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Financial Crisis, US Unconventional Monetary Policy and International Spillovers

by Qianying Chen, Andrew Filardo, Dong He, and Feng Zhu

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Prepared by Qianying Chen, Andrew Filardo, Dong He, and **Feng Zhu**[2]

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Abstract

We study the impact of the US quantitative easing (QE) on both the emerging and advanced economies, estimating a global vector error-correction model (GVECM) and conducting counterfactual analyses. We focus on the effects of reductions in the US term and corporate spreads. First, US QE measures reducing the US corporate spread appear to be more important than lowering the US term spread. Second, US QE measures might have prevented episodes of prolonged recession and deflation in the advanced economies. Third, the estimated effects on the emerging economies have been diverse but often larger than those recorded in the US and other advanced economies. The heterogeneous effects from US QE measures indicate unevenly distributed benefits and costs.

[1] The views expressed are those of the authors and do not necessarily represent the views of the Bank for International Settlements or the International Monetary Fund. We very much appreciate the comments by the journal referee, and the comments on the drafts of this and earlier versions from Jonathan Batten, Menzie Chinn, Dietrich Domanski, Alex Heath, Roong Mallikamas, Richhild Moessner, Shinobu Nakagawa, Patrizio Pagano, Eswar Prasad, John Taylor, Bernhard Winkler and the participants at the 9th Annual Hong Kong Institute for Monetary Research Summer Workshop, the 2011 Joint Workshop on Emerging Markets of the European Central Bank and the Deutsche Bundesbank, the 2012 EEA-ESEM meeting, the Bank of Canada 2013 conference on "International macroeconomic policy cooperation: challenges and prospects", the Bank of Korea Seminar on "Macro-financial linkages and macro-prudential policies" and the ECB-IMF conference on "International dimensions of conventional and unconventional monetary policy".

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Content

I. INTRODUCTION

1. The 2007–2009 US subprime mortgage crisis and the Great Recession have had a major impact on the design and implementation of monetary policy. Following the crisis, the Federal Reserve lowered the federal funds rate target rapidly to near zero, and has taken additional measures considered "unconventional" (Table 1).

2. The unconventional policy actions taken by central banks in a number of major economies have led to a burgeoning literature on their effectiveness. Most work has focused on their domestic effects and relied on event studies analysing the announcement effects of quantitative easing (QE) on asset prices: 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 Federal Reserve's and the Bank of England's large-scale asset purchase programs.

3. 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. Yet we know very little about the impact of the unconventional policies on real activity, and so far there has been little research on their cross-border spillovers, especially on emerging economies.[3]

4. 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 percent. Glick and Leduc (2012) show that commodity prices on average fell upon the announcements of US asset purchases, despite a decline in long-term interest rates and US dollar depreciation. Chen, Filardo, He and Zhu (2012, 2014a) 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. Chen, Filardo, He and Zhu (2014b) introduce estimated shadow federal funds rates in a global VAR to assess the domestic and global impact of US unconventional monetary policy. They find that US QE might not have only prevented US recessions but also had substantial global spillovers. 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.

5. 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

[3] To assess the macroeconomic effects of QE measures, Chen, Filardo, He and Zhu (2012, 2014a, b) estimate a global VAR model and Gambacorta, Hofmann and Peersman (2012) employ a panel VAR model. Hofmann and Zhu (2013) study the effects on inflation expectations of Federal Reserve asset purchases and find these were well-anchored and such purchases had little impact.

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. Moreover, Ostry and Ghosh (2013) consider uncertainties and disagreement about the cross-border effects of QE policies a major obstacle to policy coordination.

Table 1. The Federal Reserve's Large-Scale Asset Purchase (LSAP) Programs

	Announcement	Termination	Assets purchased	Amount[1]
LSAP1	Nov. 2008		Agency mortgage-backed securities (MBS) and agency debt	$600 billion
	Mar. 2009		Agency securities	$850 billion
		Mar. 2010	Longer-term US Treasury securities	$300 billion
LSAP2	Nov. 2010	Jun. 2011	Longer-term US Treasury securities	$600 billion
Maturity extension program (MEP)	Sep. 2011		US Treasury securities with remaining maturities of six to 30 years	$400 billion
	Jun. 2012	Dec. 2012	US Treasury securities with remaining maturities of six to 30 years	
LSAP3	Sep. 2012	Oct. 2014	Agency MBS	$40 billion per month[2]
	Dec. 2012	Oct. 2014	Longer-term US Treasury securities	$45 billion per month[2]

[1] Initially announced amount of asset purchases for each program or program expansion.

[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.

6. The second view argues that QE policies are less benign. Amongst 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. Besides concerns with competitive devaluation, Rajan (2013) highlights the potential danger of "competitive asset price inflation". 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. The cross-border effects of QE may also be perceived as beneficial or harmful by those affected, depending in large part on the cyclical position they find themselves in at the time when QE is adopted. There is a general consensus that that during the global financial crisis and the ensuing recession, QE policies helped to stabilize global financial markets and prevented an even further collapse in the global economic activity. As recovery languished in the advanced economies but gathered pace in the emerging economies, QE arguably contributed to

economic overheating and asset market excesses in some jurisdictions owing to the large currency appreciation and capital inflow pressures.[4]

7. In this paper, we study the macroeconomic effects of QE, both domestic and international, estimating a global vector error correction model (GVECM) covering 17 advanced and emerging economies, using monthly data spanning 2007–2013. Given the size of the GVECM and the limited data span, the elevated estimation uncertainty is reflected in the relatively large confidence bands. Our estimates suggest that the cross-border spillovers varied across economies and over time. We find that reducing the US corporate spread, and, to a lesser extent, the US term spread, had sizeable effects on financial conditions and economic activity both domestically and globally. Taken at face value, our counterfactual analysis indicates that US QE programs, especially LSAP1, were important counter-cyclical measures, apparently preventing the US and other advanced economies from prolonged recession and deflation.

8. The effects of US QE measures on the emerging economies are estimated to be generally larger and more diverse than those in the advanced economies. In our view, the strength of the effects depends partly on how each economy reacts to the US policy shocks, and partly on the distinct economic and financial structures, policy frameworks and exchange rate arrangements. Our estimates also suggest that US QE measures contributed to overheating in Brazil, China and some other emerging economies in 2010 and 2011, but supported recovery in these economies in 2009 and 2012. The diverse cross-border QE effects imply that the costs and benefits of US QE policies have been unevenly distributed between the advanced and emerging economies and have varied over time.

9. The paper is organized as follows. Section 2 describes the GVECM and provides empirical results on the cross-border impact of US QE measures with impulse responses to a US term or corporate spread shock estimated from a GVECM. Section 3 examines the domestic and spillover effects of US QE measures on financial and real activities, assessed with a counterfactual analysis based on the impulse response estimates. Section 4 concludes.

II. Estimating the Effects of US Unconventional Policies

10. To assess the domestic and foreign effects of US unconventional policies on real and financial activities, we employ a global vector error correction model (GVECM), developed by Pesaran, Schuermann and Weiner (2004), which is suited for capturing cross-border macro-financial linkages. We first estimate impulse responses for each economy using the GVECM. Based on these, we design counterfactual scenarios in which US QE measures are assumed to be absent, and evaluate their effects by comparing the "no-QE" projections to actual data.

A. GVECM Analysis: Model and Variables

11. The model is structured as follows.[5] For economy i, the model VECM* (p_i, q_i) can be written as:

[4] See BIS (2012) and De Nicolò, Dell'Ariccia, Laeven and Valencia (2010).

$$\Delta \mathbf{x}_{it} = \mathbf{c}_{0i} + \mathbf{c}_{1i} \cdot t + \mathbf{\Pi} \cdot \tilde{\mathbf{z}}_{i,t-1} + \sum_{s=1}^{p_i-1} \mathbf{\Psi}_{is} \cdot \Delta \mathbf{z}_{i,t-s} + \mathbf{\Gamma}_i \cdot \Delta \mathbf{x}_{it}^{*} + \sum_{s=0}^{r_i-1} \Lambda_{is} \cdot \Delta \mathbf{d}_{t-s} + \boldsymbol{\varepsilon}_{it}, \tag{1}$$

with $\boldsymbol{\varepsilon}_{it} \overset{iid}{\sim} (0, \sum_i)$, $z_{it} = (\mathbf{x}_{it}', \mathbf{x}_{it}^{*\prime})'$, and $\tilde{z}_{it} = (\mathbf{x}_{it}', \mathbf{x}_{it}^{*\prime}, \mathbf{d}_t)'$ (2)

where $\boldsymbol{d}_{t-s}$is the observed global factor, e.g. the CBOE Volatility Index (VIX). For every non-US economy i, we have

$$\mathbf{x}_{it} = (\Delta y_{it}\ \pi_{it}\ mp_{it}\ \Delta bc_{it}\ sp_{it}\ emp_{it})' \tag{3}$$

and

$$\mathbf{x}_{it}^{*} = (\Delta y_{-i,t}\ \pi_{-i,t}\ mp_{-i,t}\ \Delta bc_{-i,t}\ sp_{-i,t}\ emp_{-i,t})' \tag{4}$$

12. Each country VECM consists of six domestic endogenous variables: real GDP growth (⊿y), the CPI inflation rate (π), a monetary policy indicator (mp), credit growth (⊿ bc), equity price (sp) and foreign exchange pressure index (emp). The model is then augmented with a set of foreign variables which include, e.g. foreign real GDP growth and the VIX.[6] Except for the VIX, the foreign variables are constructed as the weighted averages of the corresponding variables in all other economies, and they are assumed to be weakly exogenous.

