response to a monetary loosening by the ECB. In addition, euro area monetary policy easing fails not provide a boost to US equity prices has practically no effect on US foreign exchange pressure, although it does lead to a credit expansion in the United States.

International spillovers of US and euro area monetary policies

A major focus of our analysis is the comparison of the international spillovers of US and euro area unconventional monetary policies. To this end, we compile in separate graphs the initial, maximum and cumulative impulse responses of all sample economies to a 25-basis-point reduction in the shadow federal funds rate and shadow eonia rate.[10]

Graph IV.3 contains a summary of the cumulative responses of US and euro area monetary policy shocks on the economies included in this study, which are informative on their cross-border effects. A number of considerations stand out. First, the cumulative responses to a US (red bars) and a euro area monetary policy easing shock (blue bars) tend to have a positive impact on real GDP growth, CPI inflation and credit growth in both the other advanced and emerging economies, and such responses differ in size across the economies. For instance, the cumulative output responses to a US policy shock are about 0.8, 0.7 and 0.6 percentage points in Sweden, Saudi Arabia and Thailand, but negative in Indonesia, Mexico and the Philippines. Similarly disparate responses can be found in responses of inflation and credit growth to a US shock, but the disparities turn out to be much smaller for responses to a euro area policy shock, as the effects are generally much smaller and more uneven across the economies.

Second, the cumulative responses to a US monetary policy shock are generally larger than those to a euro area policy shock. This is not surprising and also consistent with our previous findings on the domestic and trans-Atlantic effects of US and euro area monetary measures. This is even the case in some European economies, eg Sweden.

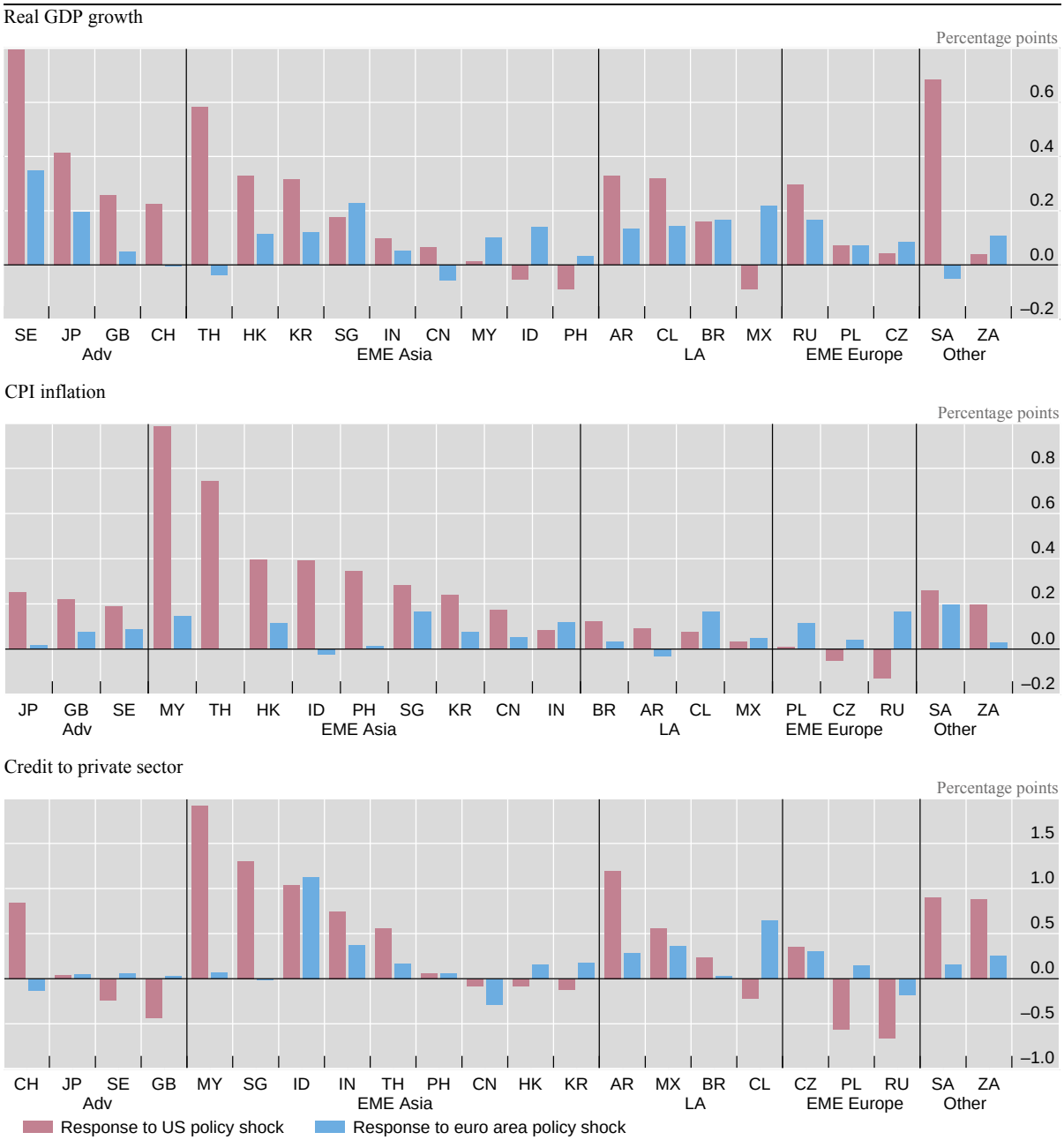
In addition, spillovers of US monetary policy to Asian economies appear greater on average, especially in terms of inflation and credit growth, and the positive impact of euro area policy easing on output growth, inflation and credit growth can be much larger in economies out of Europe. Monetary policy responses to a US policy shock tend to be larger than those to a euro area policy shock, but they are often muted (eg in all other advanced economies) and may go in opposite directions. To some extent, how monetary policy, credit growth and foreign exchange pressure respond to US and euro area policy stimuli can determine the ultimate distinct responses in output and inflation.

Interestingly, following a loosening of US and euro area monetary policy, impulse responses in equity price inflation and foreign exchange pressure tend to move in opposite directions in almost all economies. In general, a US monetary easing would lead to a boost in equity prices in most places except for a small number of economies (eg China, Chile and Malaysia), but a euro area monetary easing would slow equity price inflation across all economies. This is consistent with the findings on the domestic and trans-Atlantic impacts of each shock. Similarly, while a euro area monetary easing leads to a mild euro appreciation in most

[10] Graphs on the initial and maximum impulse responses to US and euro area monetary policy shocks can be found in Appendix V.

economies, a US monetary easing drives a sizeable depreciation in US dollar in all economies excluding Hong Kong SAR, Japan, Switzerland, Thailand and Saudi Arabia.

Cumulative impulse responses to US and Euro area monetary policy shock[1] Graph IV.3



AR = Argentina; BR = Brazil; CH = Switzerland; CL = Chile; CN = China; CZ = Czech Republic; GB = United Kingdom; HK = Hong Kong; ID = Indonesia; IN = India; JP = Japan; KR = Korea; MX = Mexico; MY = Malaysia; PH = Philippines; PL = Poland; RU = Russia; SA = Saudi Arabia; SE = Sweden; SG = Singapore; TH = Thailand; US = United States; XM = Euro Area; ZA = South Africa.

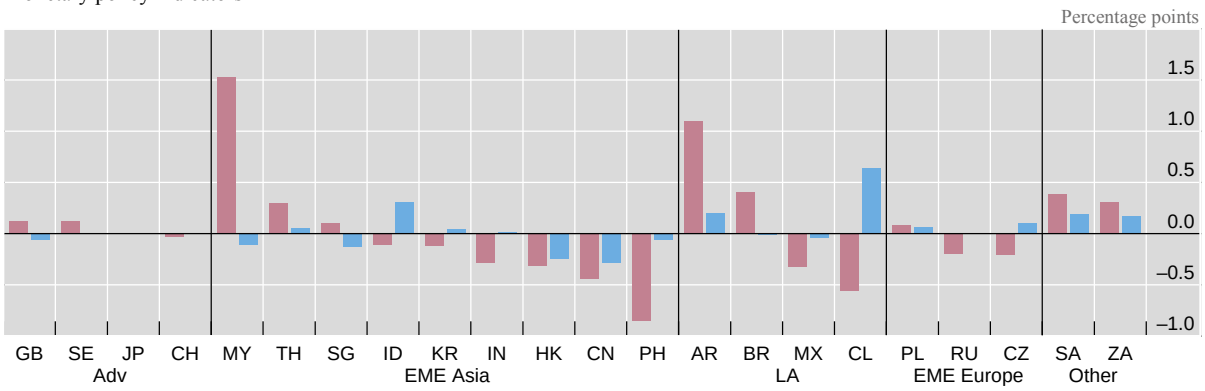
Adv = Advanced economies; EME Asia = Emerging economies in Asia; LA = Latin America; EME Europe = Emerging economies in Europe.

[1] The US and euro area monetary policy shocks are a 25 basis-point reduction in the US shadow federal funds rate and euro area shadow EONIA rate, respectively.

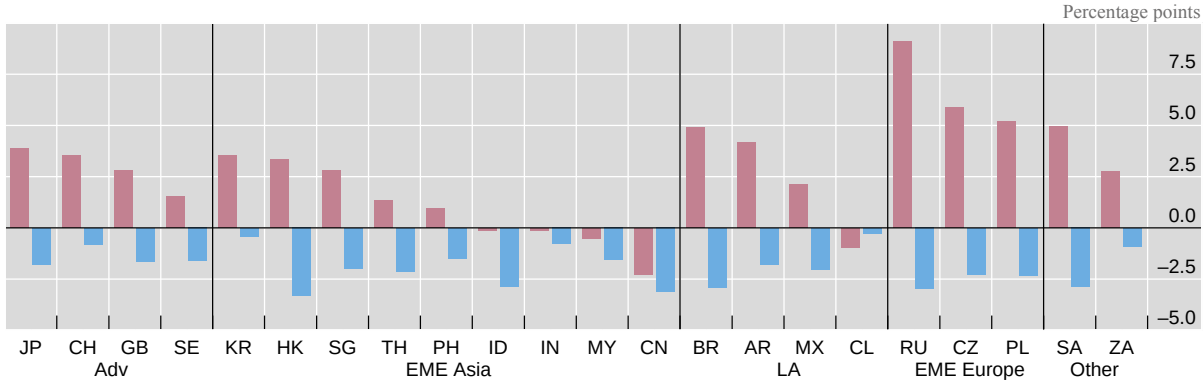
Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Cumulative impulse responses to US and Euro area monetary policy shock (cont'd)[1] Graph IV.3

