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Monetary Policy Transmission in Systemically Important Economies and China's Impact

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Abstract

This paper examines the monetary policy transmission mechanism in four systemically important economies. The impact of monetary policy is found to be broadly comparable for China, the US, the Eurozone, and Japan. Identifying a role for the financial sector is essential to unpacking various channels through which monetary policy operates. Global factors play a significant role and their impact is strongest for China and weakest for Japan. China's impact is significant with the Eurozone displaying the most interdependence and Japan the least. Time-varying VARs suggest that contrasts in the responses to monetary policy shocks persist highlighting some of the remaining differences in the transmission mechanism. Finally, there is no apparent structural change in the estimated relationships around the time when the Fed intervened after 2008. It is conjectured that Quantitative Easing may well have prevented such a break.

Keywords

monetary policy transmission, systemically important economies, QE, Factor VAR, time-varying Factor VAR

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ABSTRACT

This paper examines the monetary policy transmission mechanism in four systemically important economies. The impact of monetary policy is found to be broadly comparable for China, the US, the Eurozone, and Japan. Identifying a role for the financial sector is essential to unpacking various channels through which monetary policy operates. Global factors play a significant role and their impact is strongest for China and weakest for Japan. China's impact is significant with the Eurozone displaying the most interdependence and Japan the least. Time-varying VARs suggest that contrasts in the responses to monetary policy shocks persist highlighting some of the remaining differences in the transmission mechanism. Finally, there is no apparent structural change in the estimated relationships around the time when the Fed intervened after 2008. It is conjectured that Quantitative Easing may well have prevented such a break.

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1. Introduction

Policy makers have become acutely aware that their understanding of the monetary policy transmission mechanism, that is, how monetary policy impulses are transmitted throughout the economy, requires revisiting not only in light of the fallout from the Great Financial Crisis (GFC) of 2008-9 but also because of the emergence of China as a systemically important participant in the global economy.

The transmission of policy takes place potentially through several channels. In this paper we focus on the interest rate and financial market channels since the GFC led at least three of the central banks in our study (the U.S. Federal Reserve, the European Central Bank, the Bank of Japan) to apply various forms of unconventional policies requiring a multiplicity of instruments to carry them out. The fourth central banks (the People's Bank of China) has, throughout the sample considered, implemented monetary policy via multiple instruments.

China's economy grew rapidly especially during the 1990s and early 2000s. This was assisted by the gradual introduction of reforms aimed at allowing markets to play an increasingly important role. Combined with policy makers' express desire to open China up to the rest of the world, the People's Bank of China (PBoC) also began the process of turning itself into a central bank that resembles up to a point monetary authorities elsewhere in the world.

These developments took place just as the rest of the world seemed to converge toward reliance on a single policy instrument, namely an interest rate. Policy strategies in the advanced economies, notably in the area of monetary policy, seemed to converge at least until the GFC, with a preference for achieving a form of price stability. Since the GFC, commitment to inflation control does not appear to have changed. Yet, central banks in the economies most affected by the crisis, especially systematically important economies, notably the U.S., the Eurozone, and Japan, have found themselves in the position of having to fight the output effects of the crisis resulting in very low or even negative inflation rates. The PBoC arguably faces a different set of challenges including ensuring that growth rates remain elevated without an inflationary surge. Nevertheless, in the wake of the GFC, the Chinese government stimulated the economy ostensibly to offset negative spillovers from abroad as well as to put a floor on domestic growth rates (e.g., see Bai, Hsieh and Song 2016).

The problem of deflation never really left Japan as the Bank of Japan (BoJ) continues its attempt to reach the goal of 2% inflation. Deflation was briefly also a problem for the U.S. Federal Reserve (Fed) in the early 2000s and then again at the height of the crisis but, in tandem with the European Central Bank (ECB) in the Eurozone, it is 'lowflation' that pre-occupies policy makers in these economies. Even China faced a brief bout of deflation during the 1990s and the debate about whether this episode was demand or supply driven has not yet been settled (e.g., see Bernanke 2002, Siklos and Zhang 2010, and references therein).

Perhaps unsurprisingly, some observers began to examine more closely the monetary policy transmission mechanism. Considerable interest continues to focus on developments in the large systemically important economies such as the U.S., the Eurozone, and Japan. China, increasingly important as a global player, receives relatively less attention in this context.

Monetary policy in China and its interaction with the US, the Eurozone, and Japan is also the subject of this paper. The degree to which economic shocks from abroad influence the PBoC's monetary policy is also explored as is whether shocks originating in China are exported. The potential economic interdependence among these four economies has policy implications. For example, it is only through an examination of spillovers that we can obtain a better understanding of the consequences of the impact of independent monetary policies in large economies. This may also hold lessons for the manner in which policy makers cooperate around the globe.

To accomplish our aims we estimate not only standard vector autoregressions (VAR) but time-varying VARs to take into account the fact that the sample under investigation includes the period since the GFC (e.g., Koop et. al. 2009). In particular, we seek to determine whether the monetary transmission mechanism in China is beginning to resemble the one prevailing in the US, the Eurozone and Japan. We are referring to the sense in which monetary policy has comparable cross-country effects on inflation and real economic activity in the four economies examined. Next, our approach departs from others by including an explicit role for the financial sector, in addition to including traditional real and monetary effects. While the importance of the latter effect has been known for some time (e.g., see Bernanke and Gertler 1995) the GFC has revived this channel of the transmission mechanism (Rey 2015, Borio 2014) as well as

highlighting additional sources of macroeconomic effects from financial shocks to the macroeconomy (e.g., the financial or risk-taking channels; see Borio and Zhu 2012).

Broadening the analysis to incorporate several factors that impact macroeconomic performance places more demands on standard econometric models. Accordingly, we estimate factor VARs so that a much larger variety of time series can be brought to bear simultaneously on our understanding of the impact of monetary policy and the role of global spillovers. Thus, for example, it is well-known that the PBoC has long relied on multiple instruments to carry out monetary policy. Similarly, the literature has raised concerns about the quality of some micro and macro level data (e.g., Holz 2014, Lardy 2018) leading researchers to employ a variety of proxies for China's aggregate economic performance.

Briefly, we find that the impact of monetary policy is reasonably similar across the four systemically important economies examined. In particular, interest rates are playing a larger role in China while the introduction of additional instruments, under the umbrella of unconventional monetary policies (UMP) in the US, the Eurozone and Japan, have led the 'unorthodox' monetary policy strategies they followed to resemble China's monetary policy by adopting multiple instruments to achieve domestic monetary policy objectives. That said, differences in the monetary policy transmission mechanisms remain. Most notably, the financial factor has a smaller macroeconomic impact on China than in the other three economies. As far as we are aware the combination of these findings is new even if recent studies (e.g., Dieppe et. al. 2018, Chen, Chow and Tillmann 2017) arrive at conclusions not too dissimilar to ours even if their estimated models differ from ours. Therefore, we conclude that separately identifying a role for the financial sector is essential to unpacking the various channels in the transmission mechanism.

Although global factors play a statistically significant role in all of the economies examined, their impact is relatively strongest for China and weakest for Japan. More importantly, it is also found that China's influence on the other economies is significant with the Eurozone displaying the most interdependence and Japan the least. China's influence on the US economy is somewhere in the middle but it is not insignificant. While there is growing acceptance that shocks from China impact the rest of the world, we provide separate estimates of their source, that is, the extent to which these originate from real, monetary or financial factors.

Estimates from time-varying VARs suggest that contrasts remain in the response to monetary policy shocks across the four economies considered. Hence, additional insights are obtained from time-varying estimation. Nevertheless, there is no evidence of a structural change in the transmission mechanism around the time of events considered candidates for a break. It is conjectured that QE may well have prevented such a break. This is consistent with some recent evidence that argues for the perfect substitutability between conventional and UMP (e.g., see Debortoli, Gali, Gambetti 2018).

The rest of the paper is organized as follows. The next section provides a brief literature review. Section 3 briefly describes the estimation methods and the data used. Section 4 provides some stylized facts before proceeding to a discussion of the econometric results. Section 5 concludes with a summary and a general evaluation of the extent to which China is both an importer and exporter of real, monetary and financial shocks.

2. Literature Review

The literature on the monetary policy transmission mechanism is vast. The experience of the US, the Eurozone and Japan are discussed extensively. Hence, we can be very brief and readers can consult, inter alia, Kim (2001), Kuttner and Mosser (2002) and Endut et. al. (2016) for the U.S., Hosono (2006) for Japan, ECB (2000), and Cecioni and Neri (2010). The monetary policy transmission mechanism in China has also been of interest and study. However, as we shall see below, there is perhaps less of a consensus surrounding the key elements that drive macroeconomic outcomes and the role played by monetary policy.

The Fed describes the transmission mechanism of monetary policy as originating from its dual mandate (i.e., maximum employment, low and stable inflation). Therefore, its monetary policy achieved through to the use of its main instrument, namely the fed funds rate.[1] Monetary policy

[1] More recently, more emphasis has also been placed on communications as an additional instrument of monetary policy. Perhaps this reflects a recognition that the central bank's observed policy rate may no longer adequately convey the stance of monetary policy. Accordingly, several researchers (e.g., Wu and Xia 2016, Lombardi and Zhu 2018, Krippner 2013, 2015) promoted the concept of a 'shadow' policy rate.

then acts to influence aggregate demand via its impact on good prices, asset prices, expectations and the exchange rate.[2]

The European Central Bank's (ECB) interpretation of the monetary policy transmission mechanism is similar to the Fed's since the principal instrument of policy revolves around influencing interest rates to achieve a price stability objective.[3] However, there is explicit recognition that there are shocks that cannot be controlled via monetary policy. Moreover, the goals of the ECB are framed entirely in terms of price developments since the ECB, unlike the Fed, has a single mandate, namely price stability as defined by the central bank.[4] Finally, it is acknowledged that the supply side of the Eurozone may also be influenced by how interest rates are set.

The Bank of Japan (BoJ) does not, as such, publish a particular view of the monetary policy transmission mechanism. This is likely due to the BoJ's experience with zero and, more recently, negative interest rates, quantitative easing, and a variety of other financial market interventions ranging from the purchase of large quantities of long-term bonds to holding shares in private sector corporations (e.g., see Ueda 2000, Nakaso 2001, and Bank of Japan 2016). In other words, the BoJ acknowledges that a multiplicity of instruments are deployed to achieve its price stability objective considered the principal objective of monetary policy.[5]

Turning to the case of China the period under study is marked by gradual changes in the financial sector where reforms are aimed at liberalizing credit markets (e.g., Bell and Feng 2013, Chen, et. al. 2017). Of course, at the level of monetary policy, the PBOC does not share the same degree of autonomy granted to the other three central banks considered in this paper. Moreover, in the sample investigated here, financial markets remain in a transitional phase that

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[2] See https://www.federalreserve.gov/monetarypolicy/monetary-policy-what-are-its-goals-how-does-it-work.htm.

