HONG KONG INSTITUTE FOR MONETARY AND FINANCIAL RESEARCH

# OCEANS APART? CHINA AND OTHER SYSTEMICALLY IMPORTANT ECONOMIES

*Hongyi Chen and Pierre Siklos*

*HKIMR Working Paper No.04/2020*

March 2020

# Oceans Apart? China And Other Systemically Important Economies *

Hongyi Chen
Hong Kong Institute for Monetary and Financial Research

Pierre Siklos
Wilfrid Laurier University and Balsillie School of International Affairs

March 2020

## Abstract

For at least a decade, in policy circles, China has been considered a systematically important economy. As policy makers worldwide grapple with sluggish growth there are few studies about the extent to which the G4, which consists of the US, the Eurozone, Japan, and includes China, as a block contributes to global economic performance in a fashion that is not observed when China is omitted or treated as exogenous perhaps because of its status as an emerging-market economy. We estimate a series of panel factor vector autoregressions (VARs) because these seem best suited to exploit cross-border links and determine the relative impact of domestic and global factors. We conclude that domestic and global shocks can reinforce each other. Next, we conclude it is essential to view China on a level playing field with the US, the Eurozone and Japan if we are to better understand how shocks among these economies can interact with each other. In addition, a tightening of domestic monetary conditions results in a global deterioration in real economic conditions. This same shock also leads to global tightening of monetary policy and financial conditions. Almost 60% of the variability of the global monetary shock can be explained by shocks in global commodity factor and global real factor. We conclude that there are net benefits from greater policy coordination.

**Keywords:** Business and financial cycle synchronicity, Cross-border spillovers, factor models, time-varying panel VAR, policy coordination

**JEL code**: E32, C32, E58

---

* Email: Chen: hchen@hkma.gov.hk, Siklos: psiklos@wlu.ca

Portions of the research were undertaken while the second author was a Research Fellow at the HKIMR. He is grateful for their hospitality. To conserve space, an appendix is available from the second author containing information and results that could not be included or discussed in detail in the main body of the text. Earlier versions were presented at HKIMR and BOFIT seminars. We are also grateful for the helpful comments from an anonymous referee.

## 1. Introduction

Two notable events mark the last decade or so of economic history. They are: the rise of China as a systemically important economy and two major financial crises, the global financial crisis, followed shortly thereafter by the Eurozone sovereign debt crisis.[1] Unlike the U.S., the Eurozone, and Japan, which are economies considered systemically important, China is not yet considered an advanced economy (AE).[2] Nevertheless, according to the IMF, China is the only emerging market economy (EME) with a truly global reach suggestive of an additional, direct avenue through which global spillover effects can spread.[3] This study compares the effects of treating China as a systematically important economy that not only generates globally important shocks but also receives them, versus treating China more traditionally whereby it only exogenously impacts other large economies.

To illustrate how quickly China has grown in importance relative to the global economy consider that, on the eve of the financial crisis, the IMF reported evidence that economic shocks from China would substantially affect EMEs while their impact on AEs was believed to be considerably smaller (IMF 2007). Just over a decade later the European Central Bank (ECB) reported not only that spillovers from China to the Eurozone, and AEs more generally, are large but that China accounted for about a third of global growth since 2005 (Dieppe et. al. 2018).

While the global economy struggled to recover from the IFC, some observers expressed the hope that China would become an "engine" of global growth (e.g., Lin 2011, 2016) suggestive of positive spillovers. An older literature that emerged during an earlier era of sluggish growth would have labelled China a 'locomotive' of the global economy. Around the same time, however, some also interpreted the persistence of low inflation in AEs as partly explained by China's growing global economic impact (e.g., Eickmeier and Kühnlenz 2018) including its effect on commodity prices (e.g., Ratti and Vespignani 2015). It seems clear that the experience of the IFC contributed to this line of thought (e.g., Forbes 2016, Clarida 2018, Siklos and Bohl 2018). Our study reveals that the 'locomotive' effect of China on economic growth when it

[1] We will use the 'international financial crisis', or IFC, as a short-hand expression for both the financial crisis of 2008-9 and the European sovereign debt crisis that began in 2010. Both had global repercussions.
[2] At least according to the IMF's World Economic Outlook (WEO) country classification.
[3] WEO data reveal that China's real GDP, as a percent of global real GDP, was largely the same as the Eurozone's share (a little above 15% of global real GDP). Both are second only to the US. In 1990 China's share of global real GDP was around 2%.

simultaneously interacts in a model with the other systemically large economies, namely the U.S., Japan, and the Eurozone, is stronger than under the alternative where shocks from China are exogenous.

Outside of the real economic effects of the events singled out above is the recognition that financial shocks play a more critical role than was theretofore emphasized (e.g., see Prieto et. al. 2016, and Furlanetto et. al. 2019). While the impact of a change in the stance of monetary policy works through a transmission mechanism over a period of approximately 2 years, financial cycles can last up to 20 years. The financialization of commodity markets has also added a new dimension to the transmission of shocks and the role that monetary policy plays in the transmission mechanism (e.g., see Cheng and Xiong 2014, Chari and Christiano 2017). Accordingly, it would seem essential to explicitly allow for financial shocks to interact among the four large economies considered.

A burgeoning literature suggests a variety of mechanisms through which monetary policy combines with asset prices or credit to influence aggregate demand. To these developments one must add growing recognition that spillovers create risks and therefore opportunities for policy makers to cooperate or even coordinate policies to support stronger global economic growth. For example, as spelled out by Clarida (2018), if central banks behave as if the policy objectives of other central banks enter their reaction function, a form of policy coordination, this creates the potential for real economic benefits but also threatens the credibility of the monetary authority. Nevertheless, incorporating a role for China seems essential.

An aim of the paper is to provide new empirical evidence of the extent to which, individually and jointly, systemically important economies are an engine of global real economic conditions. In view of the rise of China's role in global economic outcomes we are especially interested in China's impact within the group of systemically important economies.

We provide evidence relying on a model that consists of four endogenous factors. They are: real, monetary, financial, and commodity price. Commodity price changes are treated as a global factor largely because prices are set in US dollars. A spate of recent papers have provided convincing evidence in favor of commodity price movements having a distinct influence on economic activity (e.g., see Alberoal and Sousa (2017), Hammoudeh et. al. (2015), and Dreschel et. al. 2019). While factors are unobserved they do permit the researcher to address the curse of dimensionality when dynamic interdependence is modeled. As a check on our results we also provide estimates that rely on observable macro-financial time series.  Further, it seems desirable to allow estimated relationships to change over time. This leads us to estimate panel vector autoregressions (PVARs) where the cross-sectional dimension is exploited.

The rest of the paper is structured as follows. Section 2 provides a literature review which motivates both the model setup and the preferred methodology. We outline factor estimation and the PVAR approach in section 3. Section 4 describes the data and provides a few stylized facts before discussing the econometric results. Section 5 concludes.

Briefly, our principal findings are as follows. The impact of a global factor rests on treating China as part of the group of systemically important economies where it endogenously interacts with the US, the Eurozone and Japan. Excluding China significantly understates its influence on the global economy. Moreover, spillover effects operate in both directions. That is, not only does China impact the U.S., Japan, and the Eurozone but monetary and financial shocks also affect China's economy. We also conclude that monetary policy shocks have a global component. As such, there is the risk that a domestic tightening can be augmented by a further global tightening with negative real economic consequences. Leaving out a role for financial shocks results in the omission of an important channel through which shocks propagate in the global economy. Finally, commodity price shocks are important, but they are found not to have domestic monetary or financial effects when estimated as a global factor. The paper concludes with a summary and some policy implications.

## 2. Literature Review

Spillovers have dominated recent discussions in the literature about the cross-border impact of monetary policy, especially since the IFC.[4] Unconventional monetary policies (UMPs) in some systemically important economies, notably the U.S., Japan, and the Eurozone, created additional sources of global spillovers. Identifying spillovers that are due purely to UMPs as opposed to

[4] Originally, the IMF's Mutual Assessment Process (MAP) focused on spillovers emanating from the systemically important economies (https://www.imf.org/en/Publications/SPROLLs/Spillover-Reports). Since 2013 the IMF examines issues that give rise to spillovers rather than the relative contribution of systemically important economies alone.

ones obtained when conventional monetary policy instruments alone (i.e., central bank policy rates) are used remains a challenge (e.g., see Lombardi et. al. 2018, Curcuru, Kamin and Rodriguez 2018). In any case, there is some recognition that monetary policy decisions taken in large economies have global consequences (e.g., Obstfeld and Rogoff 2002, Rey 2013).

Other expressions such as the coupling and decoupling of business cycles also highlight potential externalities when economic activity, particularly in systemically important economies, depends on the strength with which business cycles in different parts of the world move together. Finally, an even older literature, dating back to the 1970s, asks whether some economies can be likened to 'locomotives' that can simultaneously increase global economic activity by acting in a coordinated fashion (Wood and Jianakoplos 1978). All these expressions boil down to asking how the prevailing degree of global economic integration and business cycle synchronicity influence aggregate economic performance (e.g., see Agénor and da Silva (2018), and references therein).