13. For the US bloc, we include the same set of domestic variables as in the other economies, but only the non-US real GDP growth as a foreign variable. Given the importance of the United States in the global economy, we do not treat the other foreign variables, especially the financial variables, as weakly exogenous in the US bloc. Therefore the VIX is treated as endogenous in the US bloc:

$$\mathbf{x}_{US,t} = (\Delta y_{US,t}\ \pi_{US,t}\ mp_{US,t}\ \Delta bc_{US,t}\ sp_{US,t}\ emp_{US,t}\ vix_t)' \tag{5}$$

and

$$\mathbf{x}_{US,t}^{*} = \Delta y_{-US,t} \tag{6}$$

14. Blinder (2010) suggests that central banks use unconventional tools to reduce interest rate spreads such as "term premiums and/or risk premiums", buying long-term Treasuries or using QE to target "risk or liquidity spreads". The rationale is that "since private borrowing, lending, and spending decisions presumably depend on (risky) non-Treasury rates, reducing their spreads over (riskless) Treasuries reduces the interest rates that matter for actual transactions even if riskless rates are unchanged." We therefore describe the Federal Reserve's unconventional measures, especially the large-scale purchases of

[5] We provide further details on the structure of the GVECM and on variables and data in Appendices A-D.

[6] The VIX, a key measure of market expectations of near-term volatility conveyed by S&P 500 stock index option prices, provides a good measure of financial market developments.

sovereign (e.g. Treasuries) and private (e.g. agency MBS) assets, with two monetary policy "indicators": the US term spread between the 10-year and three-month Treasury yields; and the US corporate spread between the BofA Merrill Lynch US corporate AAA bond yield and the effective federal funds rate.

15. Admittedly, the term and corporate spreads may reflect information beyond that captured by US monetary policy, given that these spreads are important barometers of US financial sector health. But even in normal times, the term spread is considered a useful indicator, as central banks act to shape expectations of a specific interest rate path well into the future. At the zero lower bound (ZLB), the funds rate loses its information content; however, the two spreads continue to reflect the immediate objectives (and impact) of US QE measures, namely, to reduce longer-term Treasury yields, lower borrowing costs for corporates and households and restore credit flows. Purchasing Treasuries and agency MBS are expected to reduce long-term Treasury yields directly and corporate bond yields via portfolio rebalancing.[7]

16. For the other advanced economies, which have faced the ZLB and implemented unconventional measures, we use the spread between 10-year and three-month government bond yields for the United Kingdom and Japan as the monetary policy indicator, and the spread between the 10-year government bond yield and the main refinancing rate for the euro area. For the emerging economies, we describe monetary policy with the growth rates in a broad monetary aggregate, as their central banks tend to use a wide range of policy tools and a broad monetary aggregate may be the more robust indicator for monetary policy.

17. We measure stress on an economy's currency by computing an exchange rate pressure index as a weighted average of changes in the nominal effective exchange rates and in foreign exchange reserves. The index is a variant of the index proposed by Eichengreen, Rose and Wyplosz (1995), taking into account different exchange rate regimes as well as policy interventions by the respective governments.

18. One notable feature is our modelling of cross-country linkages using both the financial and trade linkages, similar to Chen, Gray, N'Diaye, Oura and Tamirisa (2010) and Eickmeier and Ng (2011). We gauge the strength of the time-varying financial interdependence across economies based on the flow data from the Bank for International Settlements' (BIS) consolidated bank lending statistics. In the construction of the foreign variables for an economy, the weights on trade and financial linkages are determined by the relative importance of trade and financial flows in that economy (see Appendix C). Our robustness analysis indicates that varying their relative weights does not significantly change the results.

[7] Chen, Filardo, He and Zhu (2012) use corporate and term spread reductions to study the impact of US QE measures, and Kapetanios, Mumtaz, Stevens and Theodoridis (2012) and Pesaran and Smith (2012) evaluate the effects of UK QE approximating it with a 100-basis-point reduction in UK term spreads or in the medium- to long-term government bond yields.

19. In addition, we use a new series of BIS total credit to the non-financial private sector.[8] The BIS series on average has a span of 45 years and is available for 40 advanced and emerging economies.[9] The database accounts for credit from all sources, not only that extended by domestic banks.

B. GVECM Analysis: Impulse Responses

20. To estimate the impulse responses, we identify the monetary policy shocks using a recursive Cholesky scheme, with the following ordering of the endogenous variables in the US VECM: real GDP growth, CPI inflation, monetary policy indicator, VIX index, equity price inflation, credit growth, and foreign exchange pressure. The ordering is consistent with the existing VAR literature. Having explored a number of alternative orderings, we find our results largely robust. In addition, we follow Dees, di Mauro, Smith and Pesaran (2007) by assuming that the US economy affects but does not respond to developments in other economies contemporaneously. This is equivalent to placing the US model as the first country bloc in the GVECM.

21. We estimate two different GVECMs, one with the term spread as the monetary policy indicator for the advanced economies, the other with the corporate spread. Correspondingly, we have two sets of results, one for the US monetary policy shock in terms of the term spread and the other in terms of the corporate spread.

22. The GVECMs are estimated for the crisis period starting from the outbreak of the US subprime mortgage crisis in July 2007 to February 2013,[10] for four advanced economies: the United States, the euro area, Japan and the United Kingdom; nine emerging Asian economies: China, Hong Kong SAR, India, Indonesia, South Korea, Malaysia, the Philippines, Singapore and Thailand; and four Latin American economies: Argentina, Brazil, Chile and Mexico.

Domestic effects of US term and corporate spread shocks

23. Figure 1 presents two sets of impulse responses for the US economy. One set refers to responses to a one-standard-deviation cut in the US term spread of 14.2 basis points, the other to a one-standard-deviation (20.7 basis points) reduction in the US corporate spread.

[8] 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 2008. In terms of financial instruments, credit covers loans and debt securities.

[9] Details of the new BIS credit series can be found at: www.bis.org/statistics/credtopriv.htm. Also see Dembiermont, Drehmann and Muksakunratana (2013).

[10] We focus on the period following the crisis, when the Federal Reserve implemented unconventional monetary policy measures. This sample period better captures the more recent domestic and international transmissions, which might have changed after the crisis. Chen, Filardo, He and Zhu (2012, 2014a) provide estimates for the pre-crisis period from February 1995 to June 2007.

24. Notably, as in many studies based on the global VAR models, the confidence bands tend to be wide.[11] This is largely due to the limited degrees of freedom in the estimation with many variables having relatively short time spans. Our confidence bands are subject to the same limitation, since we focus on the crisis period where the data sample is very short and the economic and policy uncertainties are particularly elevated.[12] To improve accuracy, we exclude from the estimation of each country model those foreign variables considered less likely to affect or be affected by the economy.

25. Several interesting results emerge. First, US credit growth begins to have a statistically significant and persistent positive response to a term spread shock in six months' time: a credit channel might be present as a 14.2-basis-point cut has sustained credit growth of over 0.3 percentage points higher thereafter. However, the term spread reduction typically has small and not statistically significant effects on US output growth, and it lowers CPI inflation and equity prices initially. It also raises the VIX by over 6 percent initially, with statistically significant effects in the first three months after the shock. This suggests that a decline in the US term spread may be perceived negatively by markets, for example as a harbinger of less encouraging prospects.

26. Second, estimates based on the corporate spread model suggest that different channels might be at play. Lowering the term spread has less impact on output, and over time it depreciates the US dollar. In contrast, a 20.7-basis-point reduction in the US corporate spread has a strong, positive and statistically significant impact on US growth, elevating real GDP growth by 0.2 percentage points throughout the three-year horizon. A cut in the US corporate spread consistently boosts equity price and CPI inflation, but it raises credit growth by less than 0.1 percentage points, and it has little impact on the exchange rate.[13]

27. Consistent with the findings in Blinder (2012),[14] it apparently pays off to take actions that target corporate borrowing costs rather than indirectly driving down such costs by purchasing Treasury securities to lower long-term sovereign yields. This corroborates the earlier findings in the literature that LSAP1 had a larger impact than later asset purchases,[15] since the LSAP1 program included an important component of private asset purchases (i.e. agency debt and agency MBS)

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[11] Examples include Pesaran and Smith (2006) and Dees, di Mauro, Smith and Pesaran (2007), where the 90 percent bootstrapped error bands around the mean estimates of impulse responses are generally large and include zero. Chudik and Fratzscher (2012) instead use the 25th and 75th percentiles as the range of their error bands.