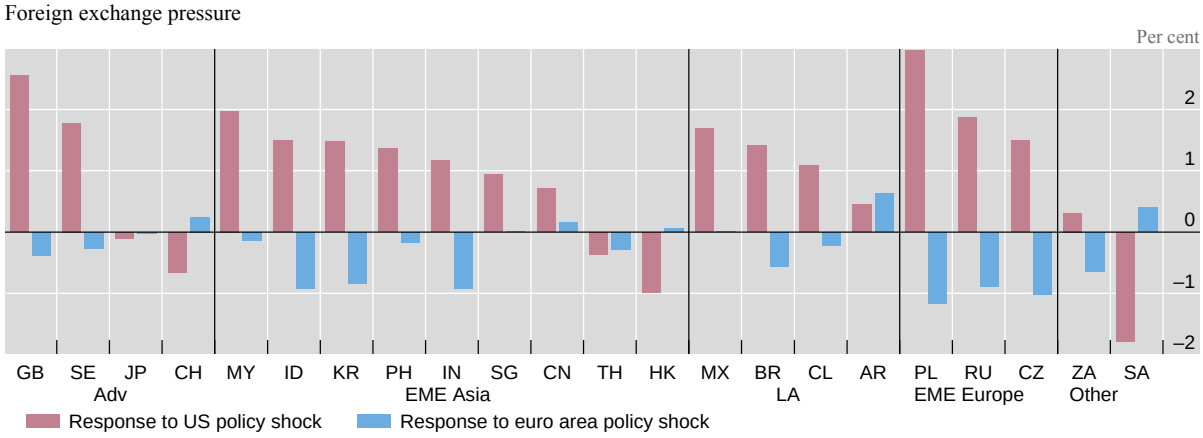
Monetary policy indicators[2]



Equity price inflation



Foreign exchange pressure



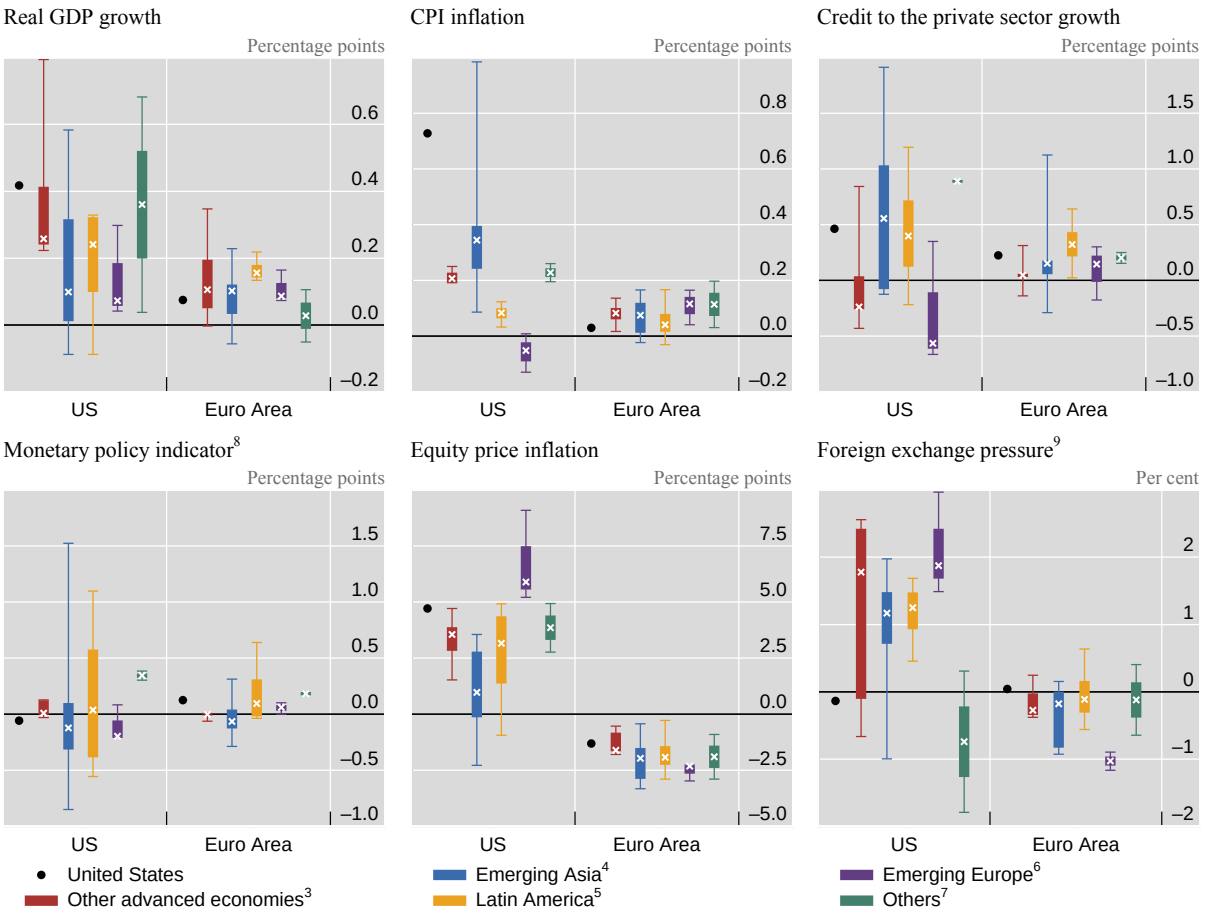
AR = Argentina; BR = Brazil; CH = Switzerland; CL = Chile; CN = China; CZ = Czech Republic; GB = United Kingdom; HK = Hong Kong; ID = Indonesia; IN = India; JP = Japan; KR = Korea; MX = Mexico; MY = Malaysia; PH = Philippines; PL = Poland; RU = Russia; SA = Saudi Arabia; SE = Sweden; SG = Singapore; TH = Thailand; US = United States; XM = Euro Area; ZA = South Africa.

Adv = Advanced economies; EME Asia = Emerging economies in Asia; LA = Latin America; EME Europe = Emerging economies in Europe.

[1] The US and euro area monetary policy shocks are a 25 basis-point reduction in the US shadow federal funds rate and euro area shadow EONIA rate, respectively. [2] Shadow interest rates for the United Kingdom; short-term interest rate for Poland and Russia; and growth rates of a broad monetary aggregate for the other emerging economies..

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Distribution of cumulative impulse responses to US and Euro area policy shocks[1, 2] Graph IV.4



[1] The US and euro area monetary policy shocks are a 25 basis-point reduction in the Lombardi-Zhu (2014) shadow federal funds and Chen-Lombardi-Zhu (2015) shadow Eonia rates, respectively. [2] In the Tukey boxplots the bottom and the top In the Tukey boxplots the bottom and top of the boxes are the first and third quartiles of the cumulative impulse responses of the region; the cross indicates the median; and the bottom and top whiskers represent the range of the responses. [3] Euro area, Japan, Sweden, Switzerland and the United Kingdom. [4] China, Hong Kong SAR, India, Indonesia, Korea, Malaysia, the Philippines, Singapore and Thailand. [5] Argentina, Brazil, Chile and Mexico. [6] Czech Republic, Poland and Russia. [7] Saudi Arabia and South Africa. [8] Shadow interest rates for the United Kingdom; short-term interest rate for Poland and Russia; and growth rates of a broad monetary aggregate for the other emerging economies. [9] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

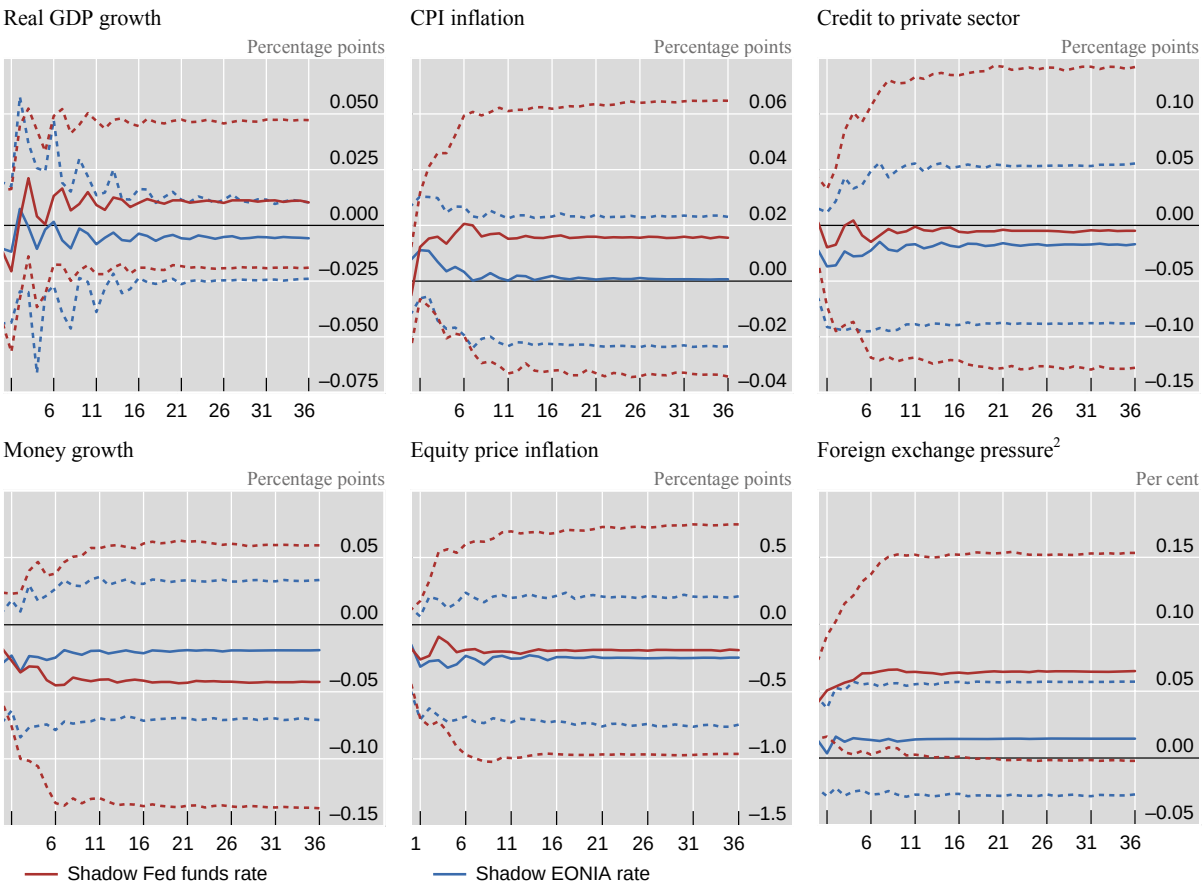
Graph IV.4 provides a different perspective on cumulated impulse responses to US and euro area monetary policy shocks, with Tukey boxplots which summarise the distributional properties of such responses across different regions. First, responses to US monetary easing tend to have greater dispersion for almost all variables except for CPI inflation; and besides monetary policy responses, they also have larger median responses in each region. This is especially the case of responses of real GDP growth. Second, while the inter-quartile ranges stay mostly above zero for responses in equity price inflation and foreign exchange pressure to a US monetary stimulus, the contrary is true in the case of a euro area monetary stimulus. Furthermore, median monetary policy responses to both US and euro area monetary stimuli tend to stick close to zero in all regions. Finally, it is remarkable that the cumulative

responses of Latin American and emerging European economies to a euro area policy shock are much more concentrated, and all turn out to be positive. This could in part be attributed to a small number of economies included in the two regions. Also the inflation responses to a euro area monetary policy shock appear to be more concentrated and generally positive.