The impact of global factors has also re-emerged via worries over the apparent decline in the neutral real interest rate used to explain low growth rates since the IFC (also see Holston, Laubach, and Williams 2017). Clarida (2018) argues that if the decline is truly global then a policy wherein domestic policy rates are partly set according to policy rates in foreign economies might yield substantial economic benefits. This result critically depends on central banks' coordinating their policy stance.[5] But there are potential negatives to policy coordination in the form of potential losses in central bank credibility and new challenges to central bank communication.[6]

Critical to the evaluation of the impact of expansionary policies on a global scale is the measurement of economic slack. There exist several alternatives, ranging from differencing and detrending to decompositions that extract the cyclical from the observed, that are routinely employed. The most common approach is to apply a filter to a time series. Some variant of the

[5] Coordination is defined to include "…the sharing of information regarding estimates of the unobservable inputs to policy rules such as the equilibrium real rate of interest and potential output as the considerations that would govern the timing and trajectory of a baseline policy path as well as trigger deviations from such a path." (Clarida 2018, p. 16). How, and in what form, this kind of behavior differs from cooperation is not spelled out.

[6] For example, if domestic inflation is below target but foreign inflation is above their target the optimal response is a rise in the domestic policy rate. Not surprisingly, this would not only be challenging to communicate but is likely to impact central bank credibility.

Hodrick-Prescott (HP hereafter) approach has proved popular in the literature, but criticisms have recently been raised (Hamilton 2018) while band pass filters also remain popular (e.g., Stock and Watson 2018).[7] In response, some have argued that not all cycles are the same and that Hamilton's approach is also susceptible to biases (Schüler 2018a, b). More importantly, the properties of business cycles differ from those that characterize financial cycles. As a result, business and financial cycles need not behave in the same manner and this also has implications for the degree to which they are synchronized [e.g., see Oman (2019) for the Eurozone case]. Other methodologies have also been proposed (e.g., see Shackelton 2018).

Arguably, incorporating a role for China potentially raises a few additional challenges though it is an empirical question whether they are sufficiently important to prevent including the relevant data in a macroeconometric model.[8] First, until the IFC, central banks elsewhere were increasingly reliant on a single instrument of monetary policy, namely a policy interest rate. In contrast, multiple instruments have been the order of the day for the People's Bank of China's (PBoC) monetary policy. Nevertheless, there is a growing body of evidence that the monetary policy transmission mechanism in China is not too dissimilar from the one found in other large economies (e.g., see Chen, Chow and Tillmann (2017), Lombardi, Siklos, and Xie 2018).[9]

Extant research suggests a role for a global factor in driving economic performance in the systemically important economies considered below although the importance of this factor over time remains an empirical issue. For example, Kose et. al. (2012) estimate a dynamic factor model and conclude, for a sample of over 100 countries, that the Great Moderation decreased the significance of the global factor in business cycle fluctuations.

[7] Indeed, to explain persistently low inflation rates, Stock and Watson (2018) propose an inflation rate adjusted for cyclical influences.

[8] We omit discussion of the oft-mentioned question of the reliability of Chinese data. See, for example, Pang and Siklos (2016), and references therein. Fernald et. al. (2019) is a recent contribution which concludes that Chinese data have become more reliable over time although the record for GDP is mixed.

[9] Empirical evidence relying on a wide variety of econometric techniques and identification assumptions about monetary policy shocks yields similar conclusions. A short list of studies includes Girardin, Lunven, and Ma (2017), Chen, Chow, and Tillmann (2017), Chen, Li, and Tillmann (2019), Pang and Siklos (2016), Chen and Tsang (2018), and Chen, Higgins, Waggoner, and Zha (2016).

More generally, the extent to which business cycle synchronicity has changed over time appears sample, methodology, and country or region specific.[10] Ostry and Ghosh (2013) provide a thorough overview of the issues while arguing that, in spite of the absence of a consensus concerning the degree of synchronicity in global economic activity, there are good reasons to support international policy cooperation if not coordination.

## 3. Methodology

### 3.1 Synchronicity

First, we evaluate the extent to which key business cycle related variables in the systemically important economies in our data set are synchronized. Table 1 summarizes the indicators employed. These range from published estimates of downturns and upturns in overall economic activity, as in the business cycle chronologies published by the NBER in the U.S., the CEPR for the Eurozone and the JCER for Japan,[11] to companion ones produced by the OECD and the ECRI, to ones constructed from estimation of gaps, that is, deviations from some trend. Estimates are for the HP filter (Hodrick and Prescott 1997), the Baxter-King band pass filter (Baxter and King 1999), and, more recently, Hamilton's filter (Hamilton 2018) developed in response to concerns about the properties of the HP filter. The notes to Table 1 provide estimation details, and we follow the choices made by many other researchers, to enhance the comparability of our estimates with ones published in the relevant literature. Alternatively, as in Burnside, Eichenbaum, and Rebelo (2016), a moving average filter can be used to explain deviations away from some fundamental value. The authors resort to this kind of filter to explain developments in housing markets which have become a critical barometer of the state of the financial system.

Since it is unclear, a priori, whether one indicator is better able to faithfully capture business cycle characteristics in the data than another, we also combine the various estimates in two different ways. The first is known as the 'wiring ratio' (e.g., see Jordà, Schularick and Taylor 2011) which indicates how the various indicators synchronize to generate a likelihood that there

[10] There is a large literature on synchronicity at the aggregate economic level which cannot be reviewed here. See, however, Henzel and Wieland (2017), Flood and Rose (2010) for inflation, and Stock and Watson (2005), De Haan, Inklaar, and Jong-A-Pin (2008) for output and the business cycle more generally.
[11] These are found, respectively, at https://www.nber.org/cycles.html, https://cepr.org/content/euro-area-business-cycle-dating-committee, https://www.jcer.or.jp/english/november-the-recession-indicator-rose-to-6-8.

is a downturn in the variable(s) of interest. We also extract the common element in the various proxies, generated via principal component analysis (PCA).[12] Both methodologies yield similar interpretations. Below, we report only results using PCA.

The foregoing provides some stylized facts about synchronicity in business and financial cycles. This sets the stage for the econometric results to follow.

### 3.2 Modelling Systemically Important Economies: a Panel Time-Varying Factor VAR

Estimation proceeds in 2 steps. We assume that economic shocks can be decomposed into four factors *i*. They are: a real economic factor, a financial factor, a monetary factor, and a commodity factor. The commodity factor is assumed to be exclusively global in nature. **X** denotes the vector of series used to estimate each one of the factors *i* which is written

$$\mathbf{X}_{it} = \boldsymbol{\alpha}_{it}\mathbf{F}_{it} + \boldsymbol{\varepsilon}_{it} \qquad (1)$$

where **X** are vectors of observable time series from which factors are estimated, **F** are the factors, $\boldsymbol{\alpha}$ are the factor loadings, and *i* = R,F,M,C denote respectively the Real, Financial, Monetary, and Commodity factors. Since it is unlikely over the sample period considered that the factor loadings are constant we estimate time-varying ones in a manner described below. Factor models enrich the number of series effectively incorporated into the model and preserve degrees of freedom. All series in **X** are assumed to be stationary. After extensive testing (see section 4) we use the annualized first (log) difference for several series or the first difference for others (e.g., interest rates).

In estimating (1) we collect series that are typically thought to be representative of each one of the factors listed. The classification is based on previous evidence of this kind (e.g., Girardin and Moussa 2011, Siklos 2018). Table 2A presents a representative listing of series that are available for all four economies in the study. These match with how economic theory would define each hypothesized factor.[13] Note that the financial factor includes the debt to GDP ratio. Hence, while

[12] Since many of the traditional measures of recessions and expansion are categorical (i.e., a 1 indicates a recession, a 0 an expansion) this requires the use of a polychoric correlation measure to estimate the principal component.
[13] A criticism that has previously been leveled at our approach is that factor models often rely on a larger number of variables than are being used. However, the total number of variables used in our study does not differ much from Stock and Watson (2018), or Hatzius, Hooper, Mishkin, Schoenholtz, and Watson (2010). More importantly, even when more than 100 series are used it is typically the case that only a few are necessary to explain the vast majority

we do not separately identify a ‘fiscal’ factor, there is some recognition that fiscal dominance is playing an increasingly important role as policy rates worldwide have declined. Indeed, there appears to be an additional nexus between commodity prices and debt levels, especially among emerging market economies (e.g., see Ahmed et al. 2020, and references therein). Nevertheless, these developments are beyond the scope of this paper.

It is reasonable to assume that each factor, other than the commodity factor, is an aggregation of domestic and global components. We identify the global component for R, F, M, again via factor model estimation. The commodity factor, C, is assumed to be global in nature because prices are denominated in US dollars (e.g., see Siklos (2018), Dreschel et. al. (2019), and references therein).