[3] Defined as: "The ECB has defined price stability as a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%. In the pursuit of price stability, the ECB aims at maintaining inflation rates below, but close to, 2% over the medium term." (https://www.ecb.europa.eu/mopo/intro/html/index.en.html).

[4] See https://www.ecb.europa.eu/mopo/intro/transmission/html/index.en.html.

[5] Since 2013 price stability is defined by a 2% inflation objective. See https://www.boj.or.jp/en/mopo/outline/qqe.htm/. Previously, a goal closer to zero percent was consistent with the BoJ's definition of price stability.

has yet to approach the relatively unfettered financial markets of the U.S., the Eurozone, and Japan. In other words, the PBoC operates in an environment characterized by financial repression. Financial repression is not, however, unique to China. Indeed, the combined impact of the series of monetary policy interventions since 2008 has been deemed by some (e.g., see Bordo 2018, and references therein) as reminiscent of the financial repression policies in place a few decades ago in many advanced economies.

The PBoC removed restrictions on interbank interest rates in June 1996. Subsequently, the PBoC canceled limitations on the volume of loans of commercial banks in January 1998. In October 2004, the PBoC began to allow commercial banks to float their deposit interest rates in a small range based on the central bank's benchmark deposit interest rates (i.e. one year deposit interest rate, five year deposit interest rate) and relaxed the upper limit for the commercial banks' loan rates. The PBoC completely canceled the administrative interventions over all commercial banks' interest rates in October 2015 (e.g., see Hou and Wang 2013, and Yang and Shao 2016). Shortly before, the PBoC announced that it would allow the RMB to be more heavily influenced by market forces (Prasad 2017) although it is fair to say that the exchange rate regime is a managed one (e.g., see Iltzetzki, Reinhart and Rogoff 2017).

The PBoC has a dual mandate, namely to maintain a stable value for its currency and promote economic growth (Zhou 2013). Like the BoJ, the PBoC relies on a multiplicity of instruments with reserve requirements and the central bank interest rate the first two on its list, followed by repos and other instruments assigned by the State Council (inter alia, see Fernald et. al. 2014, Pang and Siklos 2016, Chen, Chow and Tillmann 2017).[6] While there have been substantial changes in the conduct of monetary policy in China over the past two decades (e.g., Koch 2007, Burdekin 2008, Bell and Feng 2013) the allocation of credit has always played a critical role and, in recent years, the PBoC has increasingly relied on interest rates to achieve its policy objectives. Although price stability is not an explicit goal of the PBoC there is an expectation that inflation should be relatively low and stable. The money market in China plays a more important role in

[6] The central bank relies frequently on changes in required reserve ratios and issues central bank bills primarily to sterilize rising foreign exchange reserves (e.g., see Zhang 2011 and Wang 2012b).As a result, M2 and incremental credit loans also became the PBoC's intermediate targets (Wang 2012a, Sheng and Wu 2008). Burdekin (2008) finds that the increases in foreign exchange reserve did not have a significant influence on the monetary base. Filardo and Siklos (2016) find that there is a strong connection between asset price developments and the accumulation of foreign exchange reserves.

the monetary policy transmission mechanism after 1998 (Dai 2001). Therefore, a bank lending channel has existed in China since the 1990s (Zhou and Jiang, 2002). Pang and Siklos (2016) also report that credit shocks led to inflation in China.[7]

After the Chinese government began to promote the liberalization of interest rates some researchers sought to find out whether an identifiable interest rate channel exists. Sheng and Wu (2008) use Granger causality tests and conclude that an interest rate transmission mechanism does not exist in China. Poon and Wong (2011), using more recent data, specify a VAR model and they conclude that before the GFC the transmission mechanism followed a traditional Keynesian interest-rate channel. Thereafter, the asset-price channel becomes more prominent.[8]

Since the renminbi was pegged to the U.S. dollar for a time, standard economic theory would suggest that PBoC policy might be significantly affected by U.S. monetary policy. The renminbi exchange rate became more flexible beginning in June 2005 (He et. al. 2013, Yue and Niu 2014). In principle then China should enjoy a more independent monetary policy than in the past. But some authors argue that more flexible exchange rate regimes do not prevent spillover effects from other economies, and that capital controls are essential for maintaining an independent monetary policy (Rey 2015, Spantig 2015). Accordingly, spillovers from China's monetary policy to other countries cannot be excluded. Zhang et al. (2015) use a two-country dynamic stochastic equilibrium (DSGE) model to explore the spillover effects between China and U.S. They find that U.S. monetary policy affects China's output while China's monetary policy influences the U.S. economy through international trade and capital channels. Pang and Siklos

[7] Some studies, including the ones cited above, find that the volume of loans are more correlated with the PBoC's objectives (i.e., inflation and GDP growth) than a money supply measure.

[8] Some researchers examine the conduct of China's monetary policy by estimating a monetary policy rule, such as a Taylor rule or McCallum's monetary rule (e.g. see Burdekin and Siklos 2009 and references therein). Yue and Niu (2014) use Bayes' method to estimate the Taylor rule and McCallum's rule for China's monetary policy derived from a DSGE framework. They argue that McCallum's rule is a more suitable approach to understanding China's monetary policy. However, following interest rate liberalization, a Taylor rule may well have become more suitable. Jawadi et al. (2014) apply a smooth transition regression (STR) model to a monetary policy rule, and find strong evidence of asymmetry and nonlinearity in China's monetary policy from 1990 to 2008. One potential difference between policy rules for China and ones estimated for other advanced economies is that both external and internal factors are more likely to matter for China (Wu and Liu 2015). Girardin et al. (2014) construct a monetary policy index to explore the role of inflation and output in China's monetary policy reaction function during 2002 to 2013. They find that China's monetary policy is similar to an informal flexible inflation targeting rule and the long-term coefficient on inflation in PBoC reaction function resembles those of the G3 central banks prevailing in the post-1979 period. Major disadvantages of the reaction function approach include their reduced form nature and omission of an explicit external or global element in evaluating the impact of monetary policy.

(2016) present evidence that China's economy is significantly influenced by real and credit shocks from the U.S. economy, while the reverse is not observed. Vespigani (2015) investigates shocks to the Eurozone from the same three countries considered in the present study but emphasizes the role of commodity prices and not the interdependence of various macro-financial shocks as we do.

Common to the literature is the estimation of models that either ignore the financial sector altogether or downplay the richness of the instruments used by the PBoC to influence financial and monetary conditions. One difficulty is that some instruments play relatively more important roles at some times than at others. Moreover, it is often the case that several instruments are used simultaneously to alter the stance of monetary policy. Nevertheless, Chen, Chow, and Tillmann (2017) report that M2 and the required reserve ratio adequately proxy the stance of monetary policy. They prefer a so-called Qual VAR model where the monetary policy stance changes by steps and is proxied by a binary function driven by latent variables. Interestingly, they conclude that the transmission of China's monetary policy shocks to the rest of the economy resembles that found in other advanced economies (see below).

At least as important is that the treatment of the Chinese economy as systemically important, requiring a model that admits the interdependence with other globally systemically important economies is less prominent in the extant literature. Our study aims to begin filling these gaps.

3. Methodology and data

Although the main results presented below focus on factor based VARs (F-VAR) and time-varying VARs (TV-VAR) it is useful to begin with a brief discussion of a standard VAR. This aids in motivating the proposed departures from the more conventional methodologies that are also typically the starting point found in the existing literature.

A conventional VAR model for each individual economy is written:

$$\mathbf{Z}_t = \mathbf{A_0} + \mathbf{A_1}\,\mathbf{Z}_{t-p} + \boldsymbol{\varepsilon}_t \qquad (1)$$

where $\boldsymbol{Z_t}$ is a vector of variables, and $\mathbf{Z_t} = [\pi_{t,} y, \iota_t^{M\dot{P}}, \Delta e_t]$', and p is the lag length of the VAR. The variables π_t and $\dot{y}$ are CPI inflation and real GDP growth, respectively. The variables enter the VAR in a traditional manner that follows the ordering adopted by most in the relevant

literature. [9] We use a 10-year government bond yield to represent a long-term interest rate (i^L) for the U.S., Euro Area and Japan, while we employ the 3-month Treasury bond yield to represent same interest rate for China because there is insufficient longer-run yield data for 10-year bonds. Other than for China, where a blend of different policy instruments (i.e., a monetary aggregate, a benchmark interest rate, reserve ratios, and an exchange rate) serve to proxy the stance of monetary policy (see below), we use an observed policy rate to capture monetary policy (i_t^{MP}) or a shadow rate since the beginning of the GFC. Shadow rate data are from Wu and Xia (2016) for the US and the European Central Bank. Shadow rates for Japan are from Imakubo and Nakajima (2015).[10] For China, the Eurozone and Japan, we use the rate of change in the nominal exchange rate (Δe_t; domestic currency units per U.S. dollar).[11] For the US VAR, we use the rate of change in the nominal effective exchange rate (NEER) to capture external effects.

Because of its size, it is easy to imagine that U.S. shocks create spillover effects that are transmitted to the other economies considered in our study. However, as China's economic importance has risen over time, we allow for the possibility that shocks from China may also produce spillover effects on the other economies considered here.[12] We also recognize the potential for oil prices to exert a macroeconomic impact. Hence, lagged oil price inflation is added as an exogenous variable in the model.[13] Finally, we also permit spillovers from QE policies on all economies considered. The standard VAR model with exogenous variables is, therefore, written:

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[9] We estimated versions of the models relying on both the Akaike and Schwarz information criteria (AIC, SC, respectively). As is well known, the former typically selects longer lags than the latter. Ultimately, the choice is based on the degrees of freedom as well as the plausibility of our estimates. It is a also worth noting that changing the order of inflation and real GDP growth did not alter the results in any meaningful way.

[10] We are grateful for the Bank of Japan for providing these estimates.

[11] Using a real exchange rate does not substantively change the conclusions.

[12] Clearly, spillovers from the Eurozone and Japan are also possible. While we generated the relevant estimates which are available on request, space limitations prevent a discussion here.