Spillovers to major emerging economies

Impulse responses to US and Euro area policy shocks[1]

China — Graph IV.5



[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Lombard-Zhu (2014) shadow federal funds and Chen-Lombard-Zhu (2015) shadow Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

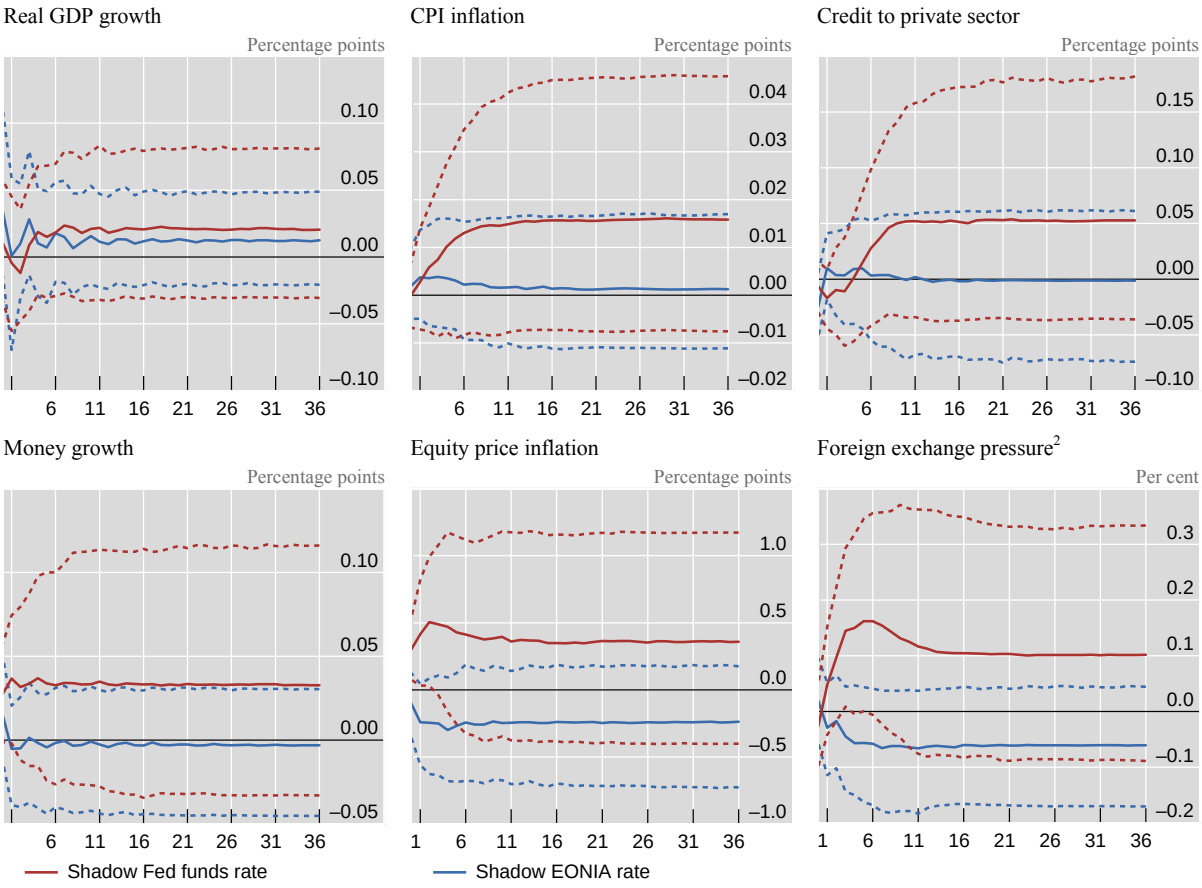
Source: Authors' calculations based on an estimated Global Vector Error Correction model.

In this section we report the estimated 36-month impulse response functions for four major emerging economies, namely the original BRIC economies: Brazil, Russia, India and China. We start with the evaluation of policy spillovers to China in Graph IV.5. The first notable feature is that a 25-basis-point reduction in the shadow federal funds rate leads to an immediate and statistically significant RMB Yuan appreciation pressure, which is sustained at a level that is over 0.06% above the no-shock case. In contrast, a euro area monetary

policy easing has little effect on RMB Yuan. Second, both a one-time US and euro area monetary easing is met with moderate tightening in money growth and credit growth, with the Chinese monetary policy tightening more against a US stimulus and its credit policy tightening more against a euro area shock.

Impulse responses to US and Euro area policy shocks[1]

Brazil — Graph IV.6



[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Lombard-Zhu (2014) shadow federal funds and Chen-Lombard-Zhu (2015) shadow Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

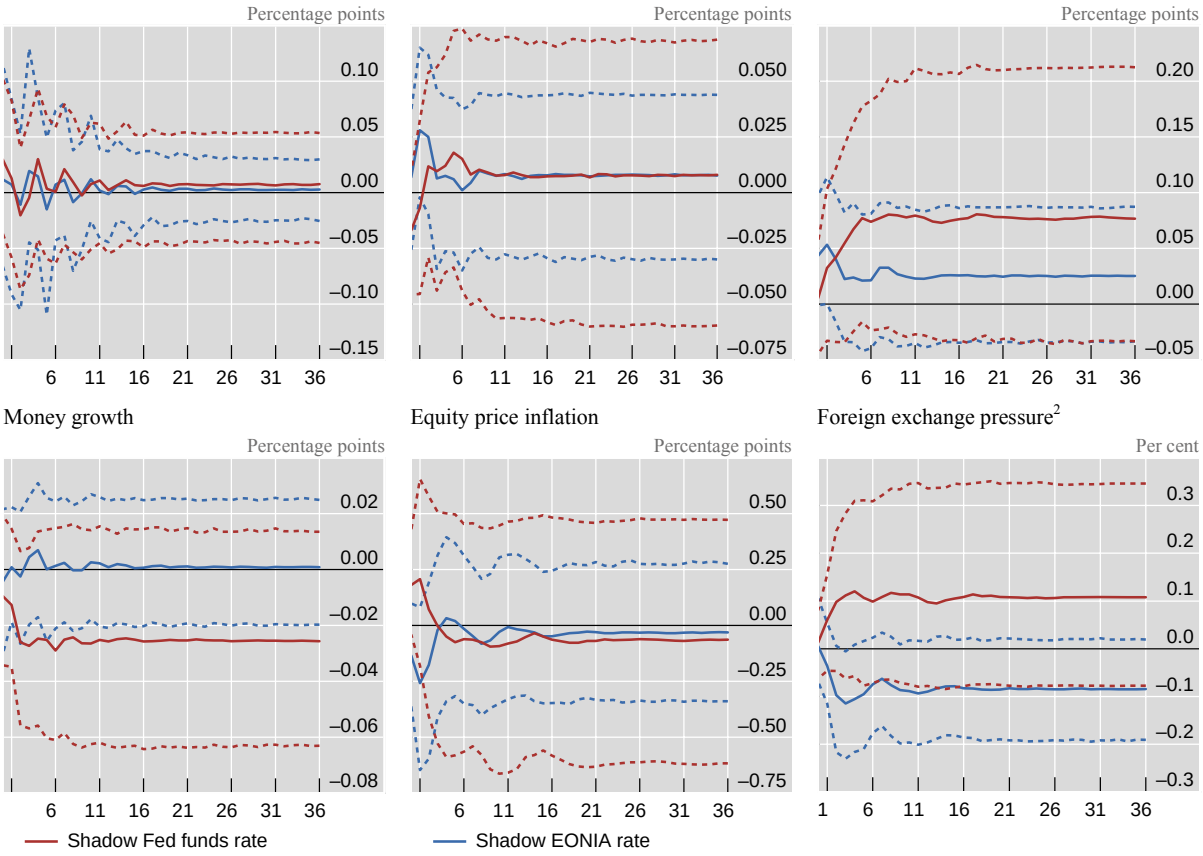
Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Third, the impacts on output growth of both US and euro area policy shocks are mixed: real GDP growth declines on impact, it turns positive in two months and stays positive in response to a US shock, but turns again negative in response to a euro area shock. The effect of a US policy shock on China's inflation is larger and more persistent, while the inflation impact of a euro area shock dies out in six months. Both US and euro area monetary policy easing appear to have negative but small impacts on Chinese equity prices, and the impacts are not statistically significant.

The international spillovers of unconventional monetary policies appear to be larger in the case of Brazil, especially in the case of a US policy loosening. A US easing leads to a statistically significant appreciation pressure on the Brazilian Real, far greater than its impact on RMB Yuan. It boosts Brazil's equity prices, with statistically significant impact in the first few months. In contrast, a euro area monetary stimulus would lead to depreciation pressure in Brazil and slow equity price inflaiton. Second, while Brazil responds with easier monetary poicy (higher money growth) and a delayed but persistent credit expansion, money and credit variables do not seem to respond to a euro area monetary stimulus. Third, Brazilian consumer price inflation and real GDP growth appear to react positively to a US monetary easing, although the response are small and not staistically significant, and impulse responses to a euro area shock are even more muted.