The global factor is the one which is the most common across all four economies and serves as the global component.[14] Next, label each individual economy by the subscript *j*. We can, therefore, modify equation (1) as follows:

$$\mathbf{X}_{\mathrm{ijt}} = \boldsymbol{\gamma}_{\mathrm{ijt}}\mathbf{F}^{\mathrm{G}}_{\mathrm{it}} + \boldsymbol{\lambda}_{\mathrm{ijt}}\mathbf{F}^{\mathrm{D}}_{\mathrm{ijt}} + \boldsymbol{\nu}_{\mathrm{ijt}} \tag{2}$$

where *i* represent the previously defined factors, *j*= US, EZ,CN,JP are the four systematically important economies, $\boldsymbol{\gamma}, \boldsymbol{\lambda}$ are, respectively, the factor loadings for the global and domestic factors ($\mathbf{F}^{\mathrm{G}}$, $\mathbf{F}^{\mathrm{D}}$), and $\boldsymbol{\nu}$ is the residual term. As before the factor loadings are time-varying. At this stage, it may be sufficient to note that the factors are estimated via rolling samples that overlap. More precise details are provided in section 4.2 below. Equation (2) makes clear that there is a global component for three of the four factors named earlier while, as explained earlier, the commodity factor is entirely global.

To exploit the cross-sectional dimension, we estimate the dynamic relationship between the factors in a panel setting in the second step. The resulting panel factor or panel factor-augmented vector autoregression model (PFVAR) is written as

$$\mathbf{P}_{\mathrm{ijt}} = \boldsymbol{\Omega}_{\mathrm{ijt}}(\mathrm{L})\mathbf{P}_{\mathrm{ijt-1}} + \boldsymbol{\psi}_{\mathrm{jt}}(\mathrm{L})\boldsymbol{\Gamma}_{\mathrm{jt}} + \boldsymbol{\xi}_{\mathrm{ijt}} \tag{3}$$

---

of variation in the data. All of the series shown in Table 2A qualify as ones that significantly explain common variation in each factor.

[14] Evaluated by the uniqueness statistical measure in principal component analysis. Typically, significance is determined by retaining the eigenvalues that exceed one (also known as the Kaiser-Guttmann procedure)..

where $\mathbf{P}_{\mathrm{ijt}} = \left[\mathrm{R}_{\mathrm{jt}}, \mathrm{F}_{\mathrm{jt}}, \mathrm{M}_{\mathrm{jt}}, \mathrm{F}_{\mathrm{i}}^{\mathrm{G}}\right]'$. $F_i^G$ represents the global factor which consists of $[R_i^G, F_i^G, M_i^G, C]'$. We consider the possibility that there are exogenous variables. These are defined by $\mathbf{\Gamma}_{\mathrm{jt}}$.

Recall that **P** consists of four elements, namely the domestic real (R), financial (F), and monetary (M) factors, the global component of these factors and the commodity factor ($F^G$). One issue that arises from (3) is the ordering of the variables. While ordering the real factor first is unlikely to be controversial, as almost all empirical work of this variety suggests that real economic factors are ordered first in a recursive or Cholesky decomposition, the rest of the ordering is less clear cut with the possible exception of the monetary (M) factor which is traditionally seen as ordered last since it is affected by all the other shocks while these same shocks only impact by M with a lag. This is also standard in almost all estimated macro-econometric models.

Arguably, one might consider identifying more precisely the structural shocks either by imposing long-run or short-run restrictions, or even sign restrictions. Such extensions are feasible (e.g., see Canova and Ciccarelli (2013), and references therein) but create additional demands on the data with the net benefits unclear since, for example, it is unclear whether the same sign restriction is valid for all four economies. In the present context the most important drawback is that the economic development of China stands out from the other economies considered. This makes it difficult to impose common structural restrictions across the four economies considered.

Specifications such as equation (3) are non-standard. Accordingly, we also consider a version of (3) where the variables are observed. Define $P_{jt}^* = [y_j, K_j, \varepsilon_j, M_j]'$ where $y_j$ is real GDP growth, $K_j$ is credit growth, $\varepsilon_j$ is the rate of change in the real exchange rate, and $M_j$ is the stance of monetary policy. The monetary factor (M) is used to measure monetary conditions in all four economies.[15] Hence, a more conventional alternative specification is written

$$\mathbf{P}_{jt}^* = \mathbf{\Omega}_j(L)\mathbf{P}_{jt-1}^* + \mathbf{\Psi}_j(L)\mathbf{\Gamma}_{jt} + \boldsymbol{\xi}_{jt} \qquad (4)$$

where all terms were defined previously, and $\mathbf{\Omega}$ and $\mathbf{\Psi}$ are time invariant.

[15] A consequence of the IFC is the limited usefulness of an observed policy rate as an indicator of the stance of monetary policy. Indeed, this is an additional motivation for estimating monetary policy using the factor model approach (also see Lombardi and Zhu 2018) to estimate the stance of monetary policy. Nevertheless, following the practice adopted by many in the literature, published shadow policy rates are used for the US, the Eurozone and Japan, once the zero lower bound is reached. Also, see the note to Table 2.

Finally, factors are time-varying which, in effect, implies that $\mathbf{\Omega}$ is also time-varying $\mathbf{\Omega}_{jt}$.[16] The same is true for the vector of exogenous variables $\mathbf{\Gamma}_{jt}$. Given equation (3) we can investigate the impact of various shocks from the systemically important economies where the inputs in the model contain a time-varying element. First, we estimate factor models using the core variables shown in Table 2 for the full available sample. Next, we estimate the same factor models for samples that range from 5 to 10 years in a rolling manner. This creates estimates for overlapping samples. The estimated factor scores are then averaged to produce an estimate that is time-varying. The results discussed below rely on 10 year rolling samples that shift ahead 8 quarters at a time.

We now turn to the data and estimation results.

# 4 Data, Stylized Facts, and Empirical Estimates

## 4.1 Data

Data were primarily obtained from four sources. They are: CEIC (https://www.ceicdata.com/en) for data on China, the Bank for International Settlements (https://www.bis.org/statistics/index.htm?m=6%7C37), for housing, credit, prices, exchange rates and policy rate data, the International Monetary Fund's *International Financial Statistics* (https://data.imf.org/?sk=4C514D48-B6BA-49ED-8AB9-52B0C1A0179B) for a few other series (e.g., current account, debt), and FRED (https://fred.stlouisfed.org/) for some country-specific time series (e.g., central bank balance sheet data, commercial interest rates). A few other series were also obtained from the Atlanta Federal Reserve's China's Macroeconomy: Time Series Data (https://www.frbatlanta.org/cqer/research/china-macroeconomy.aspx). A few series (e.g., recession indicators for Japan, retail turnover in the Eurozone, lending surveys) were obtained from country sources or individual central banks (e.g., ECB's Statistical Data Warehouse, https://sdw.ecb.europa.eu/; Cabinet Office, Government of Japan, https://www.cao.go.jp/index-e.html).[17]

[16] To assess the sensitivity of our results, we also estimate versions of (3) that are time-invariant.
[17] These are publicly accessible data sources. The forward-looking data (e.g., Consensus Economics inflation and real GDP forecasts) are not publicly available and cannot be distributed. The data were obtained from the HKIMR's library access to hard copies of the original publications (https://www.consensuseconomics.com/).

Quarterly data were collected for the 1990Q1-2017Q4 period. However, in part because of the timing of the Eurozone's creation, data availability for some series, and the desire to construct a balanced panel, the sample used for estimation is 1998Q3-2017Q4. This yields 78 observations for each of the four cross-section entities and a total of 312 observations.[18] The econometric evidence reported below relies on fourth order log differences [i.e., 100 times (log $X_t$ –log $X_{t-4}$)] or first differences (i.e., $X_t – X_{t-1}$) in the series of interest.[19]

### 4.2 Stylized Facts: Business Cycle Synchronicity and Factor Scores

Figures 1 and 2 plot the wiring ratio against available judgmental chronologies. Generally, the wiring ratios pick up all the recessions identified by the traditional chronologies for the U.S. and the Eurozone save the recession at the beginning of the sample. The same is true for Japan although the wiring ratio continues to record stress in the real economy after the end of the 2008-9 recession. There may be instances of false positives in the sense that the wiring ratio indicates some likelihood of a downturn which the standard chronologies do not report. The U.S. in 2015-16 is one example. For China the comparison is more difficult since that country does not experience any recessions as conventionally measured. Therefore, the comparisons are made against slowdowns in growth as opposed to evidence of consecutive quarters of negative growth levels. It is interesting that the wiring ratios remain positive after 2012 when the ECRI identifies a growth slowdown in China. The only other episodes that come close are the recessions identified in three of the four economies (i.e., the EA, the US, and Japan) in the early 1990s.[20]

Indicators of financial conditions are shown in Figure 2. The period after 2007 until around 2015 is one where three of the four plots show rising risks of financial instability. Japan is the only exception. It experiences bouts of financial instability during the late 1990s and early 2000s, that is, around the time when other observers (e.g., see Shizume 2018) concluded that Japan

[18] When the raw data are monthly these are converted to quarterly by arithmetic averaging. A few series' data are annual (e.g., central bank assets to GDP). These are converted to quarterly via the Chow-Lin method.
[19] We compare results with a one-sided HP filter where lambda, the smoothing parameter, is set to the standard value of 1600 for quarterly data for the group of real time series. For financial time series, following others (e.g., Drehmann and Yetman (2018), and references therein) we set the filter considerably higher (i.e., 400000) as well as experiment with the Ravn-Uhlig (2002) filter since some of the raw data are originally sampled at the annual frequency (e.g., some housing and credit data). The HP filtered series are typically the most highly correlated with the differencing filter adopted below. This is often closely followed by the moving average type filter used by Burnside, Eichenbaum, and Rebelo (2016). Our findings are robust to the filter used to obtain stationary series.
[20] This is broadly consistent with Berge (2012) although his data set does not include China.

experienced a financial crisis. However, the degree to which the wiring ratios overlap across these four economies differ. For example, the U.S. experiences financial instability earlier and emerges out of this condition before the Eurozone and China were able to.