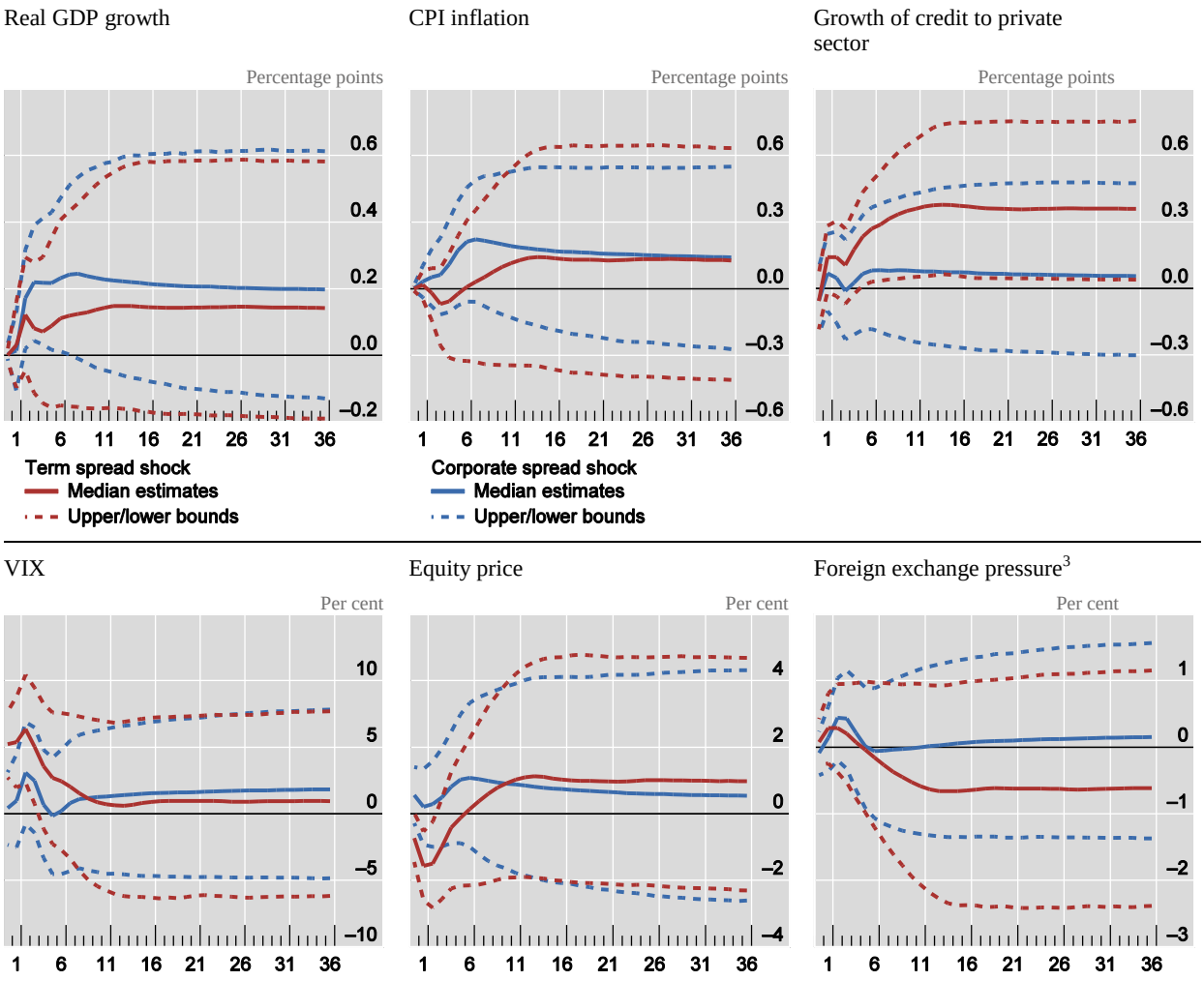
[12] We compute bootstrap confidence intervals with 5000 iterations and provide 90 percent bootstrapped error bands for the median impulse response estimates.

[13] The persistent response of real GDP growth (and other variables) to a term- or corporate-spread shock may reflect our choice of not imposing money neutrality while identifying the monetary policy shock in our GVECM, where the real GDP growth is an I(1) process in most economies.

[14] Blinder (2012) argues that "this particular brand of unconventional monetary policy (purchases of private-sector securities to reduce risk premiums) appeared to work very well in the cases of CP and MBS. But, of course, the risk spreads were then at crisis levels. One cannot expect such strong effects under more normal market conditions. That said, every private debt market is less deep and less liquid than the Treasury markets. So it is reasonable to expect more interest rate 'bang' for each 'buck' of asset purchases."

[15] See, for example, Meaning and Zhu (2011) and Goodhart and Ashworth (2013).

Figure 1. Impulse Responses to US Term and Corporate Spread Shocks: United States[1,2]



[1] The estimates correspond to the crisis sample ranging from July 2007 to February 2013.

[2] The US term spread shock is a one-standard-deviation (i.e. 14.2 basis points) negative innovation to US term spread, and the US corporate spread shock is a one-standard-deviation (i.e. 20.7 basis points) negative innovation to US corporate spread. [3] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

C. Cross-Border Monetary Policy Spillovers

28. We study the cross-border impact of US QE measures using the weighted regional average impulse responses to a one-standard-deviation shock to US term (14.2 basis points) and corporate (20.7 basis points) spreads for the other major advanced economies, emerging Asia and Latin America.[16] Figure 2 presents, for each individual economy, the corresponding

[16] The impulse responses in each region are presented as the weighted averages of the median impulse response estimates of the regional economies, the weights being their real GDP shares in the region, based on each economy's average real GDP between 1995 and 2013. The weights are similar to those calculated for 2007-2013. The averaging masks sizeable cross-economy differences, and the "averaged" confidence bands are no longer valid for the average estimates.

maximum impulse responses to a reduction in the US corporate spread; and Tukey boxplots in Figure 3 provide information on their dispersion in each region.

29. Depending on whether it is a term or corporate spread shock, the non-US economies' responses vary in terms of the size and direction. The responses to a US corporate spread shock are typically much larger. In particular, a cut in the US corporate spread tends to promote persistently higher real GDP growth and inflation in all three regions, with greater impact in a number of Latin American and emerging Asian economies. This might have resulted from stronger responses in equity prices, i.e. the cross-border confidence channels may work better when monetary policy measures focus on driving down the US corporate rather than the term spread. In addition, lowering the US corporate spread also leads to typically larger exchange rate appreciation pressure in Latin America and emerging Asia, implying a stronger exchange rate channel in the QE spillovers to the emerging economies.

30. The effects of US QE measures have differed across economies and variables, with substantial cross-region differences in the impulse responses to the US spread shocks, notably in terms of monetary and exchange rate policies. This may indicate different transmission and adjustment mechanisms in different economies. While monetary policy loosens in the advanced economies in response to a US term or corporate spread shock, the emerging economies respond to different types of US easing in different ways. Notably, besides Argentina, Malaysia and Singapore, monetary policy in most emerging economies tend to loosen in response to a cut in the US corporate or term spread. More emerging economies tend to loosen in response to a cut in the US corporate spread. Currencies in the advanced economies on average depreciate in response to a US term spread shock. But appreciation pressures tend to rise in Latin America following a cut in the US term or corporate spread, which turn out to be larger. But some emerging Asian currencies tend to depreciate while others tend to appreciate.

31. The estimated impulse responses for each economy generally confirm the results based on the regional averages, but there are sizeable cross-economy differences. To illustrate this, we first provide some measures of dispersion, e.g. the range and inter-quartile range, in the estimated maximum impulse responses over a two-year horizon for the 17 economies; we then describe and differentiate the results for the euro area, Brazil and China, the largest economies from each of the three groupings.

32. Figure 3 presents Tukey boxplots, which summarise the within-region cross-economy dispersion in each variable's estimated impulse responses; the responses are to a one-standard-deviation reduction in the US term (14.2 basis points) and corporate spread (20.7 basis points). The bottom and top of the boxes indicate the 25th and 75th percentiles of the maximum impulse response estimates in each region, the bottom and top whiskers represent the range of the estimates, and the cross indicates the median.

33. The maximum impulse response estimates deliver generally similar messages. In both cases, the within-region dispersion is sizeable and the estimates differ both in size and sign; in most cases, the range of impulse response estimates for the emerging economies includes zero. Moreover, the median estimates, e.g. for the output growth, credit growth, equity price and foreign exchange pressure, tend to have the expected sign, especially in the case of a reduction in the US corporate spread. For equity prices, while the median estimates are all

positive in the case of a cut in the US corporate spread, the median responses to a reduction in the US term spread are negative. This is due to an initial drop in the equity prices which turned out to be larger than their later persistent rise.

34. Comparing the three regions, the estimates in the non-US advanced economies typically have a much smaller dispersion, possibly reflecting more similar economic structures and a higher degree of economic and financial integration, as well as a smaller number of economies in the group (Figure 2). In contrast, impulse response estimates for the emerging economies tend to have larger dispersions. Second, the dispersion is generally greater for the estimated impulse responses to a shock to the US corporate rather than term spread, except for equity price and foreign exchange pressure. We focus our discussions on the impulse response estimates for three economies: the euro area, Brazil and China.[17]

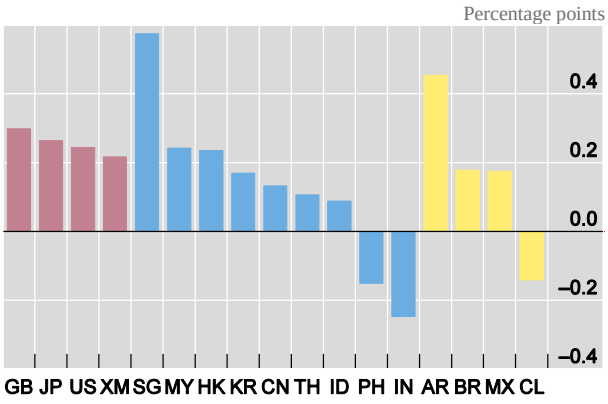
35. A US easing raises euro area inflation. Following a 14.2-basis-point cut in the US term spread, the euro area term spread falls significantly and stays lower by over 10 basis points during most of the three-year horizon. The almost one-to-one response shows a tight relationship between the two economies. A 20.7-basis-point cut in the US corporate spread also lowers the euro area term spread. It drives up euro area credit and output growth by about 0.1 and 0.2 percentage points, respectively. Euro area equity price inflation rises by over 1 percentage point in four months. Reducing the US corporate spread depreciates the euro by about 0.5 percentage points, but lowering the US term spread has little effects on the euro exchange rate.