Impulse responses to US and Euro area policy shocks[1]

India — Graph IV.7



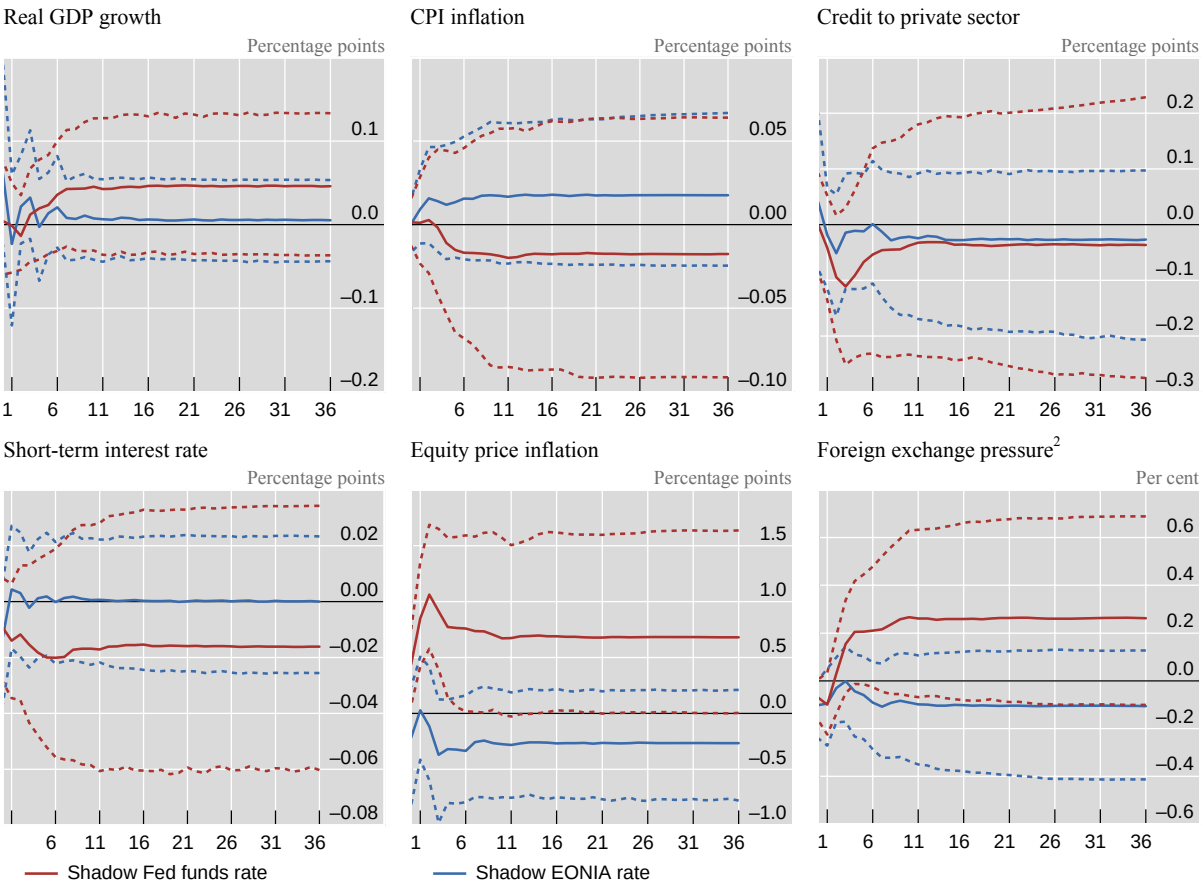
[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Lombard-Zhu (2014) shadow federal funds and Chen-Lombard-Zhu (2015) shadow Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Notably, financial spillovers to Brazil from a US or euro area monetary shock seem to work differently, suggesting distinct policy responses and transmission channels. Besides the obvious difference in their effects on equity price inflation or investor confidence, it may be the case that Brazil loosens its monetary policy and encourages credit growth in response to currency appreciation pressure caused by a US unconventional monetary easing. Such measures are not necessary in the case of euro area easing, as it is associated with deprenciation pressure on the Real and lower equity price inflation.

Impulse responses to US and euro area policy shocks[1]

Russia — Graph IV.8



[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Lombard-Zhu (2014) shadow federal funds and Chen-Lombard-Zhu (2015) shadow Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

In both India and Russia, we first notice that monetary policy basically does not react to a euro area monetary easing, but they respond in opposite directions following a US QE expansion (Graphs IV.7 and IV.8). Specifically, India tightens policy by reducing its money growth upon a US monetary easing, while Russia loosens its monetary policy by lowering its short-term

interest rate. Second, while a 25-basis-point reduction in the shadow federal funds rate tends to place persistent appreciation pressures on Indian Rupee and Russian Ruble, a similar euro area easing puts persistent depreciation pressures of about 0.1% on both currencies, suggesting an exchange rate channel which may work in opposite ways in India and Russia depending on the origin of the shock. This may be part of the explanation that CPI inflation in Russia decreases in response to a US easing shock but rises following a euro area stimulus.

There also differences in responses. For instance, credit growth in Russia slows in response to both euro area and US easing, but accelerates in India, with a typically larger response in the case of a US shock. While there is little reaction in real GDP growth following a euro area shock in both India and Russia, in Russia a persistently positive response is observed. In addition, the response of equity prices inflation to both US and euro area easing tends to be more persistence in Russia, which appears to be short-lived in India.in both cases, a US stimulus boost equity markets, while a euro area easing tends to push equity price inflation downwards.

To sum up, US and euro area unconventional monetary policies in general have an expansionary impact on output growth and inflation, but the size and persistence vary across the major advanced economies, with the effects typically much smaller and less sustained in the case of a euro area stimulus. In addition, the unconventional monetary policies can also have rather different transmissions, for instance, a US monetary easing drives up appreciation pressures in Brazil, India and Russia, while a euro area shock puts depreciation pressures on Real, Rupee and Ruble. Another example is the credit channel: while credit growth in China and Russia changes little or slows in response to a US or euro area monetary loosening, credit growth accelerates in Brazil and India a few months after a US policy shock. The confidence channel, as reflected in changes in equity prices, also operates in different ways across the major economies and depending on the origin of the monetary policy shock. The differences are even greater in the broader universe which includes other advanced and emerging economies in our sample. We suspect that in cases where the international spillovers of ECB policies appear to be relatively strong for some economies, some of this strength may be attributed to the second-round effects originating from the impact of ECB actions on the US economy.

V. CONCLUSION

We study and compare the domestic and cross-border impacts of US and euro area monetary policy in an estimated GVECM model. To better account for unconventional policy measures taken by the US Federal Reserve and the ECB, we use shadow interest rates estimated for the United States and euro area, namely the shadow policy rates developed by Lombardi and Zhu (2014) and Chen, Lombardi and Zhu (2015). The shadow rates are not constrained by the zero lower bound.

We find that US and euro area unconventional monetary policies have been effective domestically, but more so in the United States, and US measures tend to have more impact on euro area economies than the other way round. The estimated GVECM impulse responses suggest that the spillover effects of US and euro area monetary policy on the other advanced

and emerging economies are sizeable but diverse. The estimated cross-border effects of US QE are larger and more persistent, especially in terms of output growth and inflation.

In our view, the strength of the cross-border effects depends partly on how each economy reacts to the US and euro area policy shocks, and partly on the distinct economic and financial structures, policy frameworks and exchange rate arrangements. There is evidence of diverse responses in the emerging economies in terms of exchange rate pressures, credit growth as well as monetary policy. The cross-border transmission channels of US and euro area unconventional monetary policies also tend to operate in different ways, with typically smaller effects and weaker transmission in the case of euro area policies.

The heterogeneous cross-border QE effects imply that the costs and benefits of US and euro area QE policies have been unevenly distributed between the advanced and emerging economies and have varied over time.

APPENDIXES: METHODOLOGY AND DATA

APPENDIX I. STRUCTURE OF THE GVECM MODEL

The structure of the Global Vector Error Correction model (GVECM) model can be described as follows. Consider $N+1$ economies, indexed by $i = 0, 1, 2, \ldots, N$ and a vector $\{x_{it}, t = 1, 2, \ldots, T\}$ of k_i domestic variables for each economy. Stacking the vectors of country-specific variables,

$$\mathbf{x}_t = \left(\mathbf{x}_{0t}', \quad \mathbf{x}_{1t}', \quad \ldots, \quad \mathbf{x}_{Nt}' \right) \tag{1}$$

A VECM in $\mathbf{x}_t$ would contain too many parameters to be estimated for a relatively small T. Instead of regressing, without any restrictions, $\mathbf{x}_{i,t}$ on

$$\mathbf{x}_{-i,t} = \left(\mathbf{x}_{0t}', \quad \mathbf{x}_{1t}', \quad \ldots, \quad \mathbf{x}_{i-1,t}', \quad \mathbf{x}_{i+1,t}', \quad \ldots, \quad \mathbf{x}_{N,t}' \right) \tag{2}$$

the GVECM links $\mathbf{x}_{i,t}$ to a $k_i^* \times 1$ vector $\mathbf{x}_{i,t}^*$, where

$$x_{\ell it}^* = \sum_{j=0}^{N} \omega_{\ell ij} x_{\ell jt}, \quad \ell = 1, 2, \ldots, k_i^*. \tag{3}$$

The weight ω_{lij} captures the spillover effect of variable l of foreign economy j on variable l of domestic economy i. Since ω_{lij} measures the relative importance of economy j to economy i, the spillover effect of variable l is in proportion to the weight chosen to measure the relative importance. Therefore, each economy's component of GVECM is given as a VARX (p_i, q_i):

$$\mathbf{x}_{it} = \mathbf{a}_{io} + \mathbf{a}_{i1} \cdot t + \sum_{s=1}^{p_i} \mathbf{\Phi}_{is} \mathbf{x}_{i,t-s} + \sum_{s=0}^{q_i} \mathbf{\Lambda}_{is} \mathbf{x}_{i,t-s}^* + \sum_{s=0}^{r_i} \mathbf{\Psi}_{is} \mathbf{d}_{t-s} + \mathbf{u}_{it} \tag{4}$$

with $u_{it} \overset{iid}{\sim} (0, \sum_i)$, and where $\mathbf{d}_{t-s}$ is the observed common factor of $q \times 1$ dimension and $\boldsymbol{\varepsilon}_{it}$ is iid across time. The country-specific vector $\mathbf{x}_{i,t-s}^*$ reflects interdependence among economies and serves as a proxy for the unobserved common effects across economies. The country-specific foreign variables and common factors are treated as weakly exogenous (if confirmed by statistical tests), i.e. they are "long-run forcing" country-specific domestic variables. The term "long-run forcing" means that in the equations for foreign variables, the coefficients on the error-correction terms are set to zero. The dynamics of foreign variables are not influenced by deviations from the long-run equilibrium path, in contrast to the dynamics of domestic variables.