Table 3 illustrates not only the impact of estimating time-varying factor scores[21] but also the changing importance of certain variables assumed to contribute to our understanding of what drives real, financial and monetary conditions over time. The variance unique to each series not shared with other variables, called uniqueness, is shown for the three main factors used to define the panel VAR. Uniqueness measures are shown for the full sample (top portion of Table 3) as well as two sub-samples (bottom portion of Table 3). In addition, we provide separate estimates for the domestic set of factors (Dom.) as well as the global factors (Global).

Beginning with the full sample estimates we see that observed real GDP growth is consistently the most relevant indicator of real economic conditions across all four economies because the uniqueness score is relatively low. However, while real GDP forecasts are relatively important in the domestic factor models for China and the Eurozone this is not the case for Japan and the US where industrial production is a more important contributor to the common factor.

Turning to the financial factor we find that uniqueness is high across all variables in three of the four economies. Only for the U.S. do we observe housing prices and credit as making a relatively large contribution to the common factor. This suggests that, even if financial conditions are explained by several factors, they retain an important idiosyncratic element. When the monetary factor is examined we also observe considerable diversity in uniqueness measures across the four economies.

The contrast between the uniqueness for individual economies and ones derived from the global component is especially interesting as there is almost no overlap between the two sets of results. Hence, most of the variables' variances are shared with the others in the global model. This suggests that the global component contains features that are separate from the ones obtained from the factor models estimated for each of the economies individually.

[21] Factor scores represent a composite measure that creates observations extracted from each factor. They are standardized and factor weights are used together with the raw data to create a score.

The bottom portion of Table 3 serves to highlight how the relevance of each of the series in the real, financial and monetary factor models changes substantially across time. Indeed, across time, some variables that are not relevant toward the end of the sample (i.e., 2008-2018), such as inflation expectations for China, house prices in the Eurozone, the policy rate in the U.S., were far more relevant in the first sub-sample (i.e., 1995-2001).

Factor scores are plotted in Figures 3 to 6. The real factor estimates appear to capture quite well the expansion and contraction phases of all four economies.[22] A rise in the score signals an improvement in real economic outcomes. Also notable is that the 2008 economic downturn in China appears quite a bit larger in the time-varying estimates compared with full sample estimates. The reverse seems true for the U.S. and, to a lesser extent, Japan. There is almost no difference between the two estimates for the Eurozone.

Financial factor scores are shown in Figure 4. A rise in the score indicates a tightening of financial conditions. Unlike the real factor, where there is some cross-country resemblance in the scores, there is considerable diversity across the economies in financial conditions. Moreover, differences between full sample and time-varying versions are also more evident for China and Japan while, for the Eurozone and the U.S., the two sets of estimates parallel each other. It is interesting to note how financial conditions tighten in China around the time of the IFC where they become much looser in the U.S. around the same time. Thereafter, the loosening of financial conditions in China becomes more permanent, especially when the time-varying estimates are considered, while there is gradual tightening in the U.S. beginning around 2011. Similarly, in the Eurozone, the loosening of financial conditions at the time of the IFC is temporary and a sharp reversal takes place toward the end of 2011. Thereafter, as the Eurozone sovereign debt crisis takes hold, financial conditions loosen again and are more volatile than in China or the US. A similar pattern of sharply changing financial conditions is seen for Japan although a sharp loosening is evident when the Bank of Japan significantly eases monetary conditions beginning in 2013 when the quantitative and qualitative easing (QQE) program is launched.

The two global financial factors are, respectively, interpreted as global financial conditions (first factor) and global financial risks (second factor). Note the sharp difference between the full and

[22] In the case of China, the cycles identified by ECRI are in terms of growth rates.

time-varying estimates of financial conditions. However, both tell the same story of a decline in financial risks beginning in 2008 with a slow rise beginning in 2013 to the end of the sample.

Figure 5 shows the scores for the monetary factor. A rise in the factor implies a tightening of monetary policy. Also shown are the interventions by three of the four central banks in the form of unconventional monetary policies. In the case of China, the shaded areas capture changes in the exchange rate regime. Full sample and time-varying estimates are comparable in three of the four economies. It is also interesting to note that, in the aftermath of an intervention by a central bank, monetary conditions loosen. However, this kind of relationship appears to go in reverse the longer UMPs are in place. Perhaps these policies prevented even tighter monetary conditions.

The global monetary factors are interpreted as representing the monetary policy stance in the four economies (first factor) while the second factor captures monetary policy spillovers.[23] We can observe the dramatic loosening of monetary policy in 2008 with a tightening becoming evident only around 2015 when the U.S. Federal Reserve begins to raise its policy rate. The second global monetary factor suggests little evidence of spillovers prior to the IFC.

Figure 6 shows the time-varying factor scores for commodity prices. The first factor (F1) is interpreted as reflecting global demand for commodities. The second factor (F2) reflects a combination of the effects of the financialization of commodity markets as well as global supply conditions. We observe the steady rise in the first factor from around 2002 until 2008 when the IFC arrives (also see, Kilian 2009, Cheng and Xiong 2014). The second factor reflects the impact of the decline in commodity prices after the IFC and relative stability of supply conditions until prices begin to rise again once the global economy fully recovers around 2016 until the end of the sample.

### 4.3 Panel VAR Estimates

[23] The first factor reflects primarily the long-short interest rate spread in the Eurozone and the US. The second factor reflects mainly the policy rates in the U.S., the Eurozone and Japan.

Panel VARs are estimated via GMM instrumented using 2 lags of the endogenous variables [i.e., as in Holz-Eakin, Newey, and Rosen (1988); also see Abrigo and Love (2005)]. Panel-specific fixed effects are removed via a Helmert transformation to reduce dimensionality.[24]

We estimate the various panel VARs using a balanced sample that can vary depending on how the factor scores are estimated and the economies considered. The sample is 1998Q3-2017Q4 before lags. This yields 312 observations or 78 observations per each of the four cross-section entities. In all the PFVARs, the ordering is as follows: real, financial, and monetary factors, and the commodity factor. This is then followed by the three remaining global factors. A Cholesky decomposition is adopted. Placing the commodity factor after the real factor also does not, however, change the main conclusions discussed below. Similarly, placing global variables below the others also reflects the belief that these factors impact the higher order variables with a lag. As a reminder, all the results rely on first log differences of the various raw series and levels of the factor scores.[25]

#### *4.3.1 A Parsimonious Model with China as a Systemically Important Economy*

Figure 7 shows the impulse responses for the PFVAR where only the real, financial, and monetary factors for each economy are included. In all the cases we examine, the first variable listed in the IR figures represents the impulse while the second variable is one that responds. For example, the REAL: FIN case shows the response of the financial factor (FIN) to a shock in the real economic factor (REAL). There are no exogenous variables and the commodity factor is excluded. Such a model arguably comes closest to the alternative setup where allowance for separate global economic conditions is excluded from the analysis.

The impulse responses (IRs) along the main diagonal capture the usual persistence property found in most macroeconomic time series. As a result, relatively high impulse responses to own shocks decline relatively slowly. However, it is worth noting that responses to own monetary policy shocks are modest and do not decline as slowly as the other two shocks do. The only significant IR reveals that a tighter monetary policy leads to looser financial conditions (top

[24] It is a transformation used in instrumental variable estimation even if the label itself is not always used. See, for example, Arellano and Bover (1995).
[25] Panel unit root tests confirm that the factor scores are stationary or I(0). The only possible exception is the global financial factor(s). Re-estimating the models using the first differences of the scores did not change the results.

middle IR). In contrast, an improvement in real conditions leads to a temporary loosening of monetary policy for 2 quarters (bottom left IR) which appears counter-intuitive. However, this effect is partly offset by a 1 quarter tightening of financial conditions (bottom middle IR).

#### *4.3.2 What if China is Exogenous?*

Next, we turn to an intermediate case where the panel treats the U.S., the Eurozone and Japan as endogenous variables. China, however, only impacts the other three economies exogenously (see equation (3)). This comes close to a scenario whereby the systemically important AEs recognize a role for China but not as one where their economic fortunes are interdependent. Global real, financial, and monetary, and commodity factors are also added as endogenous variables. Figure 8A plots the impulse responses.