36. In Brazil, while money growth rises in response to a US term spread shock, it falls in response to a US corporate spread shock. The Brazilian equity price rises slightly and then stays almost unchanged after an initial decline of up to 2.4 percent upon a US term spread shock, but it rises consistently at 1.2 percent or more four months after a cut in the US corporate spread. Credit and output growth generally accelerate and currency appreciation pressure rises following a US easing, with a stronger eventual impact from the US corporate spread shock.

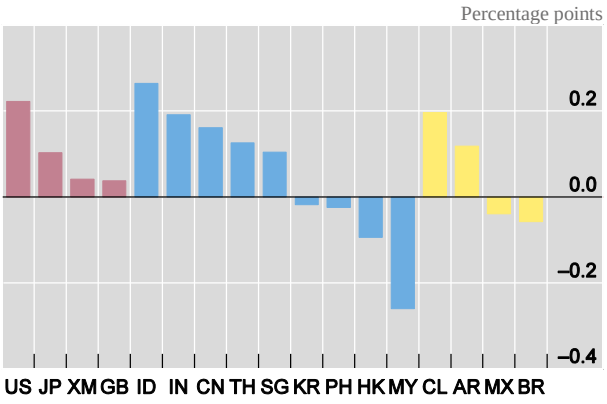
[17] The impulse response estimates for all 17 economies, with the respective confidence bands, are available upon request. They tend to be large in many cases, but often not significantly different from zero due to the estimation difficulties with large-scale GVECMs and the small crisis sample.

Figure 2. Maximum Impulse Responses to a US Corporate Spread Shock[1]

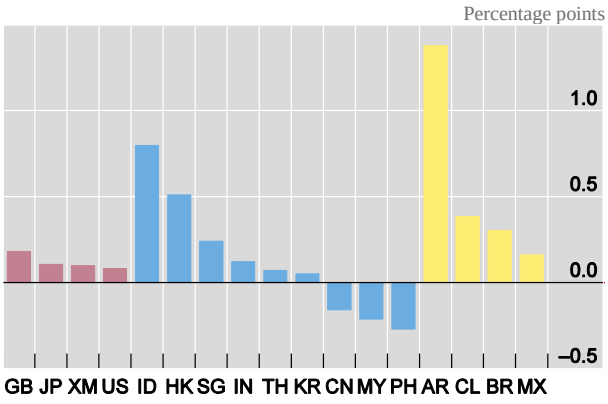
Real GDP growth



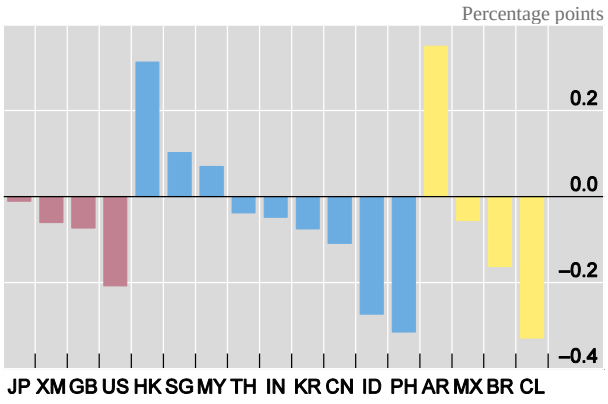
CPI inflation



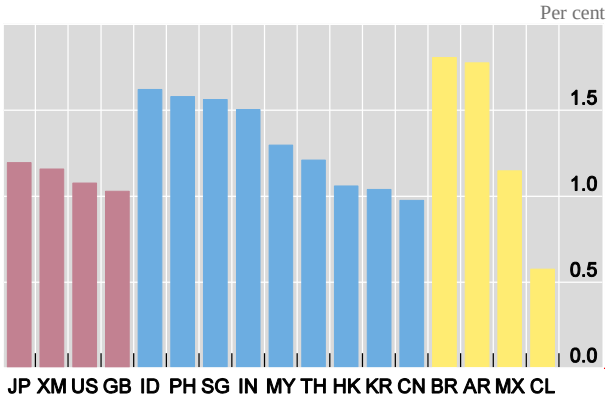
Credit growth to the private sector



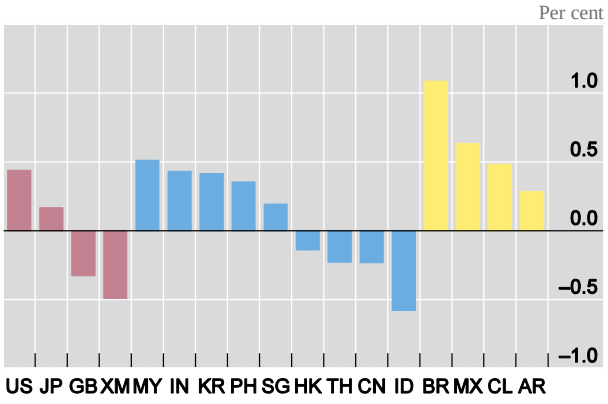
Monetary policy indicator[2]



Equity price



Foreign exchange pressure[3]

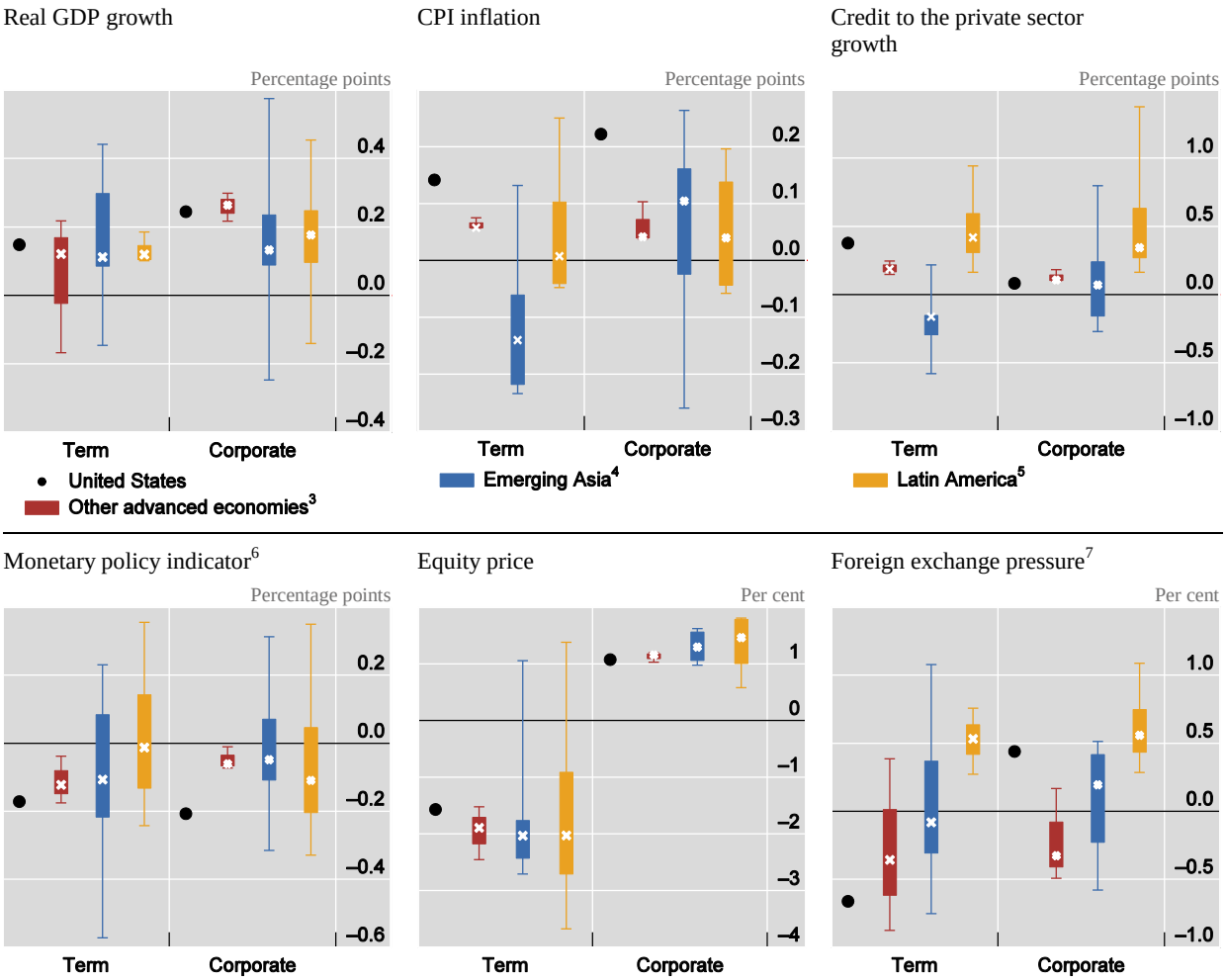


AR = Argentina; BR = Brazil; CL = Chile; CN = China; GB = United Kingdom; HK = Hong Kong SAR; ID = Indonesia; IN = India; JP = Japan; KR = Korea; MX = Mexico; MY = Malaysia; PH = Philippines; SG = Singapore; TH = Thailand; US = United States; XM = Euro area.