The VARX can be estimated economy by economy using the ordinary least squares (OLS) method or rank-reduced approach if the cross-dependence of the idiosyncratic shock is sufficiently small; that is:

$$\sum_{j=0}^{N} Cov\left(\varepsilon_{\ell it}, \varepsilon_{sjt} \right) / N \to 0, \tag{5}$$

all $i \neq j$, *l and s.*

From equation (3), it can be seen that

$$\mathbf{z}_{it} = \mathbf{W}_i \mathbf{x}_t \qquad i = 1, 2, \ldots, N \tag{6}$$

Where $\mathbf{z}_{it} = \left(\mathbf{x}_{it}^{'} \quad \mathbf{x}_{it}^{*'}\right)$, and where $\mathbf{W}_i$ is an appropriately defined weighting scheme. Thus, stacking (4) across i, the endogenous variables can be solved for in a global system:

$$\mathbf{G}\mathbf{x}_t = \mathbf{a}_{i0} + \mathbf{a}_{i1} \cdot t + \sum_{s=1}^{p} \mathbf{\Phi}_s \mathbf{x}_{t-s} + \sum_{s=0}^{r} \mathbf{\Psi}_s \mathbf{d}_{t-s} + \mathbf{u}_t \tag{7}$$

Thus:

$$\mathbf{x}_t = \mathbf{G}^{-1}\mathbf{a}_{i0} + \mathbf{G}^{-1}\mathbf{a}_{i1} \cdot t + \mathbf{G}^{-1}\sum_{s=1}^{p} \mathbf{\Phi}_s \mathbf{x}_{t-s} + \mathbf{G}^{-1}\sum_{s=0}^{r} \mathbf{\Psi}_s \mathbf{d}_{t-s} + \mathbf{G}^{-1}\mathbf{u}_t \tag{8}$$

where $p = \max\{p_i, q_i\}$, $r = \max\{r_i\}$, and

$$G = \begin{pmatrix} A_0 W_0 \\ A_1 W_1 \\ \vdots \\ A_N W_N \end{pmatrix}, \quad H_s = \begin{pmatrix} B_{s,0} W_0 \\ B_{s,1} W_1 \\ \vdots \\ B_{s,N} W_N \end{pmatrix}, \quad u_t = \begin{pmatrix} u_{0,t} \\ u_{1,t} \\ \vdots \\ u_{N,t} \end{pmatrix}. \tag{9}$$

Equation (8) is a VAR for the complete set of domestic variables for all economies.

The advantage of the GVECM model is that it makes the estimation of (8) feasible by accounting for interdependence among economies and then estimating the partial system on an economy-by-economy basis, which implies allowing for modeling a large number of economies. The impulse response is computed based on (8).

APPENDIX II. CONSTRUCTING TIME-VARYING WEIGHTS FOR FOREIGN VARIABLES

The weight of country I assigned to country j at year t is written as:

$$W_{ij,t}^{agg} = w_{i,t}^{T} W_{ij,t}^{T} + w_{i,t}^{F} W_{ij,t}^{F} \text{ , for all } i \neq j \text{ ,}$$

where $W_{ij,t}^{T}$ and $W_{ij,t}^{F}$ are the bilateral trade and financial weight computed based on the capital inflow and outflow in the previous year. $w_{i,t}^{T}$ and $w_{i,t}^{F}$ are the relative importance of trade flow and capital flow in a country respectively. They are computed according to the value of the respective aggregate trade flow (export and import) and capital flow (capital inflow and outflow) relative to the total value of these two types of flow in the previous year. The financial weight of countries without capital flow data in the 1990s is set to zero.

APPENDIX III. CONSTRUCTING A FOREIGN EXCHANGE PRESSURE INDEX

The exchange pressure index EMP_t measures the pressure of capital inflow. In economies with flexible exchange rate regimes, strong net capital inflow pushes up the demand for domestic currency, which in turn leads to an appreciation of the domestic currency. If the authorities intervene in the foreign exchange market by purchasing foreign currency with domestic currency, we may not observe significant changes in exchange rate of the domestic currency, but rather an increase in foreign reserves of the authorities' balance sheet. In economies with fixed exchange rate regimes, strong net capital inflow is reflected in the increase of foreign reserves only. Therefore, the foreign exchange pressure index is constructed in the following way, which is a variation of the index proposed by Eichengreen, Ross and Wyplosz (1995):

$$EMP_t = 100 \cdot (w_{t,e} e_t + w_{t,rev} rev_t)$$

where $w_{t,X} = \dfrac{\sigma_{t,X}^{-1}}{\sigma_{t,e}^{-1} + \sigma_{t,rev}^{-1}}$ for $X = e, rev$, with σ_t being the standard deviation.

Moreover, $e_t = \ln(E_t) - \ln(E_{t-12})$ and $rev_t = \ln(R_t) - \ln(R_{t-12})$, where E_t is the NEER and R_t denotes the foreign reserves.

APPENDIX IV. DATA

Data sources include the Bank for International Settlement (BIS), the International Monetary Fund's International Financial Statistics, CEIC, Bloomberg and Datastream.

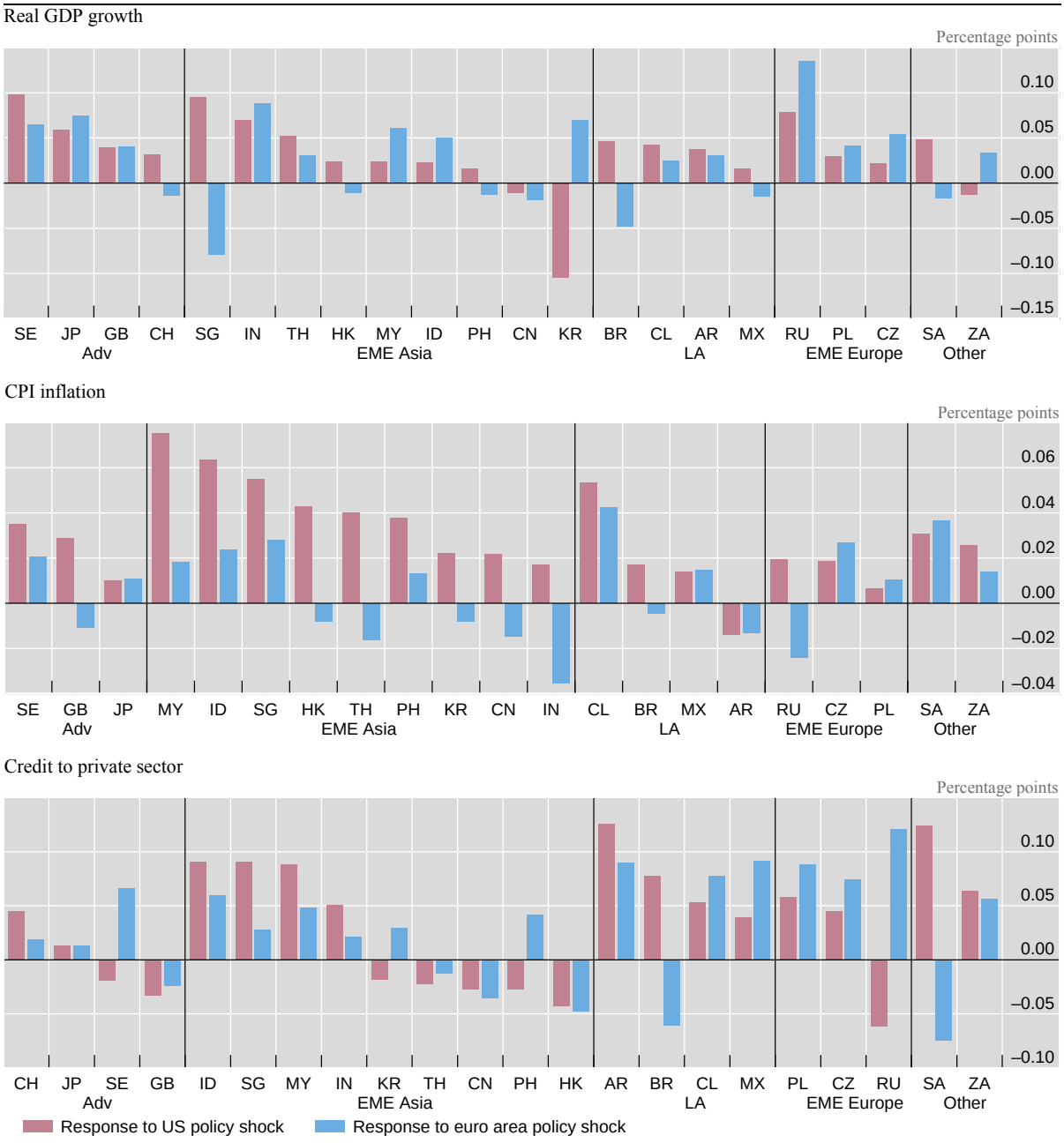
Variable	Description	Source	Notes
Real GDP		IMF IFS, national data	Real GDP of China is at 1990 prices, those of other countries at 2005 prices (billions of domestic currency units). The monthly time series are interpolated using method of Chow and Lin (1971) with industrial production series as a reference. Series for HK is interpolated using compound growth rate due to unavailability of monthly industrial production.
CPI inflation	Year-on-year change in consumer price index	CEIC, IMF IFS, national data	
Credit to the private sector			In billions of domestic currency units. Data before Sept. 1997 is computed using growth rate of banks' loan to non-government and non-banks; for China, data before Jun 1999 is interpolated from quarterly data, using monthly data on loans in China with Chow and Lin (1971) method.
Term Spread	Interest rate spreads between 10-year and 3-month Treasury bill yield	CEIC, IMF, IFS, national data	For Euro Area, due to data limitations, the main refinancing rate is used in the stead of 3-month government bond yield.
Corporate Spread	BofA Merrill Lynch US Corporate AAA minus BBB.	CEIC, IMF, IFS, national data	For Euro Area, due to data limitations, the main refinancing rate is used in the stead of 3-month government bond yield.
VIX	CBOE Volatility Index; In natural logarithm	CBOE	VIX is a key measure of market expectations of near-term volatility conveyed by S&P 500 stock index option prices.
Money Growth	Year-on-year M2 growth rate	CEIC, IMF, IFS	Billions of domestic currency units.
Equity price inflation	Stock price index	Bloomberg	Index of stock prices in each country is in "List of Stock Price Index".
	Nominal effective exchange rate	BIS	Period average; 2005 = 100.
Foreign Exchange Pressure	Foreign Reserve	IMF IFS	Total reserves minus gold, in billions of USD. Euro Area data starting from Jan 1999 are official reserves as published by ECB; data before 1999 either is estimated or is the aggregate reserve of 11 EU Member States participating in the Euro Area in 1999.
Oil price	spot oil price	IMF IFS	Brent crude oil, US dollar per barrel; period end data.
Export/import		IMF IFS	Millions of USD.
Cross-border bank lending	BIS reporting banks' cross-border claims	BIS	
Capital inflow/outflow		IMF IFS	

List of stock price index

United Kingdom	FTSE 100 Index
Japan	Nikkei 225 Index
United States	S&P 500 Index
Euro Area	Euro Stoxx 50 (Price) Index
China	Shanghai A-share Stock Price Index
Hong Kong SAR	Hang Seng Index
India	Bombay Stock Exchange Sensitive Index
Korea	KOSPI Index
Indonesia	Jakarta Equity price inflation Index
Malaysia	FTSE Bursa Malaysia KLCI Index
Philippines	Philippine Stock Exchange PSEi Index
Singapore	FTSE Straits Times Index
Thailand	Bangkok SET Index
Argentina	Buenos Aires Stock Exchange Merval Index
Brazil	São Paulo Stock Exchange Boverspa Index
Chile	Santiago Stock Exchange IGPA Index
Mexico	Mexican IPC Index

APPENDIX V. GRAPHS: IMPULSE RESPONSES BASED ON WU-XIA (2013) SHADOW RATES

Maximum impulse responses to US and Euro area monetary policy shock[1] Graph V.1



AR = Argentina; BR = Brazil; CH = Switzerland; CL = Chile; CN = China; CZ = Czech Republic; GB = United Kingdom; HK = Hong Kong; ID = Indonesia; IN = India; JP = Japan; KR = Korea; MX = Mexico; MY = Malaysia; PH = Philippines; PL = Poland; RU = Russia; SA = Saudi Arabia; SE = Sweden; SG = Singapore; TH = Thailand; ZA = South Africa.