[13] There seemed to be little difference between using real versus nominal oil price inflation. Hence, all results rely on the nominal definition. The proxy for oil prices is the West Texas Intermediate (WTI) price. However, the Brent was also considered with little effect on the results. All results discussed below rely on the WTI proxy.

$$\mathbf{Z}_t^j = \mathbf{A}_0^j + \mathbf{A}_1^j \mathbf{Z}_{t-p}^j + \boldsymbol{B}_1 \mathbf{Z}_{t-1}^{US} + \boldsymbol{C}_1 \boldsymbol{OIL}_{t-1} + \boldsymbol{D}_1 \mathbf{Z}_{t-1}^{CN} + \boldsymbol{E}_1 \boldsymbol{QE}_t + \boldsymbol{\varepsilon}_t^j \qquad (2)$$

where all variables are as previously defined and *j = US, EZ, JP, and CN.* When *j*=US, $\mathbf{B}_1 = \mathbf{0}$. When *j*=CN, $\boldsymbol{D}_1 = \mathbf{0}$. The addition of the vectors $\mathbf{Z}^{\mathbf{US}}$ / $\mathbf{Z}^{\mathbf{CN}}$ captures the interdependence between the US/China and other economies considered.[14]

While (1) and (2) represent standard representations of a small scale macro model they have their limitations. In particular, there is no explicit allowance for financial shocks that have become the focus of considerable research since the GFC. Next, it may be preferable to consider a menu of macroeconomic, monetary and financial variables as opposed to the usual approach of selecting a few series to capture all macroeconomic interactions. Of course, by expanding the vector $\mathbf{Z}$ we quickly face the curse of dimensionality. However, there exists a strategy to mitigate this problem, namely replacing individual time series via factor model estimation. In the VAR context, this implies estimating a factor VAR (i.e., F-VAR) model.[15] For example, we can write such a model by replacing $\mathbf{Z}_t$ in (1) with factors that capture the real economy, the financial sector, and monetary policy. The resulting specification is written:

$$\begin{bmatrix} \mathbf{R}_t^j \\ \mathbf{F}_t^j \\ \mathbf{M}_t^j \end{bmatrix} = \mathbf{C}(\mathbf{L}) \begin{bmatrix} \mathbf{R}_{t-i}^j \\ \mathbf{F}_{t-i}^j \\ \mathbf{M}_{t-i}^j \end{bmatrix} + \mathbf{D}(\mathbf{L}) \begin{bmatrix} \mathbf{R}_{t-1}^{US} \\ \mathbf{F}_{t-1}^{US} \\ \boldsymbol{i}_{t-1}^{US} \end{bmatrix} + \mathbf{E}(\mathbf{L}) \begin{bmatrix} \mathbf{R}_{t-1}^{CN} \\ \mathbf{F}_{t-1}^{CN} \\ \boldsymbol{M}_{t-1}^{CN} \end{bmatrix} + \boldsymbol{\varepsilon}_t \qquad (3)$$

The appendix contains the complete list of series used to estimate the factors. They were chosen on the basis of their suitability as determinants of $\mathbf{R}_t$, $\mathbf{F}_t$, and $\mathbf{M}_t$. Below we provide some additional justifications.

The real economy factor ($\mathbf{R}_t^j$) in the case, for example, of China is obtained from a vector that includes variables such as: the growth rate of real GDP, CPI inflation, real GDP growth and

[14] Our focus on spillovers between the U.S. and the other three economies is consistent with policy makers' recent interest in global spillovers (e.g., see IMF 2013). We also consider spillovers to and from the remaining economies in the data set. However, space limitations present a full discussion of all the results. Some are relegated to an appendix, others are available on request. The conclusion that spillovers and global factors are empirically important is unchanged when other forms of $\mathbf{Z}_t$ in (2) are considered.

[15] Strictly speaking, given how the monetary policy variable is estimated for China, the standard VAR (e.g., as in (1)) resembles a factor-augmented or FAVAR proposed by Bernanke, Boivin and Elias (2005).

inflation forecasts, energy production, and the ratio of the current account balance to Nominal GDP. Comparable times series are used to construct the same factor for the other three economies considered. $\mathbf{F}^{j}_{t-i}$ is the financial factor, obtained from the factor model that includes an index of stock returns, inflation in property prices, the rate of growth in bank loans, and short and long-term bond yields. $\mathbf{M}^{j}_{t-i}$ is the monetary policy factor. For the U.S. and Euro Area, we use the central bank policy rate. However, as these central banks employed unconventional monetary tools to stimulate the domestic economy beginning in 2008 we switch to using a shadow interest rate since the GFC. When j=US, **D(L)=0**. When j=CN, **E(L)=0**. In China's case four time series make up $\mathbf{M}_t$. The are: the nominal effective exchange rate, a monetary aggregate (M2), the required reserve ratio, and benchmark interest rates. All of the series, but usually not together, have been used in the previous literature (see section 2) to proxy the stance of monetary policy in China.

To estimate the various factors we use the method of principal components (PC) estimated via maximum likelihood (e.g., see Tsay 2010). To ensure ease of interpretation a rotation is applied that highlights the most important variables in the vectors that define $\mathbf{R}_t$, $\mathbf{F}_t$, and $\mathbf{M}_t$ but remains aligned with the estimated principal components. Finally, because almost half of the sample consists of the period since the GFC, the Eurozone sovereign debt crisis and its aftermath, it is conceivable that the relationships under investigation may have changed over time. Accordingly, we also estimate versions of (2) and (3) that are time-varying.

The time-varying VAR (more accurately, a time-varying F-VAR or TV-FVAR) allows for the coefficients in the fixed coefficients version to evolve as stochastic processes. As noted by Lubik and Matthes (2015) inference is a challenge with these models as additional restrictions need to be imposed prior to estimation. We estimate a standard TV-FVAR by selecting dates when, in the light of history, parameters that define the monetary transmission mechanism may have changed (see below). We follow Primiceri's (2005) Bayesian approach which adopts Gibbs sampling to construct the posterior distribution. In particular, the ordering of the variables in the VAR may be even more important than in the time-invariant case. Nevertheless, particularly in the case of the VAR defined by equation (3), this should not be controversial since the errors in the monetary policy factor equation are assumed to be uncorrelated with those of the financial and real equations, and the residuals in the financial equation are uncorrelated with those in the

real equation. Put differently, the financial factor responds contemporaneously to real GDP growth while the monetary policy factor responds contemporaneously to both the real and financial factors. This ordering is consistent with current economic theory. If we consider only the most parsimonious version of (3), the TV-FVAR is written:

$$\begin{bmatrix} \mathbf{R}_t^j \\ \mathbf{F}_t^j \\ \mathbf{M}_t^j \end{bmatrix} = \mathbf{B_t}(\mathbf{L}) \begin{bmatrix} \mathbf{R}_{t-i}^j \\ \mathbf{F}_{t-i}^j \\ \mathbf{M}_{t-i}^j \end{bmatrix} + \boldsymbol{\varepsilon_t} \qquad (4)$$

where $\mathbf{B_t(L)}$ is a vector of time-varying coefficients. The dynamics of the model's time-varying parameters are as follows:

$$\begin{aligned} \mathbf{B}_t &= \mathbf{B}_{t-1} + \nu_t \\ \alpha_t &= \alpha_{t-1} + \gamma_t \\ \log \sigma_t &= \log \sigma_{t-1} + \eta_t \end{aligned} \qquad (5)$$

The maintained assumption is that the time-varying coefficients follow a random walk. The second and third equations in (5) are, respectively, the elements from the lower and upper triangular matrices from the variance-covariance matrix such that $\mathbf{A}_t \boldsymbol{\Omega}_t \mathbf{A}_t' = \boldsymbol{\Sigma}_t \boldsymbol{\Sigma}_t'$.

The sampling frequency is quarterly and the sample begins in 1998Q1 and ends with 2016Q4. All data were obtained from FRED (St. Louis Federal Reserve Economic Data), CEIC (https://www.ceicdata.com/en), the International Monetary Fund's April 2016 International Financial Statistics CD-ROM, individual central banks, and Wind (http://www.wind.com.cn/en/edb.html).

We choose 40 observations (1998Q1 to 2007Q4) for training samples for the U.S. and Japan, and 36 observations for China and Euro Area to calibrate the prior distributions which is necessary for estimation.[16] All the estimations are based on 50,000 iterations of the Gibbs sampler,

[16] The reason is that the samples for China and Euro Area begin in 1999Q1.

discarding the first 5,000 for convergence.[17] Again, this follows standard practice for estimating TV-FVARs.[18]

4. Stylized Facts and Empirical Evidence

(a) Factor Scores[19]

In a first step the appropriate number of factors must be estimated from the number of time series that are assigned the real, financial, and monetary labels (e.g., see Tsay 2010 for details). Factors represent the number of linear combinations that describe the variables specified in (3) and (4). Consequently, the number of variables ranging from 13 to 18 are reduced to three.[20] This is one of the principal contribution of factor analysis. The factor scores are then the estimates of the otherwise unobservable factors and are used as substitutes for the large number of potential determinants that could be included in a model such as (1).[21]

Maximum likelihood estimation is used and factors whose eigenvalue is less than one are retained. Alternatively, a selection criterion that yields the same results here is to examine the proportion of the total variation explained by each factor relative to the total. This is roughly the equivalent of estimating the change in R^2 as additional factors are added. Based on these approaches we end up with one real, one financial and two monetary factors for China, two real

[17] One lag is included, and the prior parameter setting is following: $k_Q = 0.01, k_S = 0.1, k_W = 0.01$.

[18] Of course, other techniques could also be applied to the problem at hand. Since we are interested in the potential for interdependence across the four economies examined in this study the panel VAR (PVAR) and Global VAR (GVAR) approaches immediately come to mind. Like the VARs considered here all such methodologies face the curse of dimensionality problem. Both alternative techniques, therefore, require some shrinkage (i.e, simplifying assumptions) to generate estimates. In the case of PVARs identification principles are, to date, not really different from the ones used in the VARs considered in this study. An advantage of our study are the time varying estimates since it is reasonable to ask whether the period since the GFC produces a structural break. Ultimately, this is an empirical question. The GVAR has many similarities with the F-VAR (e.g., see Lütkepol 2014). However, there is a priori possibly greater heterogeneity across the economies considered than is contemplated in the GVAR approach.

[19] In what follows we focus on the factor score estimates though we provide some indications about the most important variables that load into the factor scores. Factor loading estimates are relegated to an appendix.

[20] Although some applications that resort to estimating PC start out with a large number of series, occasionally over 100, there is no minimum require to proceed with this methodology. For example, Stock and Watson (2018) use PC estimation for a data set consisting of a similar number of series as in our study while others (e.g., Hatzius et. al. 2010) may start with a larger number of series but often end up finding that only a few variables load into a single principal component.

[21] These are estimated from the loadings (i.e., the coefficients of the i^{th} variable on the j^{th} factor). As a result, the scores are used as the 'variables' in (1) and are obtained from (2).

and financial factors and one monetary factor for the U.S., the Eurozone and Japan.[22] We explain below to the interpretation of each factor.

Figures 1A through 1D display the real, financial, and monetary factor scores for the four economies in our study. The various figures also highlight key events in each economy although the GFC is an episode that is common to all four economies even if its duration differs across the economies considered (e.g., see Dominguez, Hashimoto, and Ito 2013). Two factors describe monetary conditions in China, with the interest rate dominating the first factor and reserve requirements and the monetary base generally describing the second factor. A slightly different way of interpreting the monetary factors for China is to view external pressures on monetary policy as loading into the first factor while domestic monetary conditions provide an explanation for the second factor.

One real factor is identified for China while two real factors are identified for each of the remaining three economies. Figure 1 suggests that, for the US, the first real factor describes aggregate supply – note the sharp drop around 2008 followed by the subsequent rapid recovery thereafter – while the second factor identifies aggregate demand. The reason is that inflation and inflation expectations provide, by far, the largest factor loadings for the first factor, while real GDP growth and growth forecasts are the most important loading factors for the second real factor. In the case of the Eurozone and Japan the first factor depicts aggregate demand whereas aggregate supply is captured by the second factor. In the case of China, the period under study suggests that the lone real factor captures aggregate supply conditions in that economy.[23]

The figures also permit a comparison of estimates based on the full sample versus ones obtained by rolling samples that are each five years long. Despite the different estimation approaches the patterns for both sets of factor scores broadly resemble each other although rolling estimates tend to be, not surprisingly, more volatile than results obtained over the entire sample. However, there are a few exceptions. For example, in the case of the Eurozone, real factors appear more sensitive to the rolling versus full sample estimates than is the case in the other economies

[22] Another oft-used rule of thumb is to include only factors that can explain at least 70% of the total variation among all factors. We did experiment with adding one more real factor for China but our conclusions were unchanged.

[23] A referee correctly points out that aggregate demand considerations play an increasingly important role in China's macroeconomic policy since the GFC. Empirically, however, this increased emphasis has yet to emerge empirically.

examined. This finding may be due to the fact that the Eurozone real economic conditions are clearly seen as deteriorating after the GFC while the same is not true for the US case. Clearly, this captures the impact of the Eurozone sovereign debt crisis.

In the case of China the rolling scores for the monetary factor indicate a premature monetary tightening as the GFC approaches which is then followed by a dramatic loosening once the crisis arrives and its full impact becomes evident. The sustained loosening of monetary policy in Japan, especially since the introduction of quantitative and qualitative easing (QQE) beginning in 2013, is also evident from Figure 1D (bottom right). Also worth noting is that the financial factor displays different properties from the monetary factor. This is true for all four economies considered.

Turning to the US factor scores, the various QE episodes suggest that these influenced both financial factors. Once again it is worth noting that while two financial factors are identified for the US, the Eurozone and Japan, only one factor describes the relevant data for China. Generally, in the three economies concerned, asset prices (i.e., government bond yields, stock returns) load onto the first factor while the second factor describes broad credit conditions since housing prices and credit conditions (i.e., loans) largely explain variations in this factor. In the case of China the financial factor is largely explained by the relatively large loadings from domestic interbank interest rates and property prices. Hence, it is appropriate to think of the financial factor for China as an aggregate indicator of financial conditions.

As noted in the previous section it is not obvious that estimation of factor scores from data for individual economies effectively omits the influence of spillover effects from other large economies. After all, factor scores are obtained from observed data that reflect external influences. Therefore, as an alternative, we also estimate factor scores based on panel estimation where the variables considered are restricted to those that are largely comparable across the four economies considered. In the case of the monetary factor we only consider a policy rate or a representative interest rate (e.g., in the case of China and Japan).[24] Turning to the real factor, inflation, inflation expectations, real GDP growth and growth forecasts as well as oil prices form the vector from which real factor scores are obtained. Finally, in the case of the financial factor,

[24] For Japan this is the overnight call rate; for China the 1 year central bank benchmark rate.

we consider housing prices, loans, a short-term interest rate, stock market returns and the VIX. The resulting factor scores represent global real, financial and monetary factors. For each of the four economies two global real and financial factors are identified. One global monetary factor is obtained.

The behavior of the first real global factor differs substantially across the four economies considered with China's case revealing a great deal of stability although real economic conditions decline smoothly over time. For the US the dip around the GFC is quickly reversed. The same is true for the Eurozone although two declines are observed. The first one is obviously associated with the GFC while the second one occurs around the time of the sovereign debt crisis. Japan's experience is the most volatile one. However, other than at the end of the GFC, factor scores are largely unchanged throughout the entire sample. Accordingly, one may interpret the first factor as representing global aggregate demand influences on each economy considered. This is also confirmed by the fact real GDP growth and growth forecasts load into this factor.

Examination of the factor loadings suggests the second real factor represents aggregate supply influences. Here the factor sores are broadly similar across the four economies even though the recovery post-GFC is seen as arriving later in Japan than elsewhere. The behavior of the global financial factor mirrors ones reported above for each individual economy. Hence, the first financial factor captures overall financial conditions while the second factor is explained by evolving credit conditions. Finally, global monetary conditions are shown alongside monetary conditions for each of the economies in our study. The global monetary factor captures the loosening trend that began around 2008 and this reflects a sharp easing of monetary conditions followed by continued loosening with only a brief reversal around 2013; that is, when the Fed began to taper its purchases of Treasuries. It should be noted that estimates for the global factors were obtained only for the full sample. Factor score estimates are relegated to the appendix.

(b) Impulse Response Analysis

Three sets of econometric models are estimated as outlined in the previous section. Given the large volume of results only small selections are discussed here. Testing for the appropriate lag length suggests that, in the overwhelming number of cases, reliance on the AIC criterion

produces the most consistently plausible set of results. Nevertheless, relying on other criteria (e.g., SC, Hannan-Quinn, Likelihood ratio) produces similar conclusions.

We consider the estimates for the various models for each economy in turn. The conventional model (i.e, equations (1) and (2)) for China finds that inflation responds positively to a tightening of the domestic monetary factor. This could be a Chinese version of the so-called price puzzle[25] although it is noteworthy that a shock to the domestic component of monetary policy results in a negative response to the factor that is interpreted as external pressure on domestic monetary policy (i.e., principally the exchange rate). Clearly, domestic and external pressures on China's monetary policy can be in conflict with each other. The only other variable in the standard VAR that responds significantly to various shocks is real GDP growth, and then again only to shocks emanating from the monetary sector. The statistical relevance of monetary policy, however, may well mask influences insufficiently well captured by the conventional model, since it omits a separate role for financial factors.

Next, we turn to the F-VARs estimated using either rolling or full sample factor scores. To conserve space we focus on the rolling factor scores since these are better able of capturing changes in the factor scores due to the GFC and Eurozone sovereign debt crisis, to give just two examples. Relying on factors to estimate responses to various shocks in China reveals that while real and monetary factors continue to be linked, as was true in the conventional model, it is also the case that the second monetary factor, which represents credit conditions, responds to the financial factor which could be interpreted as a proxy for financial stability. The response is negative an indication that a rise in financial instability results in a loosening of monetary conditions that are driven by domestic factors.

Turning to the US case there are two conventional variables that respond significantly to the others in the VAR, namely inflation which reacts negatively to a tightening of monetary policy (i.e., a rise in the policy rate), and the nominal effective exchange rate (NEER) which rises (i.e., appreciates) when there is a tightening of monetary policy. In contrast, the F-VAR based on the rolling factor scores estimates provide a richer set of results. Most notable of all is that both

[25] This refers to the finding that a tightening of monetary policy ought to reduce inflation instead of a rise. As Sims (1992) and others have argued, this result is likely due to a mis-specification in standard small scale VARs.

financial factors are significantly linked to the two real factors, but the first factor especially (i.e., aggregate supply). Furthermore, there are significant links between the financial factors, especially the one that captures credit conditions, and monetary policy. Indeed, there is feedback from monetary to credit conditions. Specifically, greater financial stability - that is, a positive shock to the first financial factor, which loads onto asset prices, results in a jump in the policy rate. Similarly, more financial stability results in a loosening of credit conditions.

Next, we consider the case of the Eurozone. The most important recipient of shocks in the conventional model is inflation. Inflation is seen to rise when there is a positive shock to real GDP growth, to fall when monetary policy is tightened, and rise when the exchange rate depreciates. A depreciation of the euro results in a tightening of monetary policy, possibly as a side effect of the rise in inflation. The F-VARs clearly identify an important role once again for financial factors. In particular, links between real and financial factors of the kind found for the US also emerge in the Eurozone. Similarly, greater financial stability leads to a tightening of monetary policy. These results suggest that the outcome of the transmission mechanism, as defined in our study, for the Eurozone broadly resembles that of the U.S. because of similarities in the reaction especially of inflation to the variety of shocks that were considered.

The standard VAR for Japan finds that both inflation and real GDP growth respond to the exchange rate. More precisely, a shock that produces a depreciation of the yen stimulates real GDP growth and produces a relatively larger response to inflation. Of the four economies considered, Japan is the only example where a shock to inflation leads to a decline in real GDP growth. The textbook trade-off is not found in the other conventional models estimated here. The F-VAR estimates for Japan are broadly similar to the ones reported for the US and the Eurozone although no feedback effects of the kind mentioned above are found. Nevertheless, a positive relationship between aggregate supply (i.e., the second real factor) and a tightening of monetary policy and credit conditions is obtained while a positive aggregate demand shock (the first real factor) leads to a tightening of monetary policy.

(c) The International Transmission of Shocks

A critical consideration in modelling the transmission of shocks consists in accounting for the impact of external shocks. Consequently, we now present the results of the impact of US shocks,

arguably the most important source of external shocks for the remaining three economies in the sample, on the F-VAR model where the factors are estimated in a rolling fashion.[26]

Tables 1A through 1C show the estimated coefficients from US real, financial, and monetary factors. Each one of these factors is lagged one period.[27] Perhaps the most notable result is that typically it is US financial and monetary shocks that impact the domestic real economy in China, the Eurozone, and Japan. There are relatively few instances where US real shocks impact the other economies in our sample. Nevertheless, a negative US aggregate demand shock produces a reduction in the real factor for China, that is, a fall in aggregate supply.

An improvement in US financial conditions is seen as loosening the PBoC's monetary policy. In contrast, a tightening by the US Federal Reserve is inflationary for China.[28] In the case of the Eurozone a loosening of US credit conditions (the second financial factor) impacts several macroeconomic variables in the Eurozone, including aggregate supply, Eurozone asset prices, as well as a tightening of Eurozone monetary policy. In addition, a tightening of US monetary policy results in a contraction of aggregate supply in the Eurozone. Turning to the case of Japan an improvement in US financial conditions (the first financial factor) is seen as producing an effect in the same direction for Japan. Improving US credit conditions lead to a tightening of BoJ monetary policy. Overall, the spillovers from US monetary policy are quite modest. Indeed, the influence of external shocks more generally is rather small. While this does not suggest a de-coupling of business cycles as such, it appears that in large and systemically important economies the principal sources of macroeconomic fluctuations are domestic.[29]

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[26] We also considered, via a dummy variable, the possibility that the timing of certain events (i.e., QE1, QE2, and QE3 in the US) may have exerted a separate influence on real, financial, and monetary factors in all four economies (results not shown). The effects were found to be weak to non-existent for China and Japan and strongest for the US and the Eurozone. In the US case these events were associated with lower real economic activity and a deterioration of credit conditions (i.e., the second financial factor). In the Eurozone, these events loosened monetary conditions and a deterioration of asset prices (i.e., the first financial factor). We return to the role of QE in the US when discussing time-varying results.

[27] We did experiment with longer lags wherever possible but our conclusions are unchanged (results not shown).

[28] Likely via a currency depreciation even if this is limited in nominal (but not on real) terms.

[29] It is interesting to note that the IMF's spillover reports has shifted away from focusing on the so-called systemic five economies (the four in our data set and the UK) to a more thematic view of spillovers and their effects. Perhaps this reflects a greater emphasis on domestic considerations in policy making as well as the methodological challenges in identifying spillovers. See https://www.imf.org/en/Publications/SPROLLs/Spillover-Reports .

We further investigate the global transmission of shocks by asking whether the global element of real, financial, and monetary factors discussed earlier might have an exogenous influence in each economy considered. In this manner we allow for a linear combination of external shocks generated in all four economies to exert a macroeconomic effect, call it a global effect, in each economy. Table 2 presents some key results. Generally speaking the results parallel those in Table 1. There is comparatively little influence from global real shocks. In contrast, there is more evidence of global financial and monetary shocks influencing all four economies examined here. For example, global financial and credit conditions affect real GDP growth, monetary policy, and the exchange rate in China. The easing of financial and credit conditions is seen as improving macroeconomic conditions in China as well as leading to a tightening of monetary policy by the PBoC. The same factors lead to an appreciation of the exchange rate. More interestingly, a tightening of global monetary condition leads to a loosening of both factors that describe PBoC monetary policy. Hence, monetary policy in China is seen as attempting to offset any tightening elsewhere.

In the US an improvement in aggregate supply conditions produces a rise in the 10-year yield. Otherwise, financial conditions, together with the global element of monetary policy, represent the most important influences on US economic conditions. Improvements in both financial and credit conditions produce more inflation, higher long-term yields and higher real GDP growth. A tightening by the US Federal Reserve results in lower real GDP growth and a reduction in the 10-year government bond yield.

Changes in global financial and credit conditions produce mixed effects on Eurozone real GDP growth. Otherwise, the results are not dissimilar to the US case with one notable exception, namely that the global element of monetary policy has no statistically significant impact on any of the Eurozone real and financial factors. Finally, in the case of Japan, only the first financial factor (asset prices) affects real GDP growth whereas a tightening by the BoJ is seen as reducing economic growth. In general, global factors have the weakest influence on Japan while the strongest impact is found for China.

Finally, we consider whether the emergence of China as a systemically important economy influences the other three economies. The empirical results (not shown here) suggest significant interdependence between the Eurozone and China. Real, financial and monetary conditions in

China are found to have a statistically significant impact on real, financial, and monetary conditions in the other economies. Indeed, both monetary factors (i.e., predominantly domestic and externally oriented monetary components) are seen as influencing aggregate demand in the Eurozone. In contrast, only monetary conditions in Japan are significantly impacted primarily by both monetary factors from China. The US represents the intermediate case with real economic conditions in China influencing both US aggregate demand and aggregate supply. Moreover, the external portion of monetary conditions in China (i.e., dominated by the exchange rate) impact US credit conditions and US monetary conditions.

(d) Time-Varying Estimates

It is natural to ask whether any breaks in the relationships under study may have influenced the results reported above. We consider four events that may have disrupted the monetary policy transmission mechanism. They are: QE1 (2008Q4), QE2 (2010Q4), QE3 (2012Q3), and the taper tantrum (2013Q2). Figure 2 and 3 display selected impulse responses to a domestic monetary policy shocks at the time these events took place.[30] We examine how a positive monetary shocks (i.e., a loosening of monetary policy) affects real GDP growth and financial conditions.

When the TV-VAR is estimated then, as seen in Figure 2, the responses are virtually indistinguishable for all the events considered. In other words, real GDP growth and inflation respond the same way around the time of the events considered. Nevertheless, it is interesting that while a monetary policy tightening (i.e., a positive shock) produces a contraction in economic activity in China, as well as a reduction in inflation, the impulse responses for the other three economies differ. Hence, for the U.S., the Eurozone and Japan, the eventual GDP growth contraction occurs with a longer lag ranging anywhere from 4 to 10 quarters. Moreover, only the U.S. is seen as experiencing a drop in inflation while a tightening actually raises inflation in the Eurozone and Japan, at least temporarily.

Turning to the results based on TV-FVARs we find again little or no discernible evidence of any change in the impulse responses throughout 2008 to 2013. Of course, we cannot be certain the results are consistent with the notion that QE prevented any structural break in the relationships

[30] Other dates were also considered in the period since the GFC began but the conclusions are unchanged.

of interest but this interpretation is plausible.[31] Even the taper tantrum does not appear to have altered the response of real GDP or financial conditions to a monetary shock. While the taper tantrum was a significant event, it was also short-lived, as the Fed corrected its message to financial markets in its wake. Hence, it is likely that its effects would not show up at the quarterly data frequency.

When we examine the responses to the two shocks considered, we observe some interesting difference across the four economies that provide insights that cannot be obtained from standard VARs even of the time-varying kind. First, the responses of real GDP growth to a positive monetary shock are broadly similar for the US, the Eurozone and China. However, while all three economies experience a decline followed by a recovery, suggestive of a delay (usually one quarter) after a policy change is introduced recovery is relatively faster in the U.S. and the Eurozone than in China. Whereas real GDP growth eventually turns positive in the US (about 8 quarters after the shock) growth remains negative for the Eurozone. Interestingly, a positive shock is expansionary throughout for Japan but does not appear to stimulate China's economy. Of the four economies considered China is the only one that did not engage in some form of unconventional monetary easing.[32]

Turning to the responses of the financial sector to a monetary shock, Figure 3 suggests no real impact on the financial sector in China. In contrast, the responses in the US and Japan are comparable. A loosening of monetary policy takes time to translate into an easing of financial conditions although, mirroring the results for real GDP, US financial conditions end up being looser than prior to the shock. This result is not obtained in Japan's case. Finally, the net easing result for the Eurozone does suggest that attempts by the ECB over time to reduce frictions in the

[31] It might be interesting to consider a counterfactual (e.g., what if QE had not taken place). However, this extension is left for future research.

[32] When impulse responses are evaluated using real factors instead of observed inflation and real GDP growth (see the appendix) a tightening of monetary policy produces a decline in real activity in China, the U.S., and the Eurozone. However, the effect is temporary for the U.S. while a small permanent impact is observed for China and the Eurozone with the largest drop in real activity taking place after 4 quarters for China but after 2 quarters for the Eurozone and the U.S. Japan responds positively to a monetary tightening. It is worth keeping in mind that monetary policy has been loose in Japan practically during the entire period examined. It is conceivable that a tightening in Japan is a sign of future economic improvement.

Eurozone's bank-dominated financial system, unlike the US, contributes to a net easing even if the economy does not seem to have benefited much from monetary easing.

5. Conclusions

The principal aim of this paper has been to engage in a comparison of the monetary policy transmission mechanism in China relative to three other systemically important economies, namely the US, the Eurozone, and Japan. Estimates from a conventional VAR model that uses observed macroeconomic time series are also compared with factor and time-varying factor VAR models. We also estimate a global version of real, financial, and monetary factors as well as the impact of U.S. and Chinese spillovers. Five conclusions emerge from our analysis.

First, the impact of monetary policy is more similar across the four economies in our study than an examination of real GDP growth and inflation performance alone might suggest. Second, separately estimating a financial factor is essential to obtain a proper understanding of the transmission of domestic and external shocks for all four economies in our study. Conventional models that leave out a well-defined role for financial factors omit an important element that influences the monetary policy transmission mechanism.

Third, while the impact of monetary policy in all four economies considered here is comparable, the evolution of financial factors differs across these same economies. Indeed, the main reason for differences in the transmission mechanism across the four economies stems from the behavior of the financial factor. Furthermore, there is considerable evidence of interdependence. For example, global factors are seen as having the biggest impact on the Chinese economy and the smallest effect on Japan's economy. Indeed, the Chinese economy has become as systemically important as the other three large economies considered.

Fourth, we find that interest rates, which play a critical role in the transmission mechanism in the US, the Eurozone, and Japan, are now playing an almost equally important role in China. The bottom line is that it is essential for models of the kind examined here to incorporate a role for monetary policy developments in China. It should also be noted, however, that as the so-called rebalancing of China's economy away from investment toward more consumption spending continues, it is likely that, in future, estimates for the real factor will contain both aggregate

demand and supply components and not only an aggregate supply element as assumed in our study.

Finally, there is no evidence that the great financial crisis produced a structural break in the transmission mechanism estimated in this paper at least around the dates of major monetary policy interventions by the U.S. Federal Reserve. One possibility is that QE helped prevent such breaks. In particular, QE in the US seems to have been able to boost economic activity as well as ease financial conditions even if this took several quarters to materialize.

Since spillovers to and from the systemically important economies are present it is likely that these extend to the rest of the global economy. Depending on the size, nature, and persistence of these spillovers the results of this paper suggest that incentives exist for greater international cooperation which has seemingly waned since the worst moments of the financial crisis of 2008-9.

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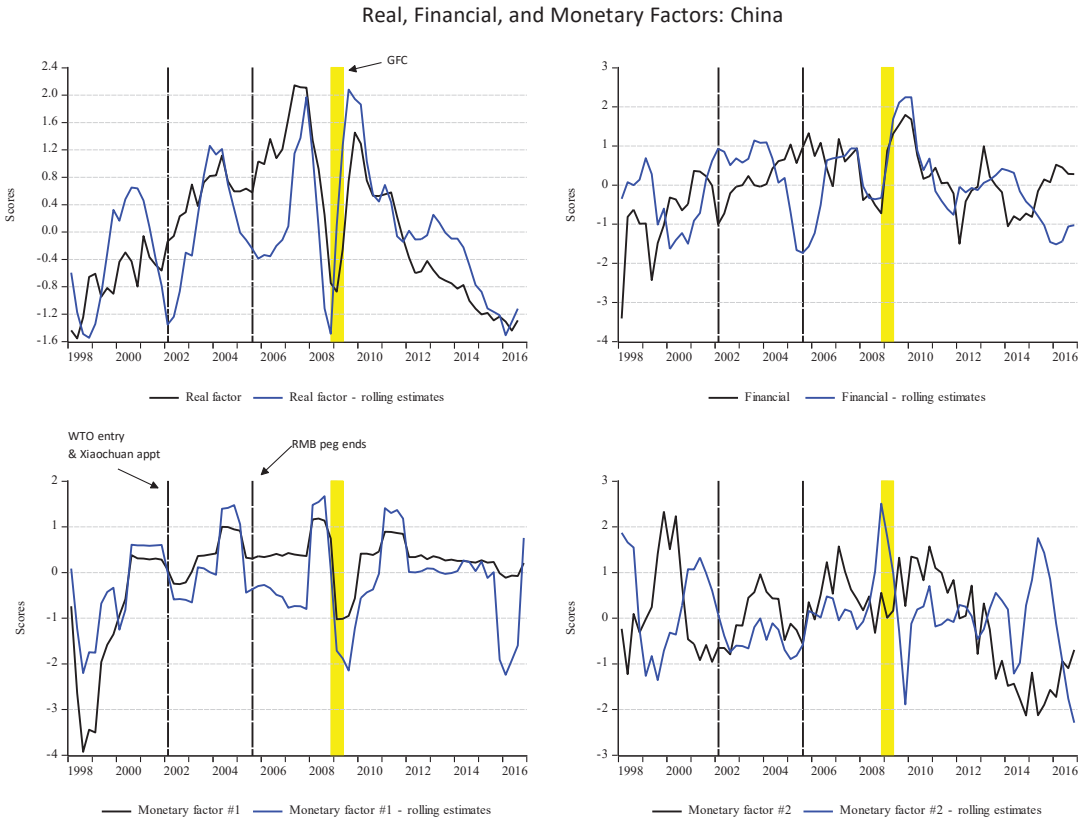
Figure 1A Factor Scores: Full Sample and Rolling Estimates



Note: Full samples are as follows (quarterly data), 1999Q1-2016Q3 (China), 1998Q1-2016Q3 (USA), 1999Q1-2016Q3 (Eurozone), Japan (1998Q1-2016Q3). Rolling factor scores were estimated for five year sample beginning with 1998Q1-2002Q4 and advancing the samples by two years. Therefore, the second sample is 2000Q1-2004Q4, and so on. Maximum likelihood estimation was used to estimate each factor. When more than one factors is estimated the varimax method is used to rotate the factors. More detailed factor scores are available from the second author or in a separate unpublished appendix. The graphs highlight some of the key events that play a role in subsequent estimation. The dating of the GFC for each economy is from Domniguez et. al. (2013).

Figure 1B Factor Scores: Full Sample and Rolling Estimates

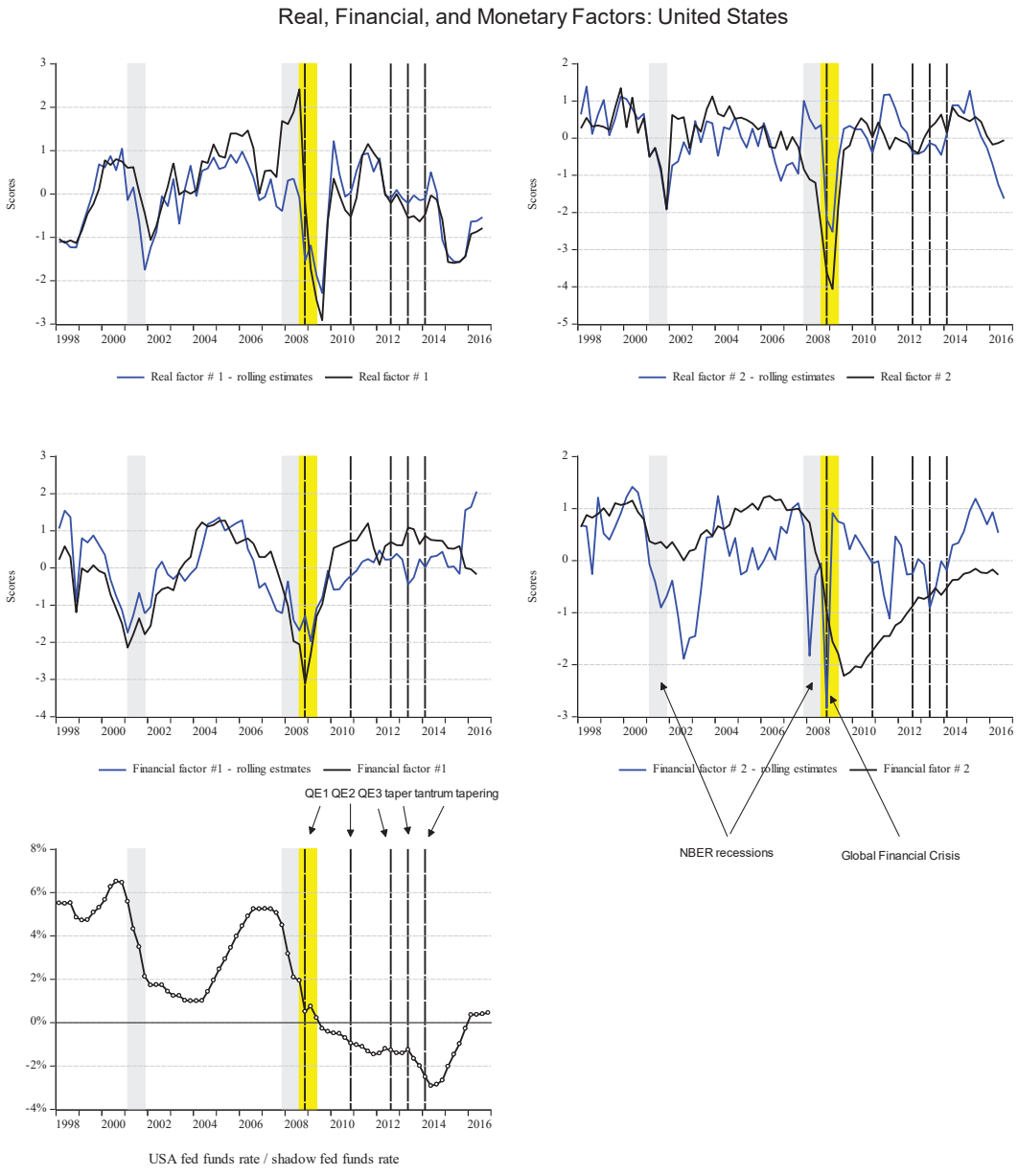


Figure 1C Factor Scores: Full Sample and Rolling Estimates

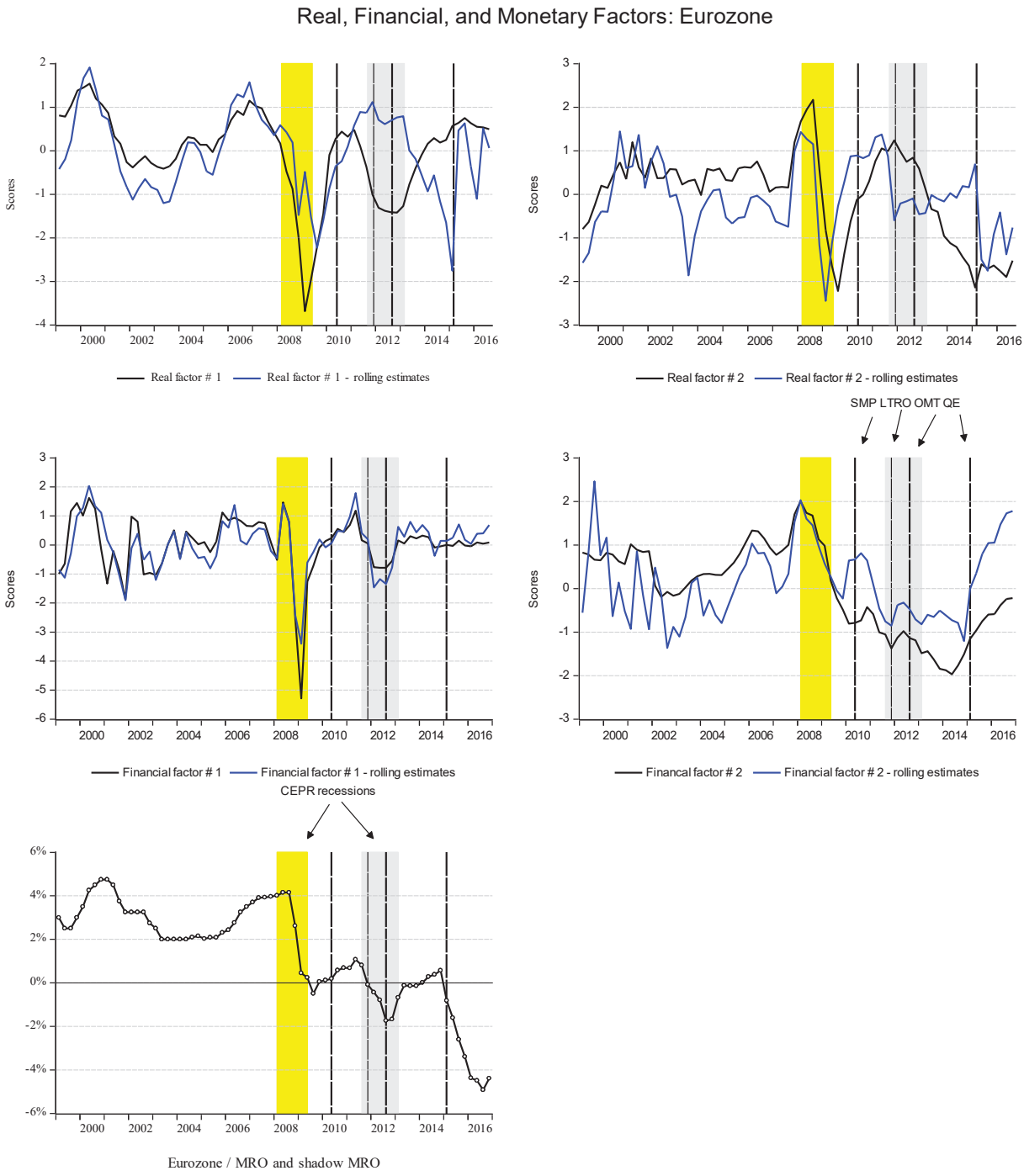


Figure 1D Factor Scores: Full Sample and Rolling Estimates

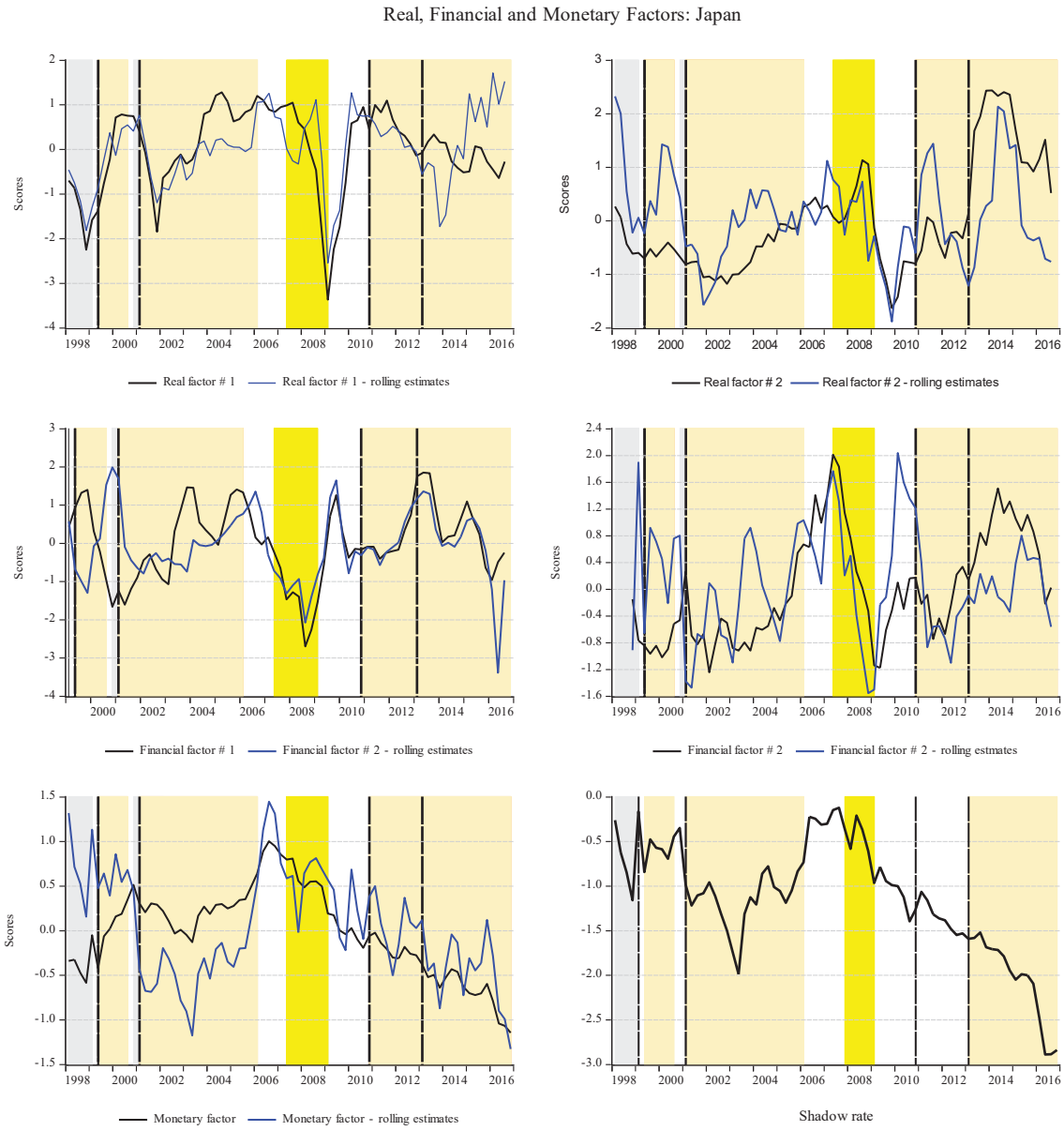


Figure 2 TV-VAR Impulse Responses: Monetary Policy Shock on Real GDP Growth and Inflation

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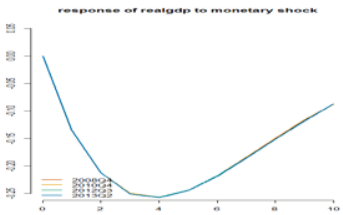
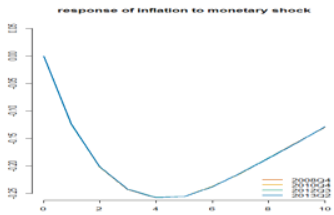
  </td><td>CHINA
  </td></tr>
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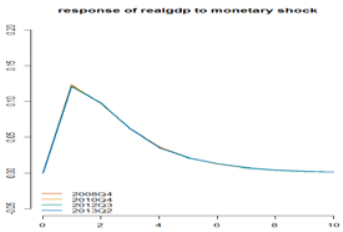
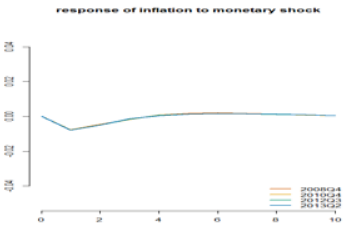
  </td><td>USA
  </td></tr>
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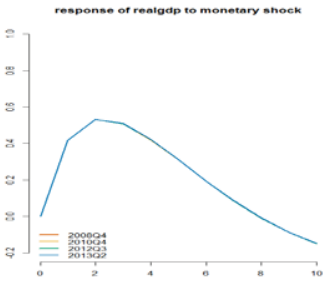
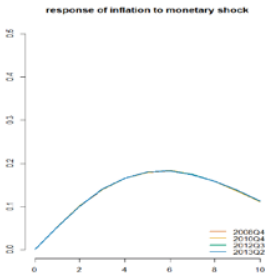
  </td><td>Eurozone
  </td></tr>
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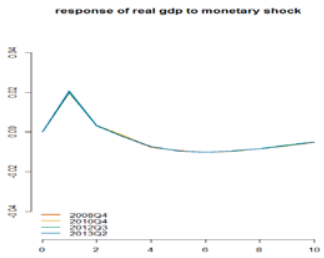
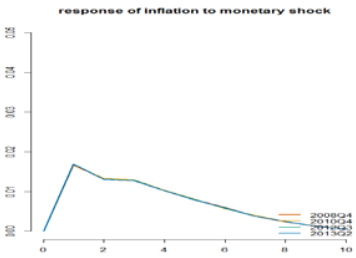
  </td><td>Japan
  </td></tr>
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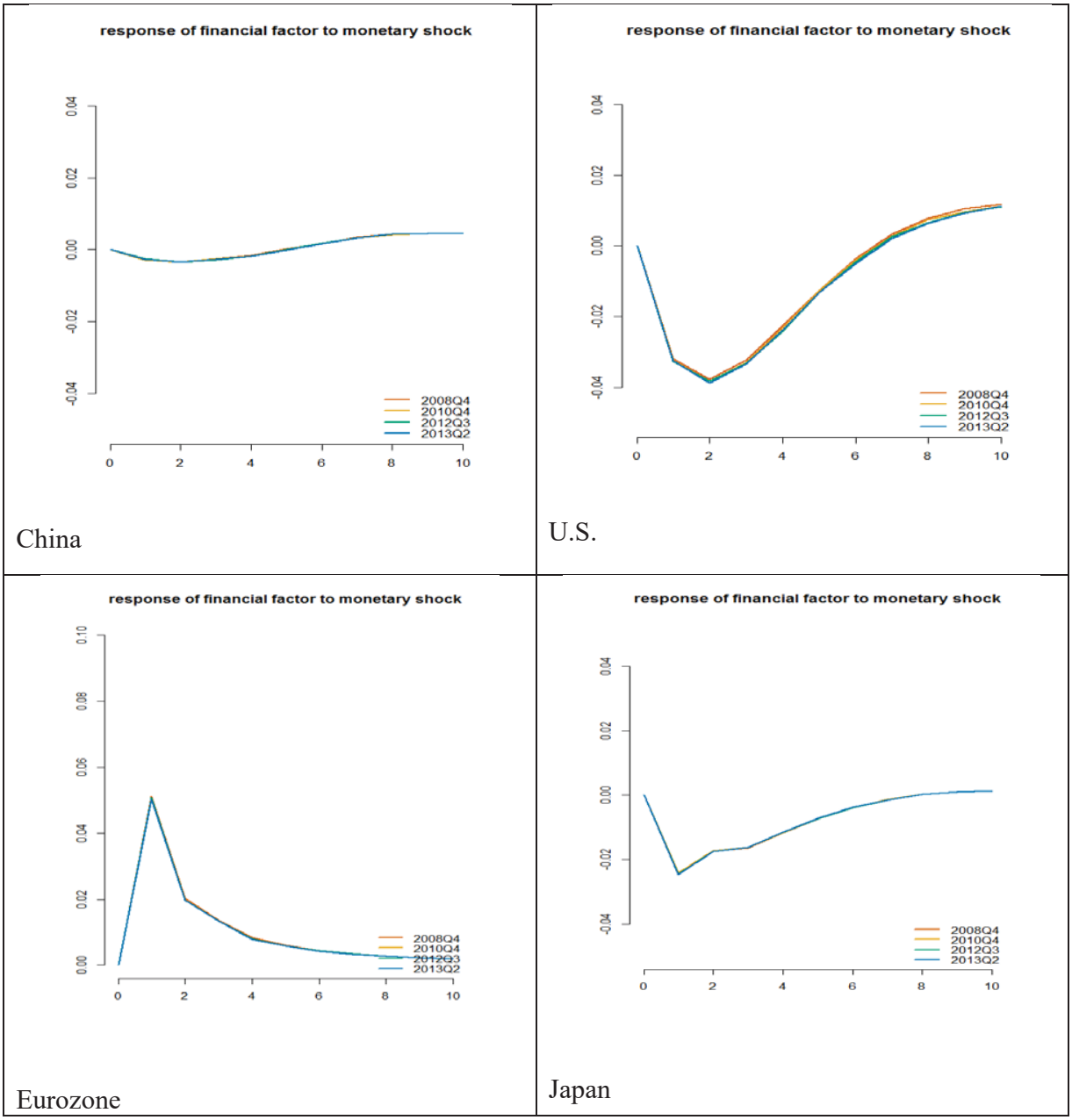
Note: Based on a TV-VAR using specification (2).

Figure 3 Time-Varying VARs: Impulse Responses from a Monetary Shock to the Financial Sector



Note: See note to Figure 2.

Table 1A Exogenous Shocks: FVAR with Rolling Factor Scores: China

	Real factor	Financial factor	Monetary factor 1	Monetary factor 2
1st Real factor USA(-1)	0.08	0.08	0.08	-0.12
	(0.09)	(0.10)	(0.14)	(0.11)
	[0.95541]	[0.83702]	[0.53925]	[-1.03837]
2nd Real factor USA(-1)	-0.14	-0.09	0.10	0.14
	(0.07)	(0.08)	(0.11)	(0.09)
	[-2.20369]	[-1.11365]	[0.90764]	[1.61322]
1st Financial factor USA (-1)	-0.11	-0.16	-0.04	-0.43
	(0.07)	(0.09)	(0.12)	(0.10)
	[-1.51174]	[-1.82503]	[-0.31124]	[-4.36059]
2nd Financial factor USA(-1)	-0.07	-0.17	-0.03	-0.04
	(0.07)	(0.08)	(0.12)	(0.10)
	[-0.93322]	[-2.04725]	[-0.24703]	[-0.38810]
Fed funds rate - change(-1)	0.17	0.01	-0.13	0.53
	(0.14)	(0.16)	(0.23)	(0.19)
	[1.20104]	[0.07202]	[-0.54412]	[2.79553]

Note: VAR as described in the text. AIC criterion used to select lag length (=2). * are coefficients that are statistically significant at the 1% (** 5%) level of significance. Coefficient estimate followed by standard error in parenthesis, and t-statistic in brackets. To conserve space the constant is omitted. The fed funds rate is the observed rate until 2008Q4. Thereafter the shadow rate us used

Table 1B Exogenous Shocks: FVAR with Rolling Factor Scores: Eurozone

	1st Real factor EURO	2nd REAL factor EURO	1st Financial factor EURO	2nd Financial factor EURO	Policy rate (change)
1st Real factor USA(-1)	0.21	-0.02	-0.17	-0.11	0.17
	(0.14)	(0.14)	(0.18)	(0.15)	(0.11)
	[1.44932]	[-0.14369]	[-0.92274]	[-0.70919]	[1.56648]
2nd Real factor USA(-1)	0.04	-0.11	0.03	0.00	-0.14
	(0.13)	(0.13)	(0.17)	(0.14)	(0.10)
	[0.28984]	[-0.86558]	[0.18924]	[0.02035]	[-1.33913]
1st Financial factor USA(-1)	0.15	0.04	0.18	0.09	0.11
	(0.12)	(0.12)	(0.15)	(0.13)	(0.09)
	[1.24987]	[0.38443]	[1.14019]	[0.65487]	[1.15787]
2nd Financial factor USA(-1)	0.02	0.40	0.28	0.16	0.27
	(0.13)	(0.12)	(0.16)	(0.13)	(0.10)
	[0.13467]	[3.33508]*	[1.76904]**	[1.16575]	[2.80244]*
Fed funds rate - change(-1)	0.13	-0.58	0.02	-0.21	-0.15
	(0.24)	(0.23)	(0.30)	(0.26)	(0.18)
	[0.52087]	[-2.54059]*	[0.05698]	[-0.83477]	[-0.79607]

Note: see note to Table 1A. 1 lag used in estimation of the FVAR based on the AIC criterion. Yellow shading indicates statistical significance at the 10% level. Also, see Table 1A. The policy rate for the Eurozone is spliced with the shadow rate.

Table 1C Exogenous Shocks: FVAR with Rolling Factor Scores: Japan

	1st Real factor JAPAN	2nd Real factor_JAPAN	1st Financial factor JAPAN	2nd Financial factor JAPAN	Policy rate - change
1st Real factor USA(-1)	-0.00	0.19	0.06	-0.13	0.05
	(0.08)	(0.08)	(0.10)	(0.08)	(0.05)
	[-0.05095]	[2.52042]*	[0.56550]	[-1.68360]	[0.91656]
2nd Real factor USA(-1)	0.07	0.07	-0.12	0.01	-0.08
	(0.08)	(0.08)	(0.10)	(0.08)	(0.06)
	[0.84067]	[0.93144]	[-1.12292]	[0.11201]	[-1.45561]
1st Financial factor USA(-1)	0.04	-0.07	0.52	-0.02	0.02
	(0.09)	(0.09)	(0.12)	(0.09)	(0.07)
	[0.42447]	[-0.80866]	[4.25532]*	[-0.26682]	[0.29513]
2nd Financial factor USA(-1)	-0.02	-0.07	0.12	-0.05	0.09
	(0.06)	(0.06)	(0.08)	(0.06)	(0.04)
	[-0.40557]	[-1.16955]	[1.58574]	[-0.87188]	[2.19340]**
Fed fuds rate - change(-1)	0.15	-0.05	-0.16	0.16	-0.12
	(0.11)	(0.11)	(0.14)	(0.11)	(0.08)
	[1.37846]	[-0.49048]	[-1.10482]	[1.41321]	[-1.51165]

Note: See note to Table 1A. 1 lag used based on the AIC criterion. The policy rate for Japan is the shadow rate throughout.

Table 2A Exogenous Shocks: FVAR with Global Factor Scores: China

CHINA	GDP growth	Inflation	3m Tbill rate	1st Monetary factor	2nd Monetary factor	Exchange rate
2nd Global Real factor(-1)	-2.05	0.67	-0.27	-2.39	-3.43	-1.26
	(2.41)	(2.06)	(1.48)	(0.53)	(1.58)	(2.23)
	[-0.85117]	[0.32629]	[-0.18006]	[-4.48242]*	[-2.17525]**	[-0.56611]
1st Global Financial factor(-1)	0.52	0.16	0.15	0.14	-0.11	-0.27
	(0.15)	(0.13)	(0.09)	(0.03)	(0.10)	(0.14)
	[3.47344]*	[1.25403]	[1.61660]	[4.31630]	[-1.16345]	[-1.96935]**
2nd Global financial factor(-1)	0.20	-0.12	0.23	0.06	0.05	0.03
	(0.18)	(0.16)	(0.11)	(0.04)	(0.12)	(0.17)
	[1.07882]	[-0.78742]	[2.08660]**	[1.57566]	[0.45276]	[0.15978]
Global Monetary factor(-1)	0.44	-0.17	0.14	-0.03	-0.38	-0.73
	(0.28)	(0.24)	(0.17)	(0.06)	(0.18)	(0.26)
	[1.54867]	[-0.72792]	[0.82830]	[-0.50101]	[-2.04059]**	[-2.79965]*

Note: Darker shading are coefficients statistically significant at the 1% (lighter shading 5%). Also see note to Table 1A. Interest rates are in first differences and exchange rates in first log differences.

Table 2B Exogenous Shocks: FVAR with Global Factor Scores: USA

USA	GDP growth	Inflation	10 yr Treasuries	Fed funds rate	NEER
2nd Global Real factor(-1)	-12.40	-1.88	3.22	0.32	3.38
	(7.47)	(1.89)	(1.20)	(1.38)	(12.12)
	[-1.65935]	[-0.99930]	[2.68214]*	[0.23412]	[0.27889]
1st Global Financial factor(-1)	0.04	0.18	0.10	-0.12	-0.10
	(0.42)	(0.11)	(0.07)	(0.08)	(0.68)
	[0.09444]	[1.67925]**	[1.45591]	[-1.50563]	[-0.14735]
2nd Global Financial factor(-1)	0.94	0.03	0.21	0.14	-0.61
	(0.50)	(0.13)	(0.08)	(0.09)	(0.81)
	[1.86751]**	[0.27587]	[2.67142]*	[1.51264]	[-0.74936]
Global Monetary factor(-1)	-0.75	0.10	-0.00	-0.14	-0.87
	(0.43)	(0.11)	(0.07)	(0.08)	(0.69)
	[-1.76022]**	[0.96323]	[-0.03306]	[-1.78810]**	[-1.25420]

Table 2C Exogenous Shocks: FVAR with Global Factor Scores: Eurozone

EUROZONE	GDP growth	Inflation	10 yr bond yield	Policy rate	Exchange rate
2nd Global Real factor(-1)	-1.29	-1.18	3.14	4.00	52.71
	(3.04)	(2.27)	(1.53)	(2.44)	(32.94)
	[-0.42349]	[-0.51825]	[2.04861]**	[1.64038]	[1.60015]
1st Global Financial factor(-1)	0.50	0.03	0.05	0.34	-0.57
	(0.12)	(0.09)	(0.06)	(0.10)	(1.35)
	[4.00610]*	[0.34682]	[0.83782]	[3.36123]*	[-0.42240]
2nd Global Financial factor(-1)	1.57	0.22	0.86	0.98	-5.20
	(0.73)	(0.55)	(0.37)	(0.59)	(7.95)
	[2.14437]**	[0.39904]	[2.32181]*	[1.67157]	[-0.65437]
Global Monetary fator(-1)	-0.25	-0.00	-0.05	-0.06	2.02
	(0.18)	(0.13)	(0.09)	(0.14)	(1.91)
	[-1.40256]	[-0.00471]	[-0.53123]	[-0.40071]	[1.05748]

Table 2D Exogenous Shocks: FVAR with Global Factor Scores: Japan

JAPAN	GDP growth	Inflation	10 yr bond yield	Policy rate	Exchange rate
2nd Global Real factor(-1)	-9.99	-6.28	1.06	0.93	38.58
	(7.20)	(3.03)	(0.89)	(1.19)	(28.97)
	[-1.39]	[-2.07]**	[1.19]	[0.78]	[1.33]
1st Global Financial factor(-1)	0.85	-0.07	0.054	0.08	1.53
	(0.30)	(0.12)	(0.037)	(0.05)	(1.19)
	[2.86]*	[-0.58]	[1.46]	[1.70]**	[1.28]
2nd Global Financial factor(-1)	-0.22	0.06	-0.003	0.001027	-0.83
	(0.42)	(0.18)	(0.05)	(0.07)	(1.71)
	[-0.51]	[0.36]	[-0.05]	[0.01]	[-0.49]
Global Monetary factor(-1)	-0.40	-0.08	0.04	0.06	-0.49
	(0.24)	(0.10)	(0.03)	(0.04)	(0.95)
	[-1.71]**	[-0.76]	[1.32]	[1.42]	[-0.52]

APPENDIX – VARIABLES EMPLOYED[33]

A. China

Real economy	Financial	Monetary Policy
Consumer price index	Foreign exchange reserves (US dollars)	NEER
Economic Climate Indicators--- Leading Index	Stock market index (Shanghai/Shenzhen)	M2
Real GDP Growth Rate	Property prices	Required reserve ratio (RRR)
Energy production (coal production) indicator[34]	Total Loan	Central Bank Benchmark Interest Rate: 3 Month or Less
Real GDP Forecast[35]	Interbank Offered Rate: Weighted Avg	Central Bank Benchmark Interest Rate: 1 Year
Inflation forecast		
Current account balance/ Nominal		
oil price inflation		

B U.S.

Real economy	Financial	Monetary Policy
Real Gross Domestic Product	Stock market index （Wilshire 5000）	Wu-Xia shadow federal funds rate (From 2009Q1 to 2016 q4)
Personal consumption expenditures (implicit price deflator)	Total Credit to Private Non-Financial Sector	Effective Federal Funds Rate (From 1990Q1 to 2008 q4)
Real GDP Forecast	Domestic Banks Tightening Standards for Loans	

[33] All the variables for factor analysis are stationary. If the original variable is not stationary we use 100 times annualized log difference (i.e., log X(t)-log X(t-4)) or annualized difference (i.e. X(t)-X(t-4)) to obtain the stationary variable. Some variables are available at the monthly or daily frequencies. We average them to convert these data to quarterly data.

[34] There are several missing observation for this variable. We use interpolation method to fill the gaps.

[35] For China's real GDP growth rate and inflation forecast, we average monthly data from Consensus Economics to get the quarterly data from 2005 to 2016, and we use the World Economic Outlook annual forecasts before 2005 and employ cubic method interpolation to obtain quarterly data.

Inflation forecast	Long-Term Government Bond Yields: 10-year	
Unemployment Rate	3-Month Treasury Bill	
oil price inflation	All-Transactions House Price Index	

C. Eurozone

Real economy	Financial	Monetary Policy
Real GDP Forecast	Monetary aggregates (M3)	Central Bank Policy Rate (interest rate on the main refinancing operations From 1998Q1 to 2004Q2
Inflation forecast	Money Market Rate	European Central Bank shadow rate (Wu-Xia version) From 2004Q3 to 2016 q4
Consumer price inflation (HICP[2015=100])	Domestic credit	
Real Gross Domestic Product (Euro/ECU series)	Euribor 1-year	
Unemployment	Euro area 10-year Government Benchmark bond yield	
oil price inflation		

D. Japan

Real economy	Financial	Monetary Policy
Real GDP Growth Rate	Stock market index (Nikkei 225 Stock)	M3
Effective Foreign Exchange Rate: Nominal	Bonds Yield (10 years)	Uncollateralized overnight call rate
Consumer Price Index	JREI Home Price Index	Shadow rate
Current Account/Nominal GDP	Bonds Yield (3 months)	
Unemployment Rate	Assets: Loan: Financial Institutions (FI)	
Real GDP Forecast	Money Market Rate	
Inflation forecast	Diffusion Index: Leading Series	
oil price inflation		