[1] The US corporate spread shock is a one-standard-deviation (i.e. 20.7 basis points) negative innovation to the corporate spread. [2] For monetary policy indicators, we use corporate or term spreads for the advanced economies, and growth rates of a broad monetary aggregate for emerging economies. [3] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

Figure 3. Distribution of Maximum Impulse Responses to US Term and Corporate Spread Shocks[1,2]



[1] The US term spread shock is a one-standard-deviation (i.e. 14.2 basis points) negative innovation to the US term spread, and the US corporate spread shock is a one-standard-deviation (i.e. 20.7 basis points) negative innovation to the US corporate spread. [2] 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 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] For monetary policy indicators, we use term and corporate spreads for the advanced economies, and the growth rates of a broad monetary aggregate for the emerging economies. [7] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

37. China's estimated policy responses to US stimulus differ depending on the nature of the US shock. Following a cut in the US term spread, China's money and credit growth rates drop by 0.2 and 0.3 percentage points in the second month after the shock, they then turn slightly positive in a few months before a persistent decline. In response to a drop in the US corporate spread, however, the money and credit growth rates rise modestly for about six months before falling persistently thereafter. For both shocks, the Chinese yuan faces persistent depreciation pressures due to its close association with the US dollar, but the pressure is greater during the first 20 months following a cut in the US corporate spread, being significant and reaching 0.23 percentage points in one month.

38. The evidence suggests that reducing the US corporate spread is more accommodative overall for the Chinese economy, even though China tends to lean against it with monetary and credit policies. Real GDP growth increases significantly and rapidly by 0.13 percentage points following a 20.7-basis-point cut in the US corporate spread, despite an initial drop, and eventually, inflation rises persistently by about 0.16 percentage points. The output response to a US term spread shock is smaller, and the inflation response is mostly negative. Equity price rises following a US corporate spread shock, and it generally falls after a US term spread shock.

39. One interesting finding is that US QE measures turn out to have a greater impact on economic and financial variables in many emerging economies than on the US economy. This is consistent with previous work. For example, Mackowiak (2007) finds that US monetary policy shocks in the pre-crisis period quickly and strongly affect interest and exchange rates in a typical emerging economy, and price and real output there respond more than the US counterparts. This evidence supports the view that cross-border monetary policy spillovers cannot be dismissed as insignificant by-products of little consequence for the global economy. As Rajan (2013) puts it, "even if the unconventional monetary policies that focus on lowering interest rates across the term structure have limited effects on interest rates in the large, liquid, sending country Treasury markets, the volume of flows they generate could swamp the more illiquid receiving country markets, thus creating large price and volume effects".

Robustness check

40. The results of impulse response analyses are robust to different model specifications and variable definitions, including the use of base money growth instead of broad money growth, the use of the federal funds rate instead of the three-month US Treasury bill rate to calculate the US term spread, and the use of the three-month US Treasury bill rate instead of the federal funds rate to calculate the US corporate spread. The results are also robust to alternative orderings of the variables in the identification scheme for the shocks to the US term and corporate spreads.

III. GVECM-BASED COUNTERFACTUAL ANALYSIS

41. We conduct counterfactual analyses to evaluate the domestic and global impact of US QE measures. We construct two counterfactual scenarios based on US corporate spread developments.[18] We then make conditional forecasts for model variables based on the assumption that the US corporate spread follows a predetermined counterfactual path. By comparing these projections to the actual data, we can assess the overall impact on the global

[18] We present the results for the counterfactual analysis based on US corporate spread developments, given that their economic effects are larger. Details on the counterfactual analysis based on US term spread developments can be provided upon request.

economy of the US QE measures, and the separate impacts of the LSAP1, LSAP2, MEP and LSAP3 programs.[19]

42. The counterfactual analysis is based on the estimated GVECM model and one-step-ahead projections. Specifically, equation (8) in Appendix A illustrates how an endogenous variable x_t can be expressed as the sum of the lagged explanatory variables (both domestic and foreign) multiplied by the corresponding parameter estimates, plus the estimated residuals. Given the values of all model variables up to time t, and conditional on the time-t counterfactual value of the corporate spread, we obtain the one-step-ahead forecasts for the endogenous variables ($\hat{x}_t^{t+1}$). In the next step, we use the forecasts $\hat{x}_t^{t+1}$ and the time t+1 counterfactual value of the corporate spread to obtain the time t+2 forecasts ($\hat{x}_{t+1}^{t+2}$), and so on. The forecasts of each endogenous variable therefore depend on the past forecasts of the other variables and the specified US monetary policy path.

43. We design two different counterfactual scenarios:[20]

1. ***Constant scenario***: we assume that the US corporate spread remains constant within each period of the QE program, at the level seen immediately before the implementation of each US asset purchase program, namely LSAP1, LSAP2, MEP and LSAP3;
2. ***Jump scenario***: we assume the US corporate spread jumps by 200 basis points at the start of each QE program, thereafter it stays above the actual values during the entire program.

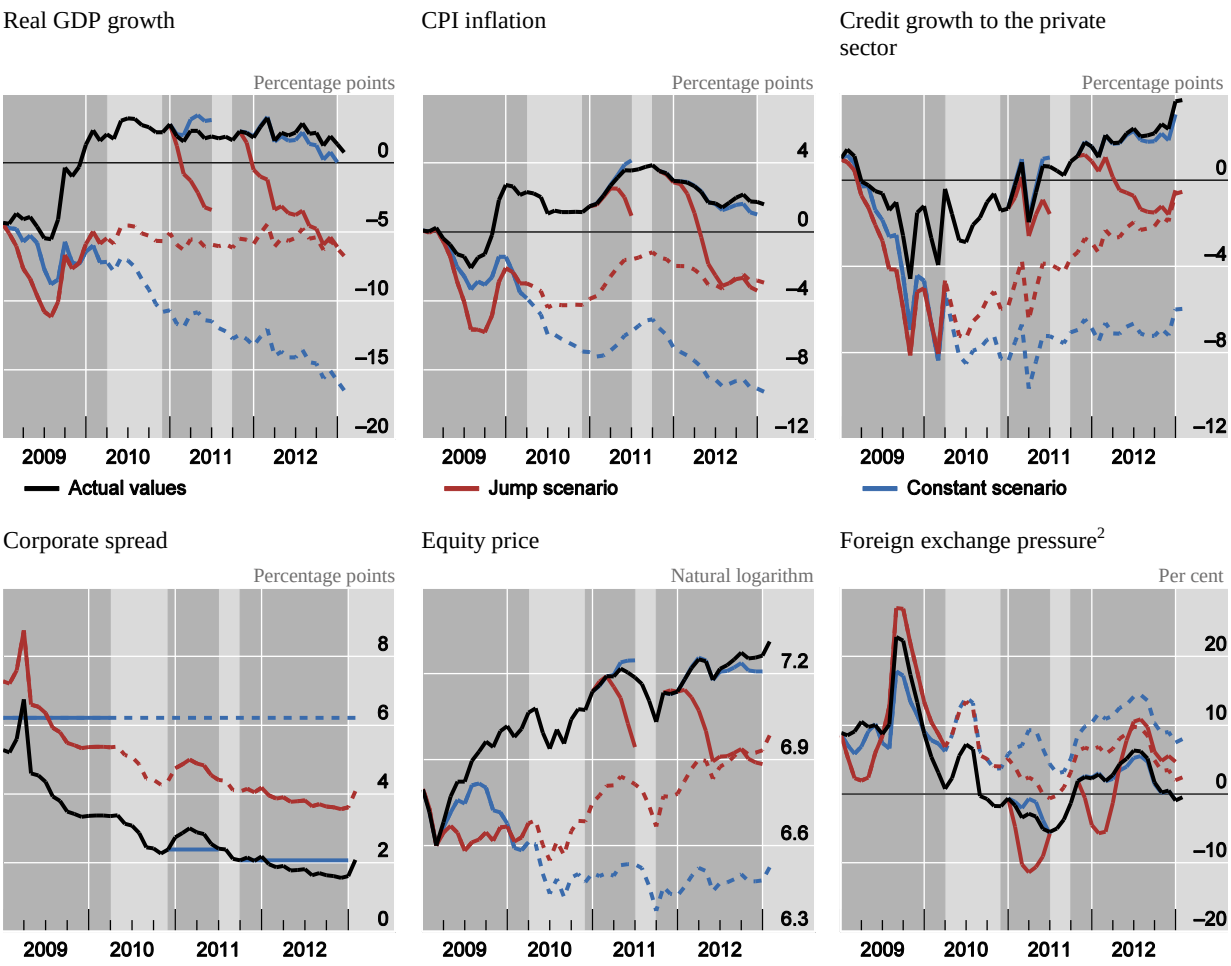
44. Figure 4 shows both the actual and the two counterfactual paths for the US corporate spread.