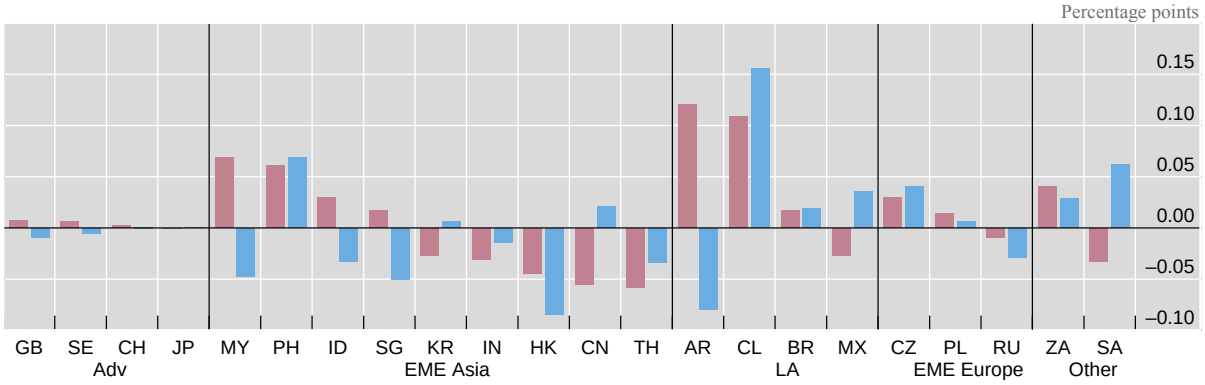
Adv = Advanced economies; EME Asia = Emerging economies in Asia; LA = Latin America; EME Europe = Emerging economies in Europe.

[1] The US and euro area monetary policy shocks are a 25 basis-point reduction in the US shadow federal funds rate and euro area shadow EONIA rate, respectively.

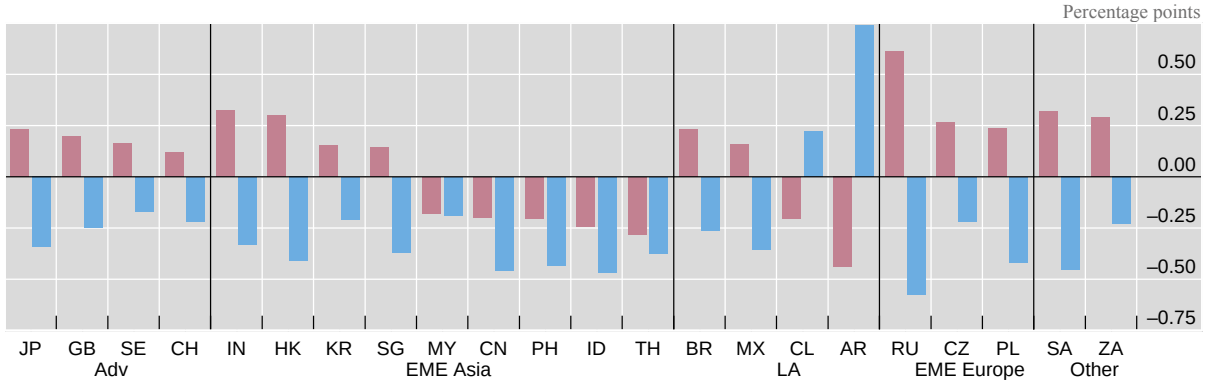
Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Maximum impulse responses to US and Euro area monetary policy shock (cont'd)[1] Graph V.1

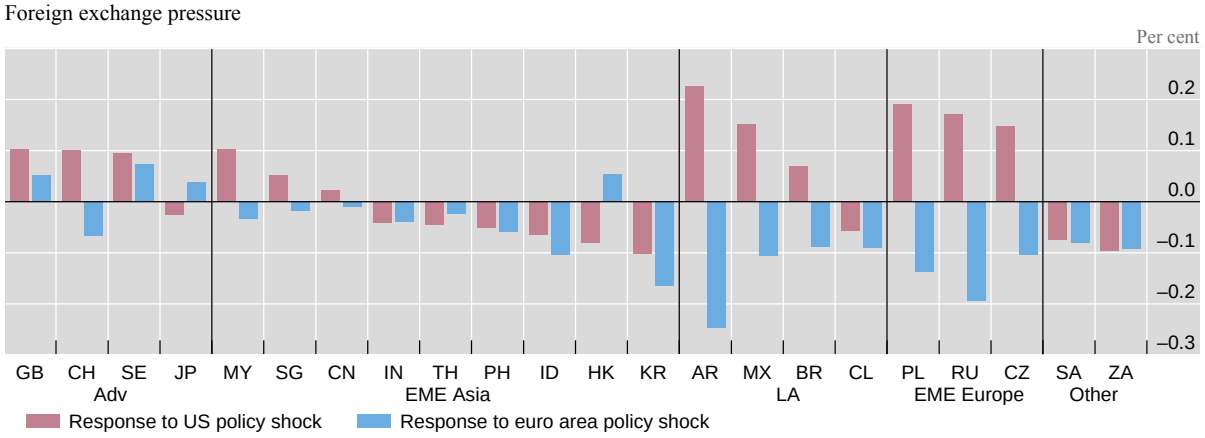
Monetary policy indicators[2]



Equity price inflation



Foreign exchange pressure



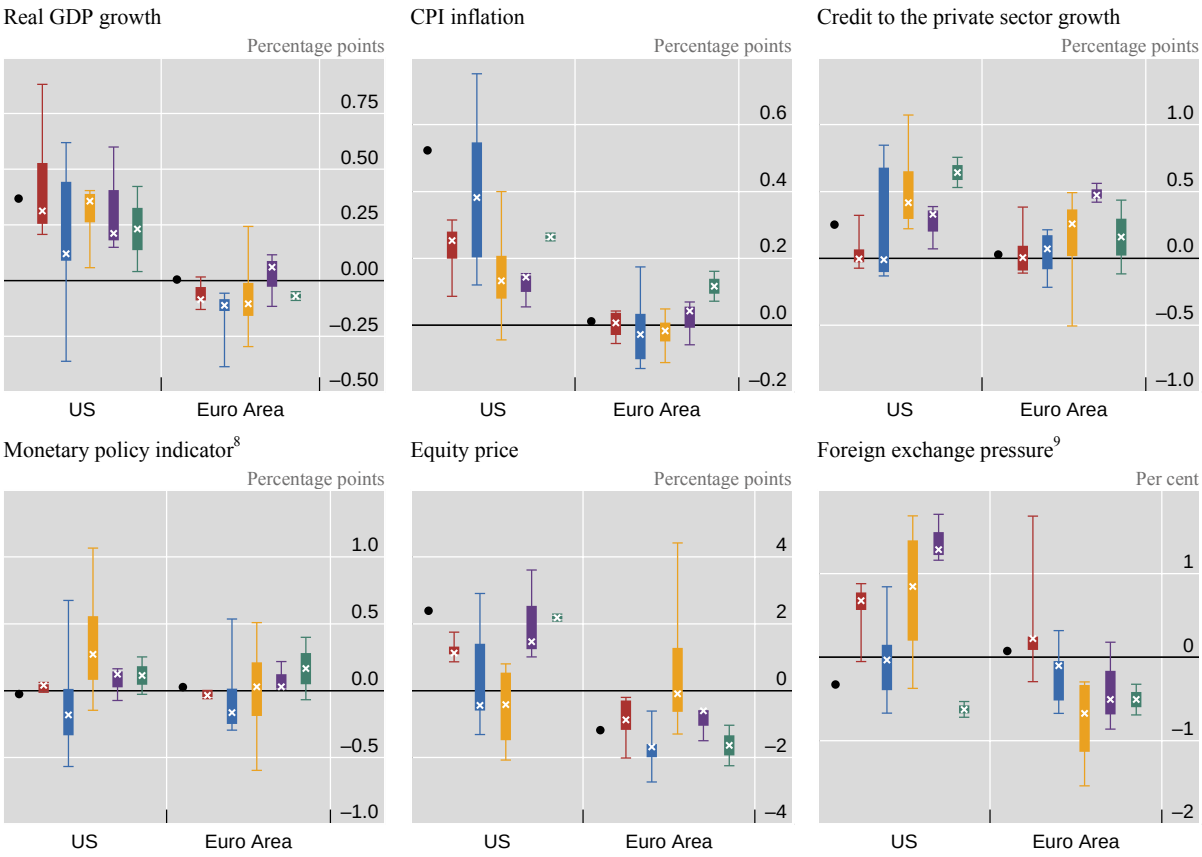
AR = Argentina; BR = Brazil; CH = Switzerland; CL = Chile; CN = China; CZ = Czech Republic; GB = United Kingdom; HK = Hong Kong; ID = Indonesia; IN = India; JP = Japan; KR = Korea; MX = Mexico; MY = Malaysia; PH = Philippines; PL = Poland; RU = Russia; SA = Saudi Arabia; SE = Sweden; SG = Singapore; TH = Thailand; ZA = South Africa.

Adv = Advanced economies; EME Asia = Emerging economies in Asia; LA = Latin America; EME Europe = Emerging economies in Europe.

[1] The US and euro area monetary policy shocks are a 25 basis-point reduction in the US shadow federal funds rate and euro area shadow EONIA rate, respectively. [2] Shadow interest rates for the United Kingdom; short-term interest rate for Poland and Russia; and growth rates of a broad monetary aggregate for the other emerging economies..