The top four rows and the bottom three rows show the impact from global (labelled 'w') and domestic shocks, respectively (see the notes to the Figure). We focus on the bottom three rows which show the IR from domestic shocks. Domestic monetary policy shocks (i.e., 5$^{th}$ row, *y3*) impact the global financial factor and domestic real economic conditions (i.e., *y1*) but none of the other factors. A monetary policy tightening produces a global easing of financial conditions and an improvement in real economic activity. Normally, a tighter monetary policy would be expected to depress economic activity but with the addition of a financial factor this is no longer the case. This suggests none of the kind of spillovers that some observers claim stem from the actions of the monetary authorities in these economies. Note, however, that a domestic tightening of financial conditions does lead to deterioration in real activity (last IR in the 6$^{th}$ row). Finally, improvement in domestic real activity produces a tightening of financial conditions, both at the global and domestic levels (i.e., *yf* and *y2* both rise) while domestic rise in economic activity results in a noticeable increase in global real economic activity (i.e., a rise in *y1* increases *yr*).

Figure 8B shows the dynamic multipliers for the series from China treated as exogenous in this version of the estimated model. The IRs reveal that a tightening monetary policy shock in China has no significant impact on the stance of monetary policy in the remaining three economies. The same is true of a shock that tightens financial conditions in China. However, a tightening of monetary policy in China does depress real economic conditions in the other systemically important economies while improved real economic conditions in China also improve real economic conditions in the US, the Eurozone and Japan. The only significant financial link from China to the other three economies is that a tightening of financial conditions in China leads to a loosening of monetary conditions elsewhere.

### *4.3.3 China as a Systemically Important Economy*

We now consider the case where China is treated on a level playing field alongside the remaining G3 economies in the sample (Figure 9). The shocks are the same as in Figure 8. Shocks that originate from domestic factors (i.e., *y1*, *y2*, and *y3*) impact all the variables in the model (last 3 rows) and highlight differences from the case (i.e., Figure 8) where China is treated as exogenous. First, a tightening of domestic monetary conditions (i.e., *y3* rises) results in a global deterioration in real economic conditions, a slight rise in commodity prices (*yc*), and a softening in domestic financial conditions (i.e., *y2* falls). Hence, spillovers are in evidence that are not observed when China is exogenous. Moreover, as seen in the 6$^{th}$ row, a domestic tightening of financial conditions produces a small but significant tightening in both global monetary and financial conditions (i.e., *ym* and *yf*) for 2 quarters. The remaining IRs are comparable to the ones shown in Figure 8 with one important exception. A domestic improvement in real economic conditions results in a global loosening of monetary policy on top of a domestic loosening in monetary policy, for one quarter, as is found when China enters the model exogenously (7$^{th}$ row). This may appear counter-intuitive but it is worth remembering that the period under study is dominated by an era of 'lower for longer' policy rates.

Additional insights are found from forecast error variance decompositions (VDs; the table is in appendix, available on request). Other than the persistence of economic shocks, shown by the slow decline in VDs, only a few factors explain movements in both economy-specific and global factors. Thus, the global components of financial and monetary shocks together explain a quarter of the variance of country-specific real shocks after 10 quarters. Similarly, the commodity factor and the global component of monetary shock significantly explain the variation in domestic financial conditions. Interestingly, the global commodity factor explains over 10% of the domestic monetary factor after 10 quarters. Not surprisingly, the global real factor also explains almost one-third of the variation in the global commodity factor and close to the same proportion vice-versa. Finally, global monetary conditions are the most sensitive of all. The majority of its variability (almost 60%) comes from the combined impact of the commodity factor and the global element of the real economic factor.[26]

### *4.3.4 Comparisons with VARs Based on Observables*

Figure 10 presents IRs for a version of equation (4) where real GDP, credit, oil prices, the real effective exchange rate, and the monetary factor are endogenous while expected real GDP growth, and housing prices are exogenous, and dummy variables for unconventional monetary policy actions introduced by the US, Eurozone and Japanese central banks are included. In China's case we identify changes in exchange rate policy regimes as having possibly an exogenous influence in the model.[27]

Much as in the factor-based PFVAR in Figure 9 tighter monetary policy and tighter financial conditions go hand in hand (4th row, *y2* is the shock source, *y3* is the response). Arguably, one interesting insight that is not as evident when PFVARs are estimated, is the significant link between oil prices and real and financial conditions. Higher oil prices (i.e., a rise in *y8*) produce tighter MP (3rd row) but softer financial conditions (*y2* is negative when *y8* is shocked; third row). We also observe that better real economic conditions lead to a MP tightening (last row) as well as higher oil prices (*y8* rises when *y1* is shocked).

The finding that China, when treated as part of the 'club' of systemically important economies, amplifies the impact of various shocks, notably real and financial shocks, is perhaps not surprising. However, differences from the impulse responses obtained when China is viewed as contributing only exogenously to the interactions between real, financial, and monetary shocks among the U.S., Japan, and the Eurozone suggest that transmission mechanisms in large economies have been significantly impacted by the rise of China as a global economic power.

## 5 Conclusions

Typically, cross-border studies of the transmission of shocks focus on a homogeneous set of economies. For example, one might be interested in the impact of economic shocks among the G7 or advanced economies more generally. Similarly, other studies will concentrate on how

[26] Granger-causality tests (not shown) confirm the interpretations from the variance decompositions.
[27] The precise dating of the dummy variables is provided in the appendix (available on request).

shocks from AEs will impact EMEs. In principle, there is nothing wrong with such a strategy. However, such an approach also risks omitting a role for one of the most important developments of the past two decades, namely the rise of China whose economy has, for some time now, attained a global reach and has become increasingly interdependent with other large economies around the globe. While many policy makers and policy studies recognize this development there is a dearth of research examining the interaction of shocks among a group of systemically important economies that includes China. Accordingly, our study estimates models where cross-border effects between China and AEs are explicitly taken into account, and where shocks of various kinds, including real, financial, monetary, and commodity prices, are endogenously related to each other in a dynamic model. We also allow the specifications to contain a time-varying element.

A second development that motivates our analysis is the recognition that global and domestic shocks can build on each other thereby increasing the impact of shocks beyond what one would expect if spillovers were ignored. Therefore, our estimated models identify shocks whose source is domestic and separate from shocks that are global. Finally, while the factor model approach in a panel VAR setting has considerable appeal it is based on unobservable variables. Therefore, we supplement our preferred results with a more standard set of models where observables replace the estimated factors. Nevertheless, we stress that these models are relatively less flexible in allowing for global shocks to be considered.

Our principal findings are as follows. Global shocks can exacerbate shocks that originate from the individual economies considered. For example, a monetary policy tightening shock has negative real economic consequences that are magnified when the global component is added. On the other hand, improvement in real economic conditions due to a domestic shock is also amplified thanks to the global component of a real shock. Next, a shock that tightens monetary policy is often reflected in a companion hardening of financial conditions. Finally, the treatment of China in our models has a critical impact on our findings. For example, treating shocks from China as exogenous yields differences in the impulse responses from our preferred case where shocks emanating from that country are treated as endogenous as are the shocks from the US, the Eurozone and Japan. Arguably, our estimates are economically more plausible when China is considered to be endogenously linked to other large economies.

Our findings also have implications for the ongoing debate about whether large economies ought to cooperate in economic policy making and how this should be done. There is considerable synchronicity in real economic factors but much less so between the financial factors. The latter is true for monetary policies which seem to be driven primarily by the domestic component of the factor. Nevertheless, the fact that global shocks can amplify domestic shocks ought to be sufficient in convincing policy makers to cooperate. Coordination may be more desirable once we have a better understanding of the size of the global versus domestic impact of the various shocks considered. An explicit recognition of a role for fiscal policy is also likely required before we can reach a more definitive conclusion. Indeed, both debt levels, incorporated into our analysis, the composition of debt and commodity price movements might help trace the evolution of policy making from monetary dominance to fiscal dominance. The richness of potential sources of shocks also suggests that the debate about the existence of a dilemma or a trilemma in international economic relations masks the fact that, when time-varying models are considered, the number of avenues through which shocks can be globally transmitted rises.

In the meantime, however, China's role among the systemically important economies cannot be ignored. Its links with the US, the Eurozone, and Japan are quantitatively and economically significant.

References

Abrigo, M., and I. Love (2005), "Estimation of Panel Vector Autoregression in Stata: a Package of Programs", manuscript, February.

Agénor, P.-R., and L. A. Pereira da Silva (2018), "Financial Spillovers, Spillbacks, and the Scope for International Policy Coordination", BIS working paper no. 97, April.

Ahmad. R., J. Aizenman, and Y. Jinjarak (2020), "Inflation and Exchange Rate Targeting Under Fiscal Dominance", NBER working paper 25996, January.

Alberola, E., and R. Sousa (2017), "Assessing Fiscal Policy Through the Lens of the Financial and Commodity Price Cycle", BIS working paper 638.

Arellano, M., and Bover, O. (1995), "Another Look at the Instrumental Variables Estimation of Error Component Models", *Journal of Econometrics*, 68, 29-51.

Auer, R., C. Borio, and A. Filardo (2017), "The Globalisation of Inflation: The Growing Importance of Global Value Chains", CESifo working paper No. 6387, March.