45. Our counterfactual analyses suggest that US QE measures had sizeable domestic effects, and such effects varied substantially depending on whether the measures led to a substantial fall in the US corporate spread. In cases where the Federal Reserve asset purchases kept the US corporate spread at a low level relative to the baseline, such actions appeared to have contributed to stronger US economic recovery.

[19] In doing this exercise, we need to bear in mind that the actual data could also reflect many other factors affecting the global economy; these may include supply-side shocks such as euro area sovereign debt crisis, large fiscal stimulus in China, and commodity price fluctuations.

[20] We also examine an "increasing scenario", in which the US corporate spread is assumed to rise by 10 basis points, in each and every month during each QE program. As the results are similar, we only present the results associated with the "constant" and "jump" scenarios.

Figure 4. Counterfactual Analysis of Domestic US QE Impact: US Corporate Spread[1]



[1] The grey areas indicate the periods of implementation of LSAP1, LSAP2 and MEP. The black lines are actual values. The red lines are the values associated with the jump scenario where the US corporate spread jumps by 200 basis points and stays 200 basis points above the actual levels throughout the respective QE program, and the blue lines depict the scenario where the US corporate spread stays equal to the actual level observed just before the QE program. [2] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

46. Figure 4 presents the dynamics of US economic and financial variables under the "constant" and "jump" scenarios for the US corporate spread.[21] The counterfactual exercise, at face value, indicate that without QE, especially the purchases of agency MBS and agency debt which helped to lower the US corporate spread, the US economy would have remained mired in a recession with deflation. The "jump" scenario suggests that asset purchases may have supported higher real GDP growth by about 8 percentage points, and inflation by over

[21] Notice that during LSAP1, the US corporate spread actually drifted back up midway through the program to levels higher than when LSAP1 began, and then kept climbing during LSAP2 (Figure 4). This can be interpreted to suggest that the LSAP1 and LSAP2 programs had a transitory impact on the US corporate spread, and would raise questions about whether the "constant" scenarios are truly "stress" scenarios. Another possible explanation is that other factors such as adverse supply shocks or further financial sector strains could have diluted the effects of the asset purchases and pushed the US corporate spread higher than otherwise.

5 percentage points. Equity prices would have been much lower without the QE measures. The "constant" scenario indicates even greater effects. In addition, while the "jump" scenario points to appreciation pressures on the US dollar during much of the implementation of each program, cumulatively the programs exerted sizeable depreciation pressures. Moreover, the counterfactual exercise indicates that the programs actually slowed credit growth.

47. In sum, the counterfactual exercises suggest that the domestic effects of different US QE measures were diverse. In the model, QE programs which reduced the US corporate spread delivered a sizeable stimulus to US output growth and equity markets and led to substantial currency depreciation. If the counterfactual exercise is seen as a reasonable approximation to what would have happened, the findings suggest that QE programs helped to prevent the US economy from sliding into a prolonged recession with severe deflation. The results suggest that if policymakers aim to lower private-sector borrowing costs and stimulate growth, it pays to design programms to influence the corporate spread.

A. Spillovers from Reductions in the US Corporate Spread

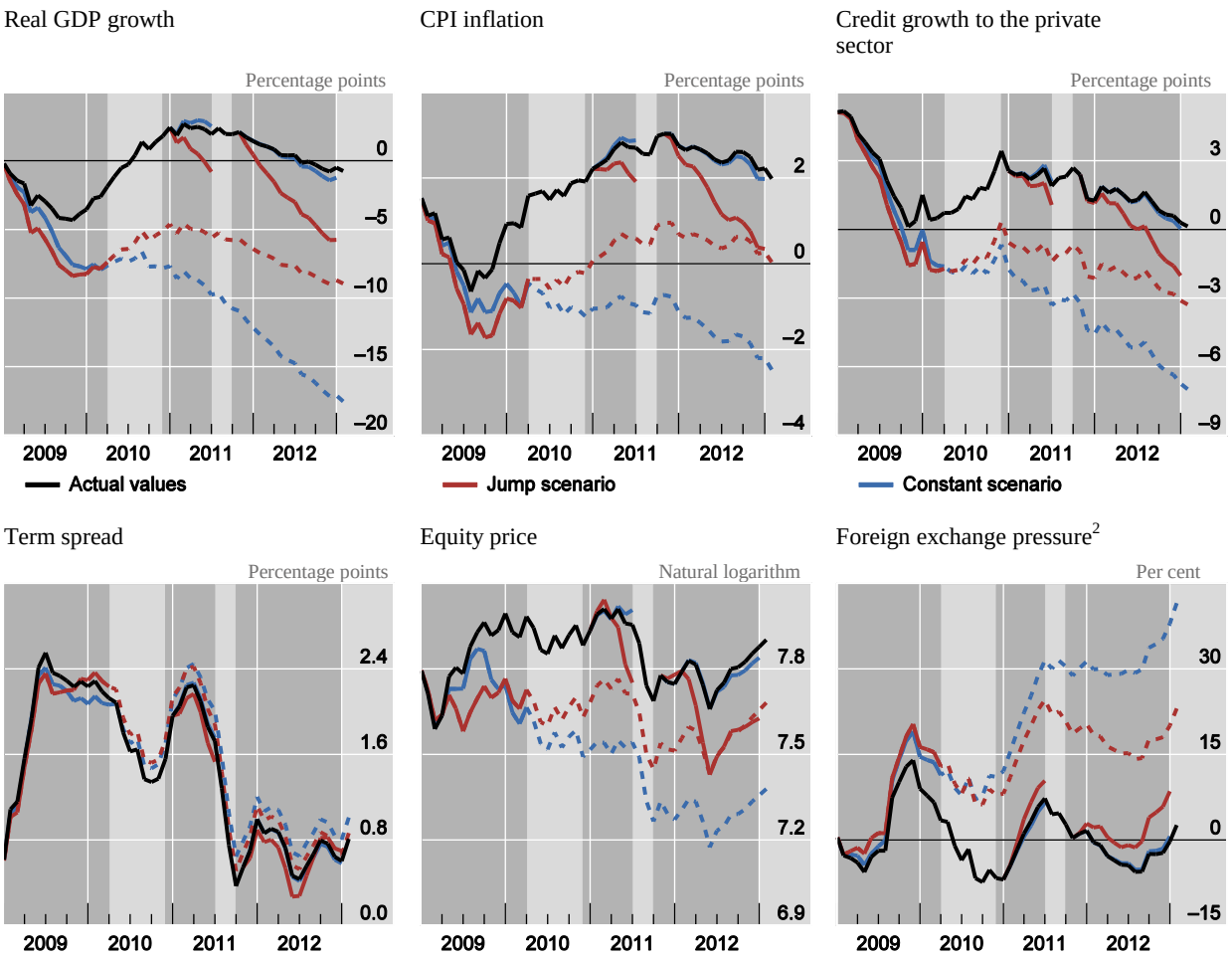
48. The results in this section show that the cross-border spillover effects from US QE policies that reduce the US corporate spread are sizeable. We present the results on the euro area, Brazil and China.

49. In the counterfactual analysis, US unconventional policies are estimated to have had an important impact on the euro area (Graph 3.2.1): the lower US corporate spread is estimated to have supported euro area credit and output growth, with the impact ranging from 3 and 8 percentage points (jump scenario) to 7 and 16 percentage points (constant scenario), respectively, significantly boosting equity prices.

50. The analysis also suggests that US QE measures had even greater spillover effects on the emerging economies, again much through the reduction in the US corporate spread. The estimated impact tended to be diverse across economies and across variables, which may reflect diverse policy responses, exchange rate regimes and economic structures.

51. The evidence from the counterfactual exercise also suggests that lowering the US corporate spread stimulated Brazil's output growth while having little impact on inflation. Arguably, this evidence suggests that LSAP1 helped the Brazilian economy recover rapidly from the 2009 recession, and that MEP and LSAP3 might have helped Brazil avoid a possible recession in 2012. But LSAP2 began when Brazil's output growth reached a peak of almost 8 percent, and therefore might be interpreted as having contributed to Brazil's overheating at the time. These Brazilian episodes highlight that the perception of monetary policy spillovers may be influenced by the receiving country's cyclical position.