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Distribution of cumulative impulse responses to US and Euro area policy shocks[1, 2] Graph V.2



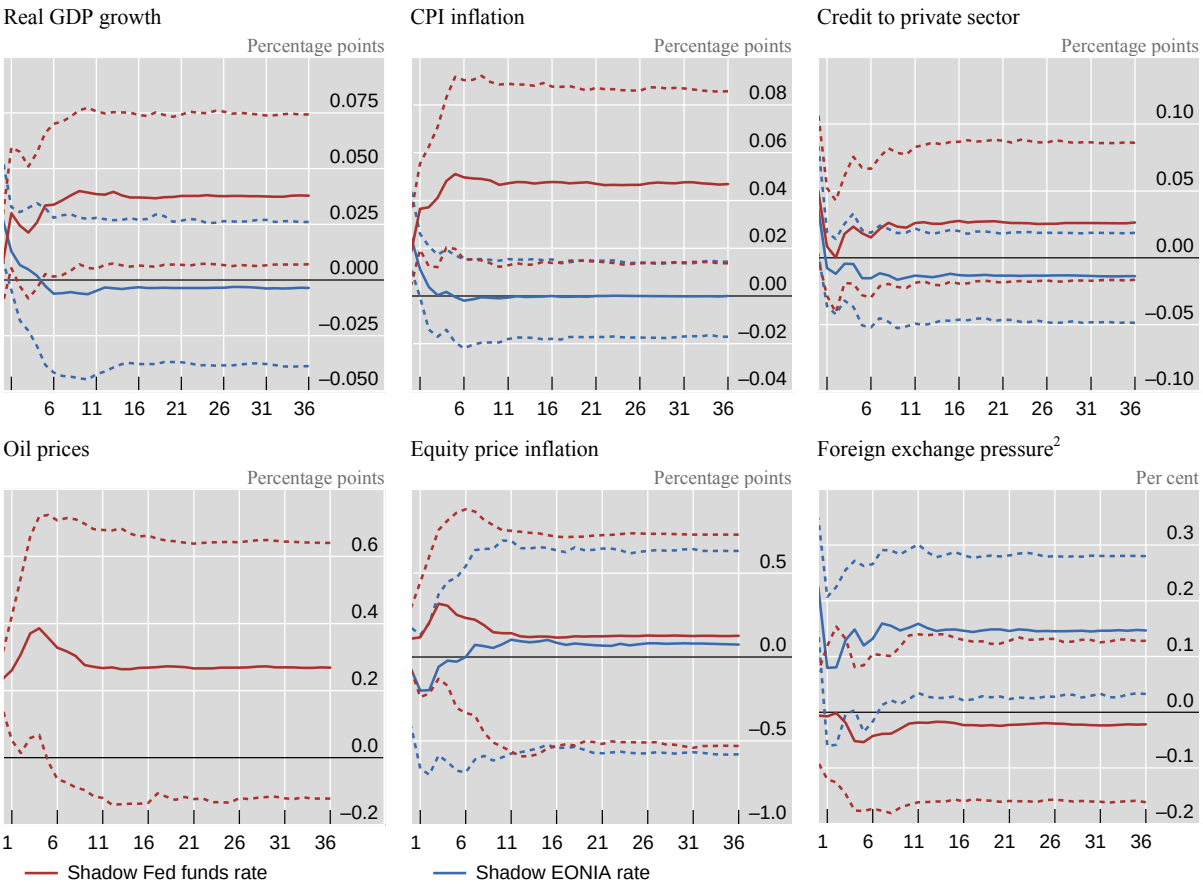
[1] The US and euro area monetary policy shocks are a 25 basis-point reduction in the Wu-Xia (2013) shadow federal funds and shadow Eonia rates, respectively. [2] In the Tukey boxplots the bottom and the top In the Tukey boxplots the bottom and top of the boxes are the first and third quartiles of the cumulative impulse responses of the region; the cross indicates the median; and the bottom and top whiskers represent the range of the responses. [3] Euro area, Japan, Sweden, Switzerland and the United Kingdom. [4] China, Hong Kong SAR, India, Indonesia, Korea, Malaysia, the Philippines, Singapore and Thailand. [5] Argentina, Brazil, Chile and Mexico. [6] Czech Republic, Poland and Russia. [7] Saudi Arabia and South Africa. [8] Shadow interest rates for the United Kingdom; short-term interest rate for Poland and Russia; and growth rates of a broad monetary aggregate for the other emerging economies. [9] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Impulse responses to US and Euro area policy shocks[1]

Graph V. 3

Domestic impacts



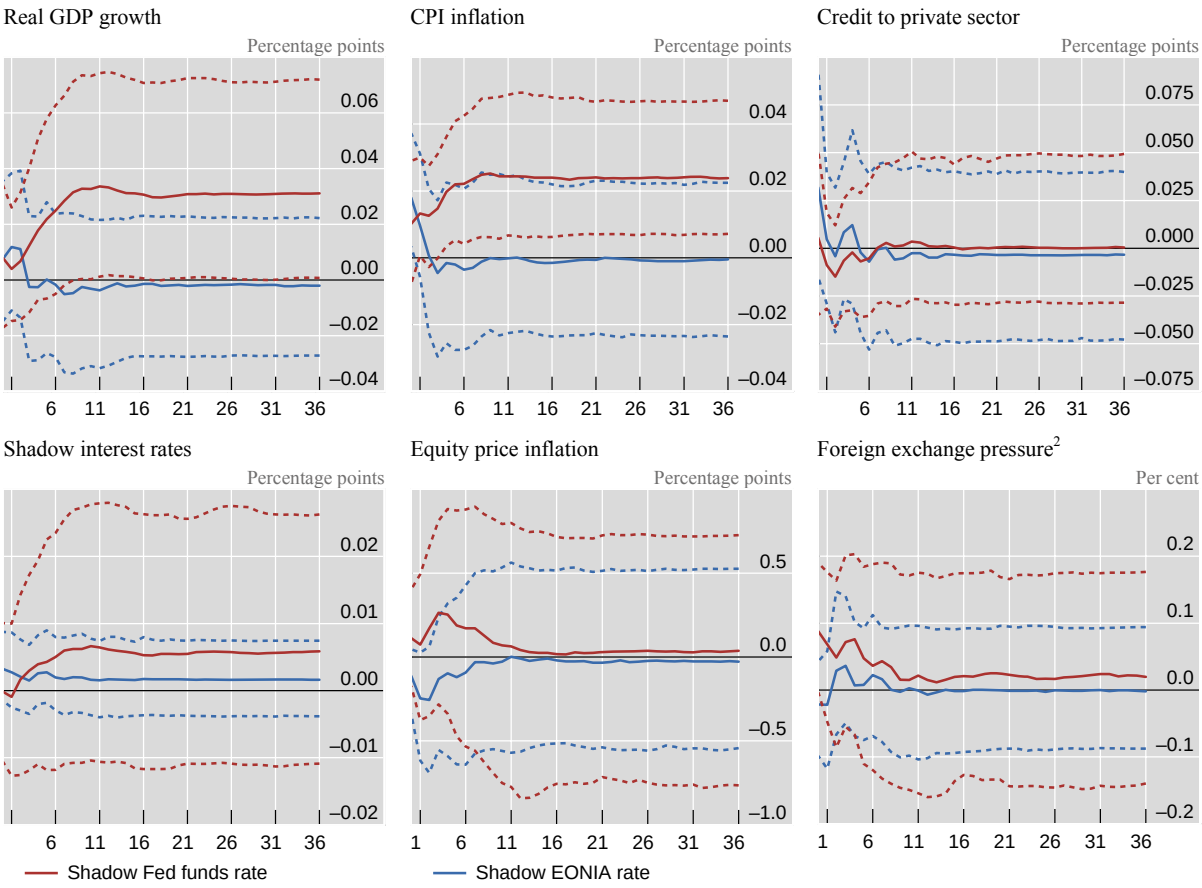
[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Wu and Xia (2013) shadow federal funds and Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Impulse responses to US and Euro area policy shocks[1]

Graph V. 4

Trans-Atlantic impacts



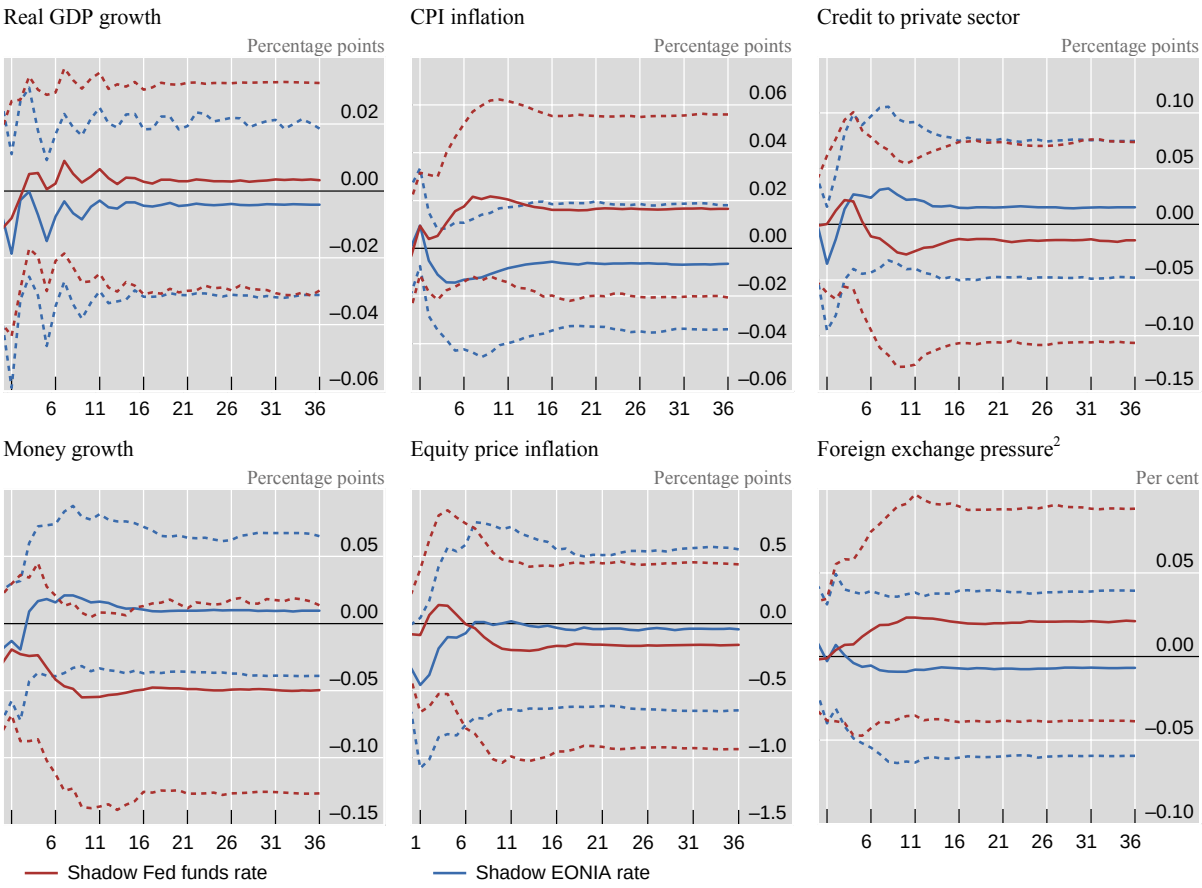
[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Wu and Xia (2013) shadow federal funds and Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Impulse responses to US and Euro area policy shocks[1]