Baxter, M., and R. King (1999), "Measuring Business Cycles: Approximate Band-Pass Filters For Economic Time Series," Review of Economics and Statistics, 81(November): 575-593

Berge, T. (2012), "Has Globalization Increased the Synchronicity of International Business Cycles", *Economic Review*, Federal Reserve Bank of Kansas City, Third Quarter, 5-39.

Burnside, C., M. Eichenbaum, and S. Rebelo (2016), "Understanding Booms and Busts in Housing Markets", *Journal of Political Economy*, 124 (July): 1088-1147.

Canova, F., and M. Ciccarelli (2013), "Panel Vector Autoregressive Models: A Survey", ECB working paper No. 1507, January.

Chen H., and A. Tsang (2018), "Impact of US Monetary Policy Rate Shock and Other External Shocks on the Hong Kong Economy: A Factor-augmented Vector Autoregression Approach", *Pacific Economic Review*, April, 2018.

Chen, H., R. Li, and P. Tillmann (2019), “Pushing on a String: State-Owned Enterprises and Monetary Policy Transmission in China”, *China Economic Review* 54, April 2019, Pages 26-40

Chen, H., K. Chow, and P. Tillmann (2017), “The Effectiveness of Monetary Policy in China: Evidence from a Qual VAR”, *China Economic Review* 43: 216-231.

Chen, Q., A. Filardo, D. He, and F. Zhu (2016), “Financial Crisis, US Unconventional Monetary Policy and International Spillovers”, *Journal of International Money and Finance* 67: 62-81.

Cheng, I.-H., and W. Xiong (2014), “The Financialization of Commodity Markets”, *Annual Review of Financial Economics*,

Organization for Economic Cooperation and Development OECD (2019), “OECD Economic Surveys: China”, April.

Chari, V. and L. Christiano (2017), “Financialization in Commodity Markets”, Federal Reserve Bank of Minneapolis, Staff Report 752, August.

Chen, K., P. Higgins, D. Waggoner and T. Zha (2018), “Impacts of Monetary Stimulus on Credit Allocation and Macroeconomy: Evidence from China,” NBER Working Paper No. 22650.

Christiano, L. J., and T. J. Fitzgerald (1999), “The Band Pass Filter”, NBER working paper 7257, July.

Clarida, R. (2018), “The Global Factor in Neutral Policy Rates: Some Implications for Exchange Rates, Monetary Policy, and Policy Coordination”, BIS working paper No. 732, July.

de Hann, J., R. Inklaar, and R. Jong-A-Pin (2007), “Will Business Cycles in the Euro Area Converge? A Critical Survey of Empirical Research”, *Journal of Economic Surveys* 22 (2): 234-273.

Del Negro, M., and C. Otrok (2008), “Dynamic Factor Models With Time-Varying Parameters”,: Measuring Changes in Business Cycles”, working paper.

Dieppe, A., R. Gilhooly, J. Han, I. Korhonen, and D. Lodge, Editors (2018), “The Transition of China to Sustainable Growth – Implications for the Global Economy and the Euro Area”, Occasional Paper No. 206, January.

Drehmann, M., C. Borio, and K. Tsatsaronis (2012), “Characterising the Financial Cycle: Don’t Lose Sight of the Medium Term!”, BIS working paper No. 380, June.

Dreschel, T., M. McLeay, and S. Tenreyro (2019), “Monetary Policy for Commodoty Booms and Busts”, CEPR discussion paper 14030.

Ductor, L., and D. Leiva-Leon (2016), “Dynamics of Business Cycle Interdependence”, *Journal of International Economics* 102: 110-127.

Eickmeier, S., and M. Kühlenz (2018), “China’s Role in Global Inflation Dynamics”, *Macroeconomic Dynamics*22: 225-254.

Eickmeier, S., W. Lemke, and M. Marcellino (2010), “The Changing International Transmission of Financial Shocks: Evidence from a Classical Tim-Varying FAVAR”, working paper, August.

Fernald, J., E. Hsu, and M. Spiegel (2019), “Is China Fudging Its GDP Figures? Evidence From Trading Partners”, working paper, Federal Reserve Bank of San Francisco.

Flood, R., and A. Rose (2010), “Inflation Targeting and Business Cycle Synchronization”, *Journal of International Money and Finance* 29(4): 707-727.

Forbes, K. (2016), “Much Ado about Something Important: How do Exchange Rate Movements Effect Inflation”, *The Manchester School* 84 (S1, September): 15-41.

Furnaletto, F., F. Ravazzolo, and S. Sarferaz (2017), “Identification of Financial Factors in Economic Fluctuations”, *Economic Journal*: 1-27.

Girardin, E., S. Lunven, and G. Ma (2017), “China’s Evolving Monetary Policy Rule: From Inflation-Accommodating to Anti-Inflation Policy”, BIS working paper 641, May.

Girardin, E., and Z. Moussa (2011), “Quantitative Easing Works: Lessons from the Unique Experience in Japan 2001-2006”, *Journal of International Financial Markets, Institutions and Money* 21: 461-495.

Hamilton, J. (2018), “Why You Should Never Use the Hodrick-Prescott Filter”, *Review of Economics and Statistics* 100 (5): 831-843.

Hammoundeh, S., D.K. Nguyen, and R. Sousa (2015), "US Monetary Policy and Commodity Sector Prices", *Journal of International Moneya and Finance* 57: 61-85.

Hatzius, J., P., Hooper, F. Mishkin, K. Schoenholtz, and M. Watson (2010), "Financial Conditions Indexes: A Fresh Look After the Crisis", Proceedings from the Monetary Policy Forum 2010, also NBER working paper 16150, July.

Henzel, S. and E. Wieland (2017),"International Synchronization and Changes in Long-Term Inflation Uncertainty", *Macroeconomic Dynamics* 21(4): 918-946.

Hodrick, R., and E. Prescott (1997), "Postwar U.S. Business Cycles: An Empirical Investigation", *Journal of Money, Credit and Banking* 29(1): 1-16.

Holston, K., T. Laubach and J. Williams (2017), "Measuring the Natural Rate of Interest: International Trends and Determinants", *Journal of International Economics* 108 (S1): S29-S75.

Holt-Eakin, D., W. Newey, and H. Rosen (1988), "Estimating Vector Autoregressions with Panel Data", *Econometrica* 56(6): 1371-1395.

Ilzetzki, E., and K. Jin (2013), "The Puzzling Change in the International Transmission of U.S. Macroeconomic Policy Shocks", working paper, February.

International Monetary Fund (2017), "The Changing Dynamics of the Global Business Cycle", World Economic Outlook, Chapter 5, pp. 67-94.

International Monetary Fund (2007), "Spillovers and Cycles in the Global Economy", *World Economic Outlook,* April.

Jannsen, N., G. Potjagailo, and M. Wolters (2016), "Monetary Policy During Financial Crises: Is the Transmission Mechanism Impaired?", working paper, January.

Jordá, Ó., M. Schularik, and A. M. Taylor (2011), "Financial Crises, Credit Booms, and External Imbalances: 140 Years of Lessons", *IMF Economic Review* 59 (2): 340-378.

Kabukçuoğlu, A., and E. Martínez-García (2018), "Inflation as a Global Phenomenon – Some Implicatins for Inflation Modeling and Forecasting", *Journal of Economic Dynamics and Control* 87: 46-73.

Kamber, G., and B. Wong (2018), “Global Factors and Trend Inflation”, BIS working paper No. 688, January.

Kilian, L. (2009), “Not All Oil Prices Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market”, *American Economic Review* 99 (June): 1053-69.

Klotz, P., T. Calvin Lin, and S.-H. Hsu (2014), “Global Commodity Prices, Economic Activity and Monetary Policy: The Relevance of China”, *Resources Policy* 42: 1-9.

Kose, A., C. Otrok, and E. Prasad (2012), “Global Business Cycles: Convergence or Decoupling”, *International Economic Review* 53 (May): 511- 538.

Lin, J. (2016), “Will China Continue to Be the Engine of Growth in the World?”, *Journal of Policy Modeling* 38: 683-692.

Lin, J. (2011), “China and the Global Economy”, Proceedings of the Asia Economic Policy Conference, Federal Reserve Bank of San Francisco, pp.213-229.

Lombardi, M., and F. Zhu (2018), “A Shadow Policy Rate to Calibrate U.S. Monetary Policy At the Zero Lower Bound”, *International Journal of Central Banking* (December): 305-346.

Lombardi, D., P. Siklos, and S. St. Amand (2018), “A Survey of the International Evidence and Lessons Learned About Uncovnventional Monetary Policies: Is A ‘New Normal’ in Our Future?”, *Journal of Economic Surveys* 32 (December): 1229-1256.

Lombardi, D., P. Siklos, and X. Xie (2018b), “Monetary Policy Transmission in Systemically Important Economies and China’s Impact”, *Journal of Asian Economics* 59(C): 61-79.

Obstfeld, M. and K. Rogoff (2002), “Global Implications of Self-Oriented National Monetary Rules”, *Quarterly Journal of Economics* (May): 503-535.

Oman, W. (2019), “The Synchronization of Business Cycles and Financial Cycles in the Euro Area”, *International Journal of Central Banking* (March): 327-352.

Ostry, J., and A. Ghosh (2013), “Obstacles to International Policy Coordination, and How to Overcome Them”, IMF Staff Discussion Note 13/11, December.

Pang, K., and P. Siklos (2016), "Macroeconomic Consequences of the Real-Financial Nexis: Imbalances and Spillovers Between China and the US", *Journal of International Money and Finance* 65 (C): 195-212.

Prietto, E., S. Eickmeier, and M.Marcellino (2016), "Time Variation in Macro-Financial Linkages", *Journal of Applied Econometrics* 31(November/December): 1215-1233.

Ratti, R., and J. Vespigani (2015), "Commodity Prices and BRIC and G3 Liquidity: A SFAVEC Approach", *Journal of Banking and Finance* 53: 18-33.

Ravn, M., and H. Uhlig (2002), "On Adjusting the Hodrick-Prescott Filter For the Frequency of Observations", *Review of Economics and Statistics* 84 (May): 371-376.

Rey, H. (2013), "Dilemma Not Trilemma: The Global Financial Cycle and Monetary Policy Independence", Proceedings, Economic Policy Symposium, Jackson Hole.

Schüler, Y. (2018a), "On the Cyclical Properties of Hamilton's Regression Filter", Deutsche Bundesbank Discussion Paper, 03/2018.

Schüler, Y. (2018b), "Detrending and Financial Cycle Facts Across G7 Countries: Mind a Spurious Medium-Term", European Central Bank working paper 2138.

Shackelton, R. (2018), "Estimating and Projecting Potential Output Using CBO's Forecasting Growth Model", working paper 2018-03, Congressional Budget Office, February.

Shizume, M. (2018), "Historical Evolution of Monetary Policy (Goals and Instruments) in Japan: From the Central Bank of an Emerging Economy to the Central Bank of a Mature Economy", in Stefano Battiloss, Youssef Cassi, Kazuhiko Yago (Editors), *Handbook of the History of Money and Currency* (New York: Springer), pp. 1-30.

Siklos, P. (2018), "Boom-and-Bust Cycles in Emerging Markets: How Important is the Exchange rate?", *Journal of Macroeconomics* 56: 172-187.

Siklos, P. (2013), "Sources of Disagreement in Inflation Forecasts: An International Empirical Investigation", *Journal of International Economics* 90: 218-231.

Siklos, P., and M. Bohl (2018), "The Anatomy of Inflation: An Economic History Perspective", ", in Stefano Battiloss, Youssef Cassi, Kazuhiko Yago (Editors), *Handbook of the History of Money and Currency* (New York: Springer), pp. 1-26.

Stock, J., and M. Watson (2018), "Slack and Cyclically Sensitive Inflation", ECB Forum on Central Banking, "Price and Wage Setting in Advanced Economies".

Stock, J., and M. Watson (2005), "Understanding Changes in International Business Cycle Dynamics", *Journal of the European Economic Association* 3(September): 968-1006.

Wood, G., and N. Ammon Jianakoplos (1978), "Coordinated International Economic Expansion: Are Convoys or Locomotives the Answer?", *Review* of the Federal Reserve Bank of St. Louis, July: 11-19.

**Table 1 – Alternative Metrics to Identify the State of the Economy**

| *Methodology* | *Time Series* | *Type* | *Method to Evaluate Synchronicity* |
|---|---|---|---|
| Institutional | Real GDP<br>Inflation<br>Housing prices<br>Credit<br>Inflation forecasts<br>Real GDP growth forecasts<br>Equity prices<br>Real exchange rate | | |
| NBER<br>CEPR<br>JCER<br>ECRI | | Judgmental and estimated | Wiring ratio<br>Uniqueness |
| Statistical: | | | |
| H-P filtered gap | | Estimated | |
| Hamilton (2018) linear projection gap | | Estimated | |
| Gaps derived from 1st principal component | | Estimated | |
| Burnside et. al. (2016) threshold-based | | Estimated | |

Note: The Hodrick-Prescott (H-P) filter (1997) assumes that the trend and cyclical components of a time series $y_t$ are additive yielding $y_t = \tau_t + c_t$ and the objective is to minimize $\sum_{1}^{T}(y_t - \tau_t)^2 + \lambda\sum_{2}^{T-1}[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2$. Hamilton (2018) recommends the following projection: $y_{t+h} = \beta_0 + \beta_1 y_t + \beta_2 y_{t-1} + \beta_3 y_{t-2} + \beta_4 y_{t-3} + \zeta_{t+h}$. Hence, the gap is simply the residual $\zeta_t$ (h=8 for quarterly data). Burnside et. al. (2016) compute a centered moving average for a time series (usually in the log levels), denoted by $x_t$, such that $x_t = (2n+1)^{-1}\sum_{j=-n}^{n} y_{t+j}$. Upturns and downturns are defined according to whether $\Delta x_t$ is greater than or less than 0, where n=4 (=10 for financial series) so that $x_t$ is a 9 quarter centered moving average. The authors also introduce a variant to identify boom and bust periods. NBER is the National Bureau of Economic Research, CEPR is the Centre for Economic Policy Research, JCER is the Japan Center for Economic Research, and ECRI is the Economic Cycle Research Institute. The wiring ratio is $w_t = \frac{\kappa_t(\kappa_t - 1)}{\eta_t(\eta_t - 1)}$ where κ is the number of indicators that signal a downturn (or recession) and η are the number of indicators used that signal upturns and downturns. Uniqueness is derived from principal component analysis and indicates the proportion of the variance that is unique to a particular series. The more unique, the smaller the common factor. Note also that while the various gaps are estimated there is an element of judgment also involved (e.g., the smoothing parameter in the HP filter, the value of η in the Burnside et. al. (2016) indicator). All series, except inflation and growth rates, are expressed in logarithms of the levels.

**Table 2 – Time Series in Factor Model Estimation**

A. Core series

| *Factor* | | |
|---|---|---|
| *Real* | *Financial* | *Monetary* |
| Inflation | Equity prices | CB policy rate/benchmark/ shadow policy rate |
| Real GDP growth | Property prices | Monetary aggregate |
| Inflation forecast | (Private non-bank financial assets)/GDP | (Central bank assets)/GDP |
| Real GDP growth forecast | Short-term interest rate | Long-short term interest rate spread |
| Industrial production | Foreign exchange reserves | Unconventional monetary policies |
| Economic policy uncertainty | | |
| Real exchange rate | | |

Note: Factor modeling requires that the series are stationary. This is accomplished by taking first log differences (annualized, if necessary), or first differences, or by estimating a gap (also see Table 1). The series listed in the Table are defined in their stationary equivalent. Each factor also includes time series that are available idiosyncratically for each economy in the data set. See below. Not shown: commodity prices. Individual commodity prices are obtained from the IMF (https://www.imf.org/en/Research/commodity-prices). Forecasts are from Consensus Economics. Other data sources are listed in the main body of the text. The dating of UMP is from Lombardi et. al. (2018).

B. Additional Time Series

| *Factor* | | |
|---|---|---|
| *Real* | *Financial* | *Monetary* |
| CHINA: Business climate index, Consumer confidence index, Current account/GDP, Electricity consumption | CHINA: Loans | CHINA: 7 day repo rate, Exchange rate regimes |
| EUROZONE: Unemployment rate, Retail sales (turnover) | EUROZONE: Credit conditions from bank survey (forward, backward looking), Domestic credit | EUROZONE: Unconventional monetary policy interventions |
| JAPAN: Current account/GDP, Leading economic index indicator | JAPAN: Tankan survey of large, medium and small enterprises, Govt. debt/GDP | JAPAN: Unconventional monetary policy interventions |
| US: Current account/GDP, Unemployment rate | US: Loan officer survey (commercial loans), Natl fin. cond. index, Govt. debt/GDP | US: Unconventional monetary policy interventions |

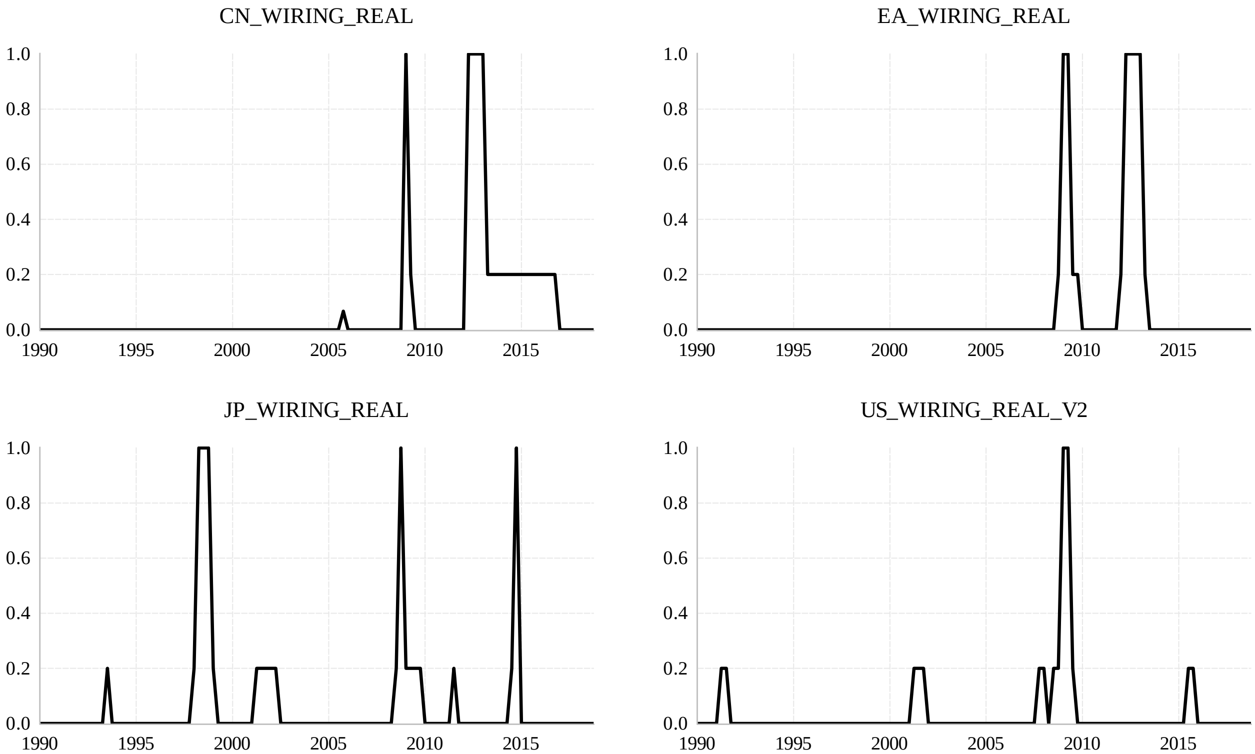
Note: See the appendix (available on request) for data sources and additional details.

## Table 3 – Uniqueness in Factor Model Estimates

| Full Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Factor | CN | | EA | | JP | | US | |
| *Real* | Dom. | Global | Dom. | Global | Dom. | Global | Dom. | Global |
| GDP | .36 | .71 | .27 | .43 | .41 | .24 | .24 | .42 |
| INF | .99 | .47 | .97 | .91 | .75 | .98 | .78 | .62 |
| INF fcst | .83 | .89 | .65 | .37 | .60 | .85 | .91 | .42 |
| GDP fcst | .43 | .99 | .33 | .36 | .73 | .93 | .92 | .58 |
| REER | .99 | .57 | .99 | .97 | .91 | .87 | .89 | .66 |
| Ption | .74 | .79 | .50 | .26 | .58 | .19 | .26 | .41 |
| EPU | .85 | .51 | .73 | .28 | .87 | .75 | .75 | .66 |
| *Financial* | | | | | | | | |
| RES | .83 | .27 | .99 | .84 | .71 | .71 | .70 | .64 |
| EQU | .85 | .81 | .96 | .54 | .51 | .51 | .97 | .51 |
| HOUSE | .80 | .97 | .85 | .39 | .36 | .36 | .43 | .27 |
| STIR | .91 | .65 | .71 | .17 | .47 | .47 | .70 | .34 |
| PNFS | .83 | .50 | .64 | .57 | .66 | .66 | .24 | .19 |
| *Monetary* | | | | | | | | |
| Money | .99 | - | .25 | - | .30 | - | .43 | - |
| Pol. Rate | .73 | .97 | .99 | .77 | .99 | .92 | .93 | .97 |
| CBGDP | .65 | - | .98 | - | .21 | - | .38 | - |
| Spread | .93 | .88 | .20 | .63 | .82 | .91 | .78 | .51 |
| RRR | .46 | - | - | - | - | - | - | - |
| Repo | .70 | - | - | - | - | - | - | - |
| QE | .67 | - | .89 | - | .99 | - | .79 | - |
| Sub-samples | | | | | | | | |
| Factor | CN | | EA | | JP | | US | |
| *Real* | 95-01 | 08-18 | 95-01 | 08-18 | 95-01 | 08-18 | 95-01 | 08-18 |
| GDP | .12 | .07 | .31 | .03 | .19 | .06 | .18 | .10 |
| INF | .25 | .38 | .70 | .37 | .32 | .53 | .47 | .18 |
| INF fcst | .11 | .72 | .47 | .19 | .06 | .38 | .87 | .52 |
| GDP fcst | .23 | .15 | .32 | .31 | .12 | .87 | .62 | .38 |
| REER | .34 | .28 | .57 | .78 | .67 | .32 | .78 | .39 |
| Ption | .24 | .48 | .33 | .05 | .36 | .07 | .18 | .03 |
| EPU | .83 | .47 | .42 | .80 | .59 | .59 | .63 | .61 |
| *Financial* | | | | | | | | |
| RES | .15 | .24 | -.02 | .78 | .48 | .62 | .86 | .49 |
| EQU | .37 | .90 | .37 | .47 | .66 | .31 | .91 | .62 |
| HOUSE | .47 | .43 | .04 | .74 | .96 | .34 | .29 | .06 |
| STIR | .06 | .51 | .17 | .23 | .44 | .24 | .59 | .21 |
| PNFS | .59 | .18 | .64 | .88 | .56 | .28 | .16 | .07 |
| *Monetary* | | | | | | | | |
| Money | .10 | .48 | .40 | .16 | .53 | .24 | .64 | .41 |
| Pol. Rate | .58 | .35 | .77 | .90 | .70 | .98 | .66 | .97 |
| CBGDP | .43 | .53 | .59 | .82 | .99 | .02 | .54 | .42 |
| Spread | .29 | .66 | .35 | .17 | .66 | .20 | .68 | .41 |
| RRR | .72 | .49 | - | - | - | - | - | - |
| Repo | .31 | - | - | - | - | - | - | - |
| QE | .47 | - | .73 | - | - | - | - | - |

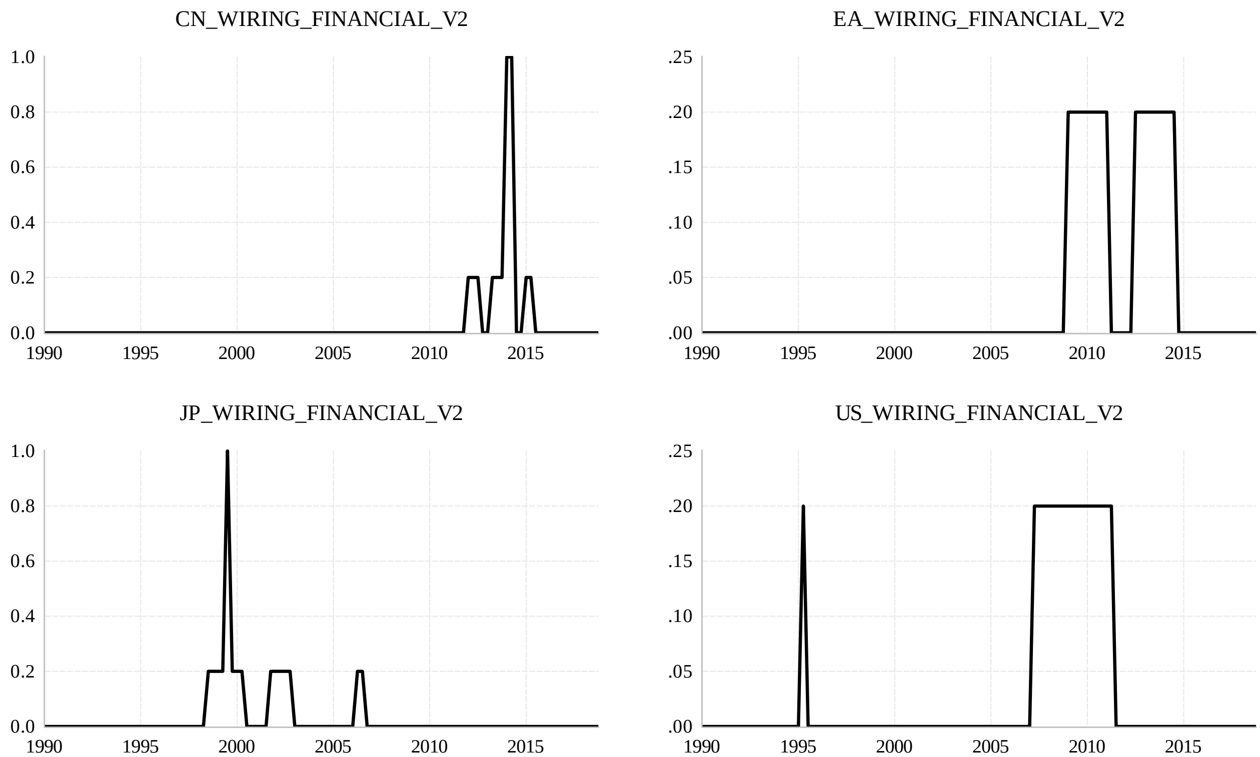
Note: uniqueness provides an indication of the variance of factor that is unique to the series from which factors are estimated (i.e., the principal components). The higher the value the less relevant is the variable in the factor model.

**Figure 1 – Wiring Ratios for Business Cycle Indicators**