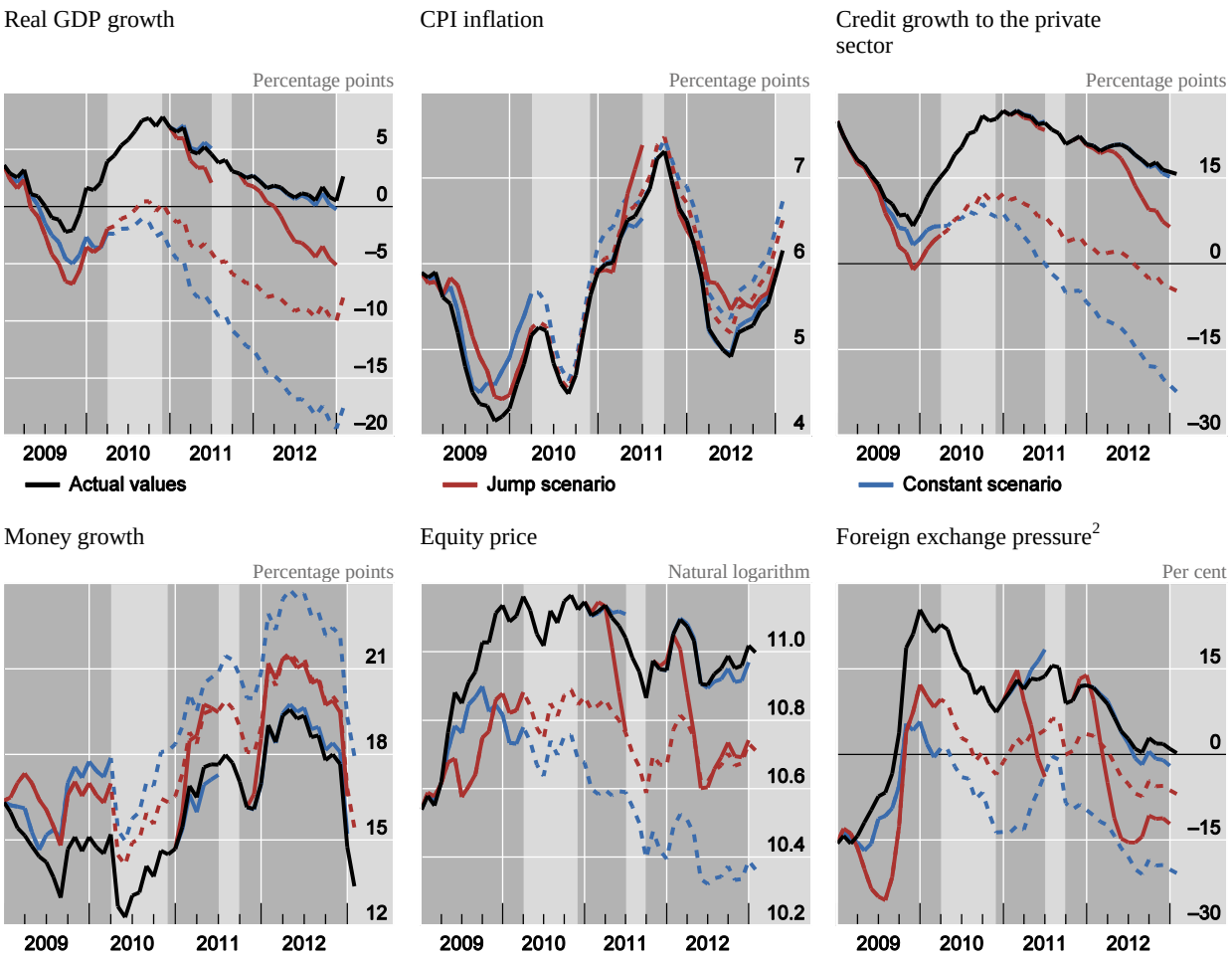
Figure 5. Counterfactual Analysis of Euro Area Impact: US Corporate Spread[1]



[1] The grey areas indicate the periods of implementation of LSAP1, LSAP2 and MEP. The black lines are actual values. The red lines are the values associated with the jump scenario where the US corporate spread jumps by 200 basis points and stays 200 basis points above the actual levels throughout the respective QE program, and the blue lines depict the scenario where the US corporate spread stays equal to the actual level observed just before the QE program. [2] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

Figure 6. Counterfactual Analysis of Impact in Brazil: US Corporate Spread[1]



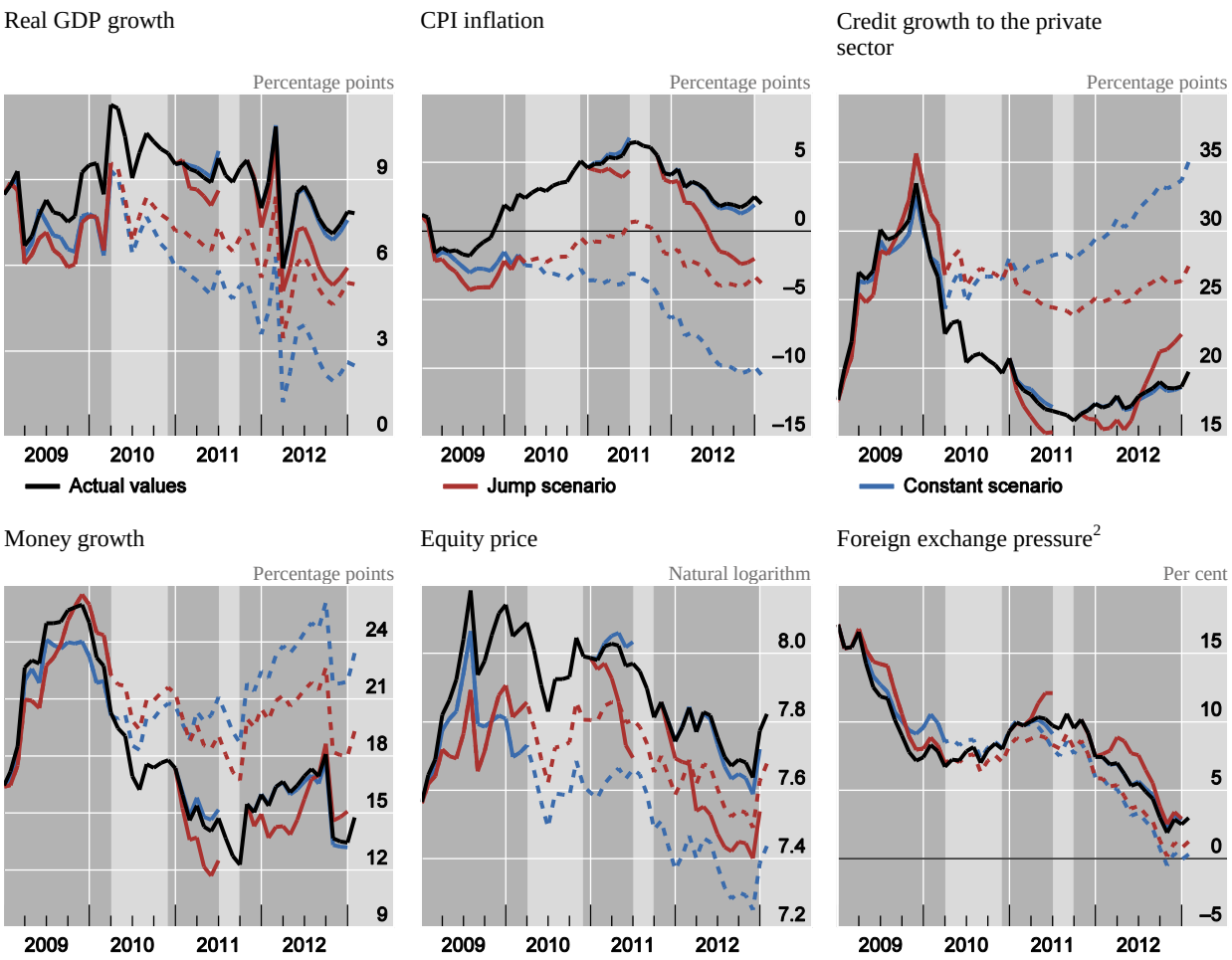
[1] The grey areas indicate the periods of implementation of LSAP1, LSAP2 and MEP. The black lines are actual values. The red lines are the values associated with the jump scenario where the US corporate spread jumps by 200 basis points and stays 200 basis points above the actual levels throughout the respective QE program, and the blue lines depict the scenario where the US corporate spread stays equal to the actual level observed just before the QE program. [2] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

52. The counterfactual exercise provides evidence that US QE programs had an expansionary spillover to the Chinese economy, but lower US corporate spreads were less expansionary than in the case of Brazil, with China's real GDP growth being boosted by 2.5 (jump) to 5.5 (constant) percentage points by the end of 2012 (Figure 7). One possible reason for the weaker impact is the apparently tighter Chinese monetary and credit conditions that accompanied the lowering of the US corporate spread: cumulatively, money and credit growth were estimated to be lower by up to 8 and 15 percentage points, respectively, compared to the jump and constant counterfactuals. As well, currency appreciation pressures rose moderately relative to the counterfactuals since mid-2010. Taken together, the evidence suggests that the responses in money growth, credit growth and exchange rate pressure tended to offset the accommodative spillover effects from the US monetary stimulus. However, as in the case of Brazil, the timing of the estimated spillover from US monetary

policy suggests that it contributed to China's overheating, i.e. when China's output growth exceeded 9 percent in 2010–11, and inflation was over 5 percent in 2011.[22]

Figure 7. Counterfactual Analysis of Impact in China: US Corporate Spread[1]



[1] The grey areas indicate the periods of implementation of LSAP1, LSAP2 and MEP. The black lines are actual values. The red lines are the values associated with the jump scenario where the US corporate spread jumps by 200 basis points and stays 200 basis points above the actual levels throughout the respective QE program, and the blue lines depict the scenario where the US corporate spread stays equal to the actual level observed just before the QE program. [2] A rise in the foreign exchange pressure index represents stronger appreciation pressure.