Graph V.5

China



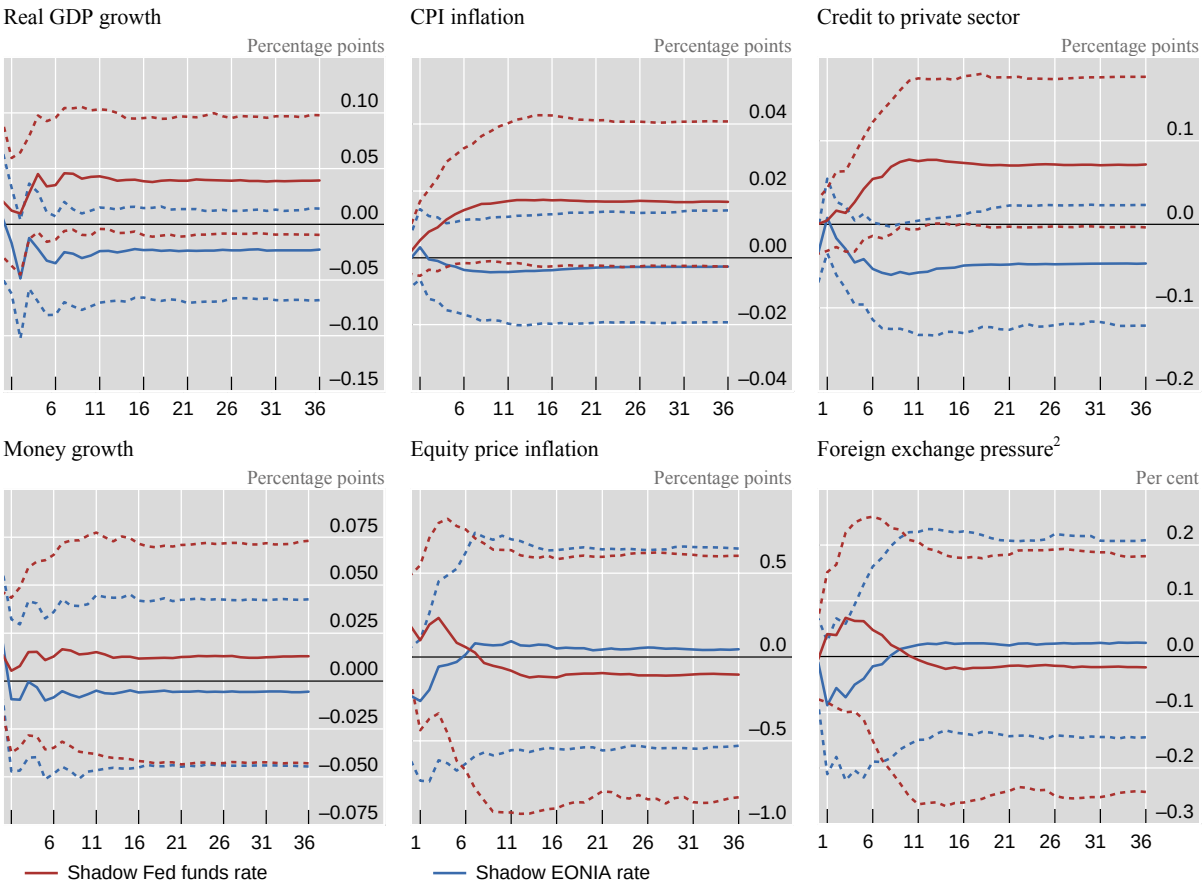
[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Wu and Xia (2013) shadow federal funds and Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Impulse responses to US and Euro area policy shocks[1]

Graph V.
6

Brazil



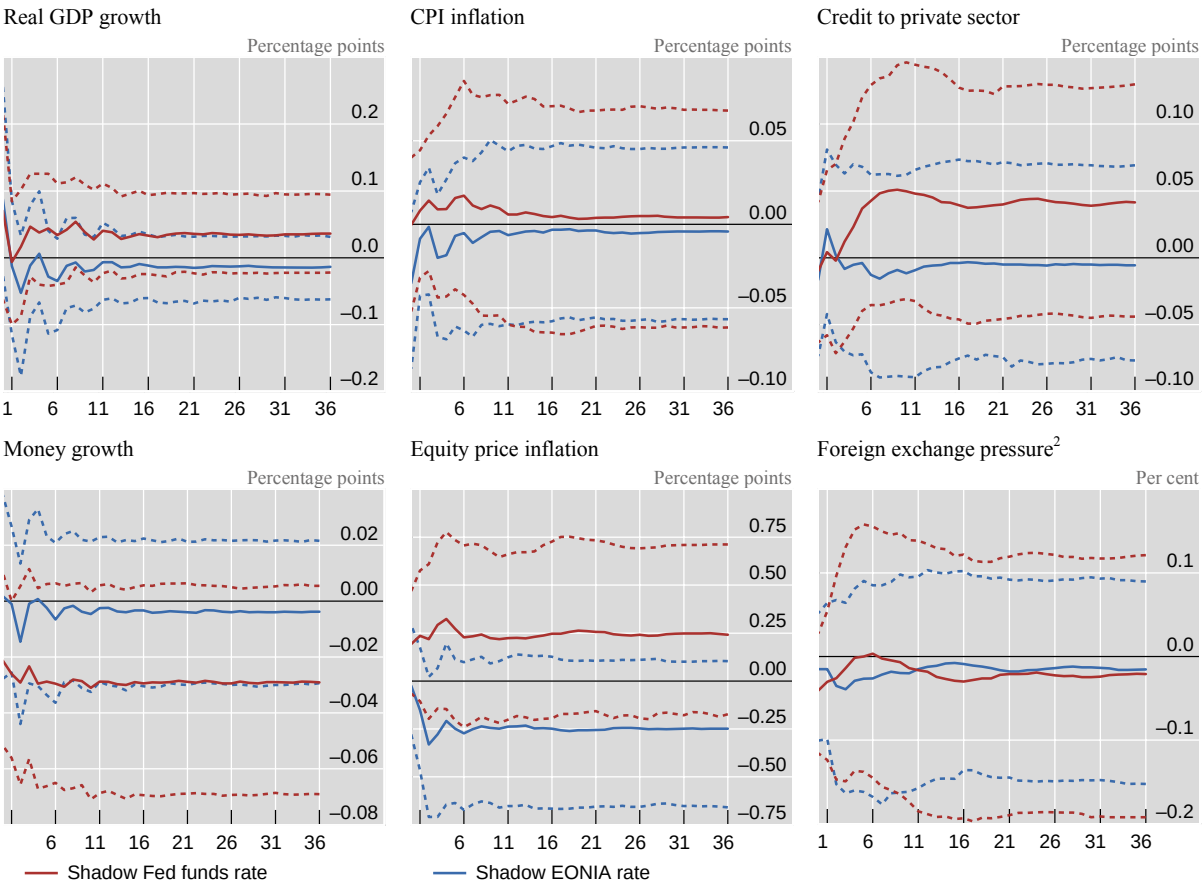
[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Wu and Xia (2013) shadow federal funds and Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Impulse responses to US and Euro area policy shocks[1]

India

Graph V.
7



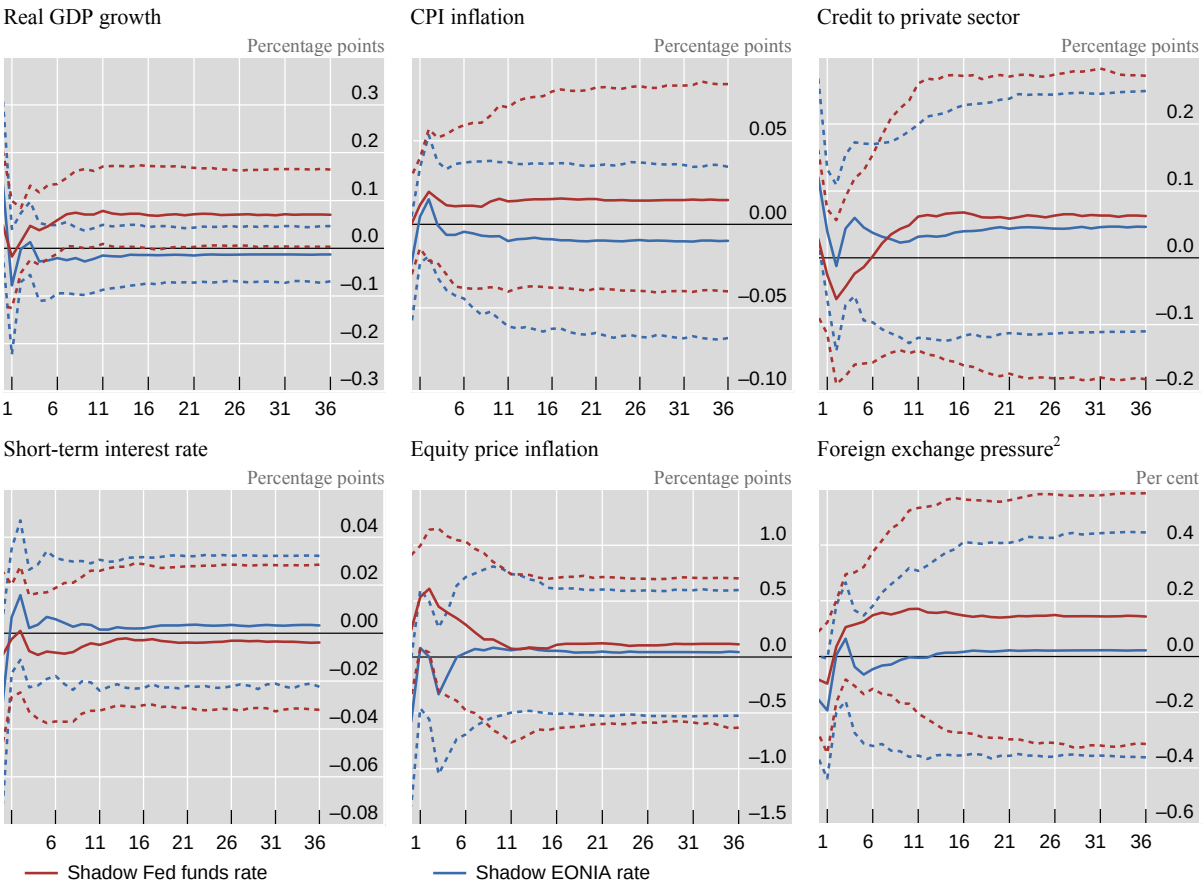
[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Wu and Xia (2013) shadow federal funds and Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

Impulse responses to US and euro area policy shocks[1]

Graph V.
8

Russia



[1] The estimates correspond to a sample period beginning in October 2008 and ending in June 2014. The solid lines represent the median estimates while the dashed lines represent the upper or lower bounds. The shocks to the US and euro area monetary policy correspond to a 25-basis-points reduction in the Wu and Xia (2013) shadow federal funds and Eonia rates, respectively. [2] A rise in foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated Global Vector Error Correction model.

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