Source: Authors' calculations based on an estimated GVECM.

IV. Conclusion

53. We examine the domestic and cross-border effects, both real and financial, of the Federal Reserve's unconventional monetary policies using an estimated GVECM. First, we find that QE measures which lower the US corporate spread have had sizeable effects, which

[22] There are at least two key reasons for the Chinese economy being less affected by US QE than Brazil. First, the Chinese economy was far bigger and more diversified, capable of absorbing large external shocks. Second, our results suggest that China responded to the US stimulus with tighter monetary and credit policies and cushioned the impact of the stimulus on the yuan exchange rate.

vary significantly across regions and individual economies. This is consistent with Blinder (2012) that purchasing US Treasuries to lower the term spread may be a weak tool, and reducing risk premia by acquiring private-sector assets is much more potent. Second, monetary policy and exchange rate responses have been diverse in the emerging economies, which may partly explain the important cross-economy differences in the responses of output, inflation and credit. Third, US QE measures have had sizeable and widespread effects on global equity prices, and the confidence channel may be important. Fourth, such measures tend to have a greater impact on many emerging economies than on the US economy.

54. Our counterfactual analyses suggest that, first, US QE measures have supported the advanced economies, countering forces which might have led to a prolonged recession and deflation. Second, the cross-border impact of such measures appear to have helped support the recovery in the emerging economies in 2009 and 2012, as well as contributing to their overheating in 2010 and 2011. Third, some of the differential cross-border impacts might depend on policy responses to the US policy actions. For example, there is evidence that China tightened the monetary and credit conditions in response to lower US corporate spreads, which tended to partially offset their expansionary impact on its output growth. In Brazil, the evidence suggests that a sizeable credit expansion led to more expansionary overall economic and financial conditions.

55. There is evidence that cross-border monetary policy spillovers can be important sources of macroeconomic and financial instability. This raises important questions about whether central banks should do more to take into account the unintended consequences of their actions on others and how to best promote stability. While having made some progress in quantifying monetary policy spillovers, we are still some distance from being able to assess the nature, as well as the costs and benefits, of international policy coordination.[23]

[23] As Cœuré (2014) points out, "the case for formal central bank cooperation remains limited, and practical consideration makes its implementation difficult," yet "central banks need to be engaged in a constant dialogue so as to remain ready for rapid coordinated action in exceptional circumstances."

APPENDIX I. STRUCTURE OF THE GVECM MODEL

Consider N+1 economies, indexed by i = 0, 1, 2, ..., N, and for the *i-th* economy, a vector $\mathbf{x}_{it}$ of k_i domestic variables. By stacking the vectors of country-specific variables, we have

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

A VAR model in $\mathbf{x}_t$ would contain too many parameters to be estimated if the data's time dimension T is large enough relative to N+1, the number of economies.

Instead of regressing $\mathbf{x}_{i,t}$ on $\mathbf{x}_{-i,t}$, where

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

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

$$x_{lit}^* = \sum_{j=0}^{N} \omega_{lijt} x_{ljt} \quad with \quad l = 1,2,\ldots,k_i^* \tag{3}$$

The weight ω_{lijt} captures the spillover effect of variable l of foreign economy *j* on variable *l* of domestic economy i. Since ω_{lijt} 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 strength. Hence each economy's component model of the GVECM is given as a VECM*(p_i, q_i):

$$\Delta \mathbf{x}_{it} = \mathbf{c}_{0i} + \mathbf{c}_{1i} \cdot t + \mathbf{\Pi} \cdot \tilde{\mathbf{z}}_{i,t-1} + \sum_{s=1}^{p_i - 1} \mathbf{\Psi}_{is} \cdot \Delta \mathbf{z}_{i,t-s} + \mathbf{\Gamma}_i \cdot \Delta \mathbf{x}_{it}^* + \sum_{s=0}^{r_i - 1} \Lambda_{is} \cdot \Delta \mathbf{d}_{t-s} + \boldsymbol{\varepsilon}_{it} \tag{4}$$

where $\mathbf{d}_{t-s}$is the observed common factor ($q \times 1$) and $\boldsymbol{\varepsilon}_{it} \overset{iid}{\sim} \left(0, \sum_i\right)$.

The economy *i*, the vector $\mathbf{x}_{i,t-s}^*$ reflects its interdependence with other economies, and it serves as a proxy for the unobserved common effects across the economies. The foreign variables and common factors are assumed to be weakly exogenous, i.e., they are "long-run forcing" the domestic variables, in the sense that the coefficients on the error-correction terms are set to zero in the equations for foreign variables. The dynamics of foreign variables are unaffected by any deviations from the long-run equilibrium path, in contrast to the dynamics of domestic variables.

The VECMX* can be estimated for each economy with the ordinary least squares (OLS) or rank-reduced approach if the cross-dependence of the idiosyncratic shock is sufficiently small:

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

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

From equation (3), it can be seen that

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

where $\mathbf{z}_{it} = (\mathbf{x}'_{it}, \mathbf{x}^{*\prime}_{it})$ and $\mathbf{W}_i$ is a properly defined weight matrix. Stacking (4) across i, the endogenous variables can be solved for a global system:

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

and

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

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 GVECM model makes it feasible to estimate (8) by explicitly taking into account the cross-economy interdependence while estimating each economy separately, allowing the inclusion of a large number of economies. The impulse responses are then estimated based on (8).

We conduct the augmented Dickey-Fuller (ADF) and the weighted-symmetric Dickey-Fuller (WSDF) unit root tests for all model variables. The two tests produce broadly similar results. At the 5 percent significance level, we find that in most economies, the domestic variables are tested to be integrated of order 1, i.e. I(1), with the exception of some variables being tested to be I(0) or near I(1). These include: based on the WSDF test results, real GDP growth in Hong Kong, Thailand and the United Kingdom, and CPI inflation in Chile, China and the Philippines, foreign exchange pressure indices of Argentina and the euro area, equity price inflation in Hong Kong, Indonesia and South Korea, and monetary aggregates in India; and based on the ADF test results, the foreign exchange pressure index of India and monetary aggregates in Singapore. Most foreign variables are tested to be I(1), so is the global factor VIX. The form in which the model variables are included in the GVECM ensures a stable global solution with an eigenvalue less than or equal to 1.

APPENDIX II. FOREIGN EXCHANGE PRESSURE INDEX

The foreign exchange pressure index emp_t measures the pressure of capital inflows. In economies with flexible exchange rate regimes, strong net capital inflows push up the demand for domestic currency, which in turn leads to its appreciation. If the authorities intervene in the foreign exchange market to moderate the currency appreciation, we may not observe significant changes in the exchange rates, but rather a rise in the foreign reserves. In a fixed-exchange-rate regime, strong capital inflows are reflected in an increase of foreign reserves only. We therefore construct the foreign exchange pressure index as follows, similar to Eichengreen, Rose and Wyplosz (1995):

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

$$w_{t,X} = \frac{\sigma_{t,X}^{-1}}{\sigma_{t,e}^{-1} + \sigma_{t,rev}^{-1}}, \qquad \text{for } X = e, rev$$

where σ_t is the standard deviation of the corresponding variable in the previous five years, for $t \geq 6$. For $t < 5$, we use the standard deviation based on the data for the first five years.

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 nominal effective exchange rate and R_t denotes the foreign reserves.

APPENDIX III. TIME-VARYING WEIGHTS FOR FOREIGN VARIABLES

The weight that an economy-i foreign variable assigns to economy j at year t is

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

where $W_{ij,t}^{T}$ and $W_{ij,t}^{F}$ are the bilateral trade and financial weight (based on capital flows in the previous year), respectively. $w_{i,t}^{T}$ and $w_{i,t}^{F}$ are the relative importance of trade and capital flows in an economy, respectively. They are computed according to the values of the respective aggregate trade flow (export and import) and capital flow (both inflow and outflow) relative to the total value of these two types of flows in the previous year. The financial weight of economies with no capital flow data in the 1990s is set to zero.

APPENDIX IV. DATA

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

Variable	Description	Source	Notes
Real GDP (y)		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 the 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 (π)	Year-on-year change in consumer price index	CEIC, IMF IFS, national data	
Credit (bc)	Total credit to the non-financial private sector	BIS	
Term spread (mp)	Difference between 10-year US Treasury bond yield and 3-month US Treasury bill rate	CEIC, IMF, IFS, national data	For euro area, due to data limitations, the main refinancing rate is used instead of 3-month government bond yield.
US corporate spread (mp)	BofA Merrill Lynch US Corporate AAA minus the federal funds rate.	CEIC, IMF, IFS, national data	
Implied volatility (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 (mp)	Year-on-year M2 growth rate	CEIC, IMF IFS	
Equity price (sp)	Stock price index; in natural logarithm	Bloomberg	Index of stock prices in each economy.
Foreign exchange pressure (emp)	Nominal effective exchange rate	BIS	Period average; 2005 = 100.
	Foreign reserves	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 are either an estimate or the aggregate reserves of 11 EU Member States participating in the euro area in 1999.
Oil price	Spot oil price	IMF IFS	Brent crude oil, US dollars per barrel; period end data.
Export/import		IMF IFS	
Cross-border bank lending	BIS consolidated bank lending statistics	BIS	
Capital inflow and outflow		IMF IFS	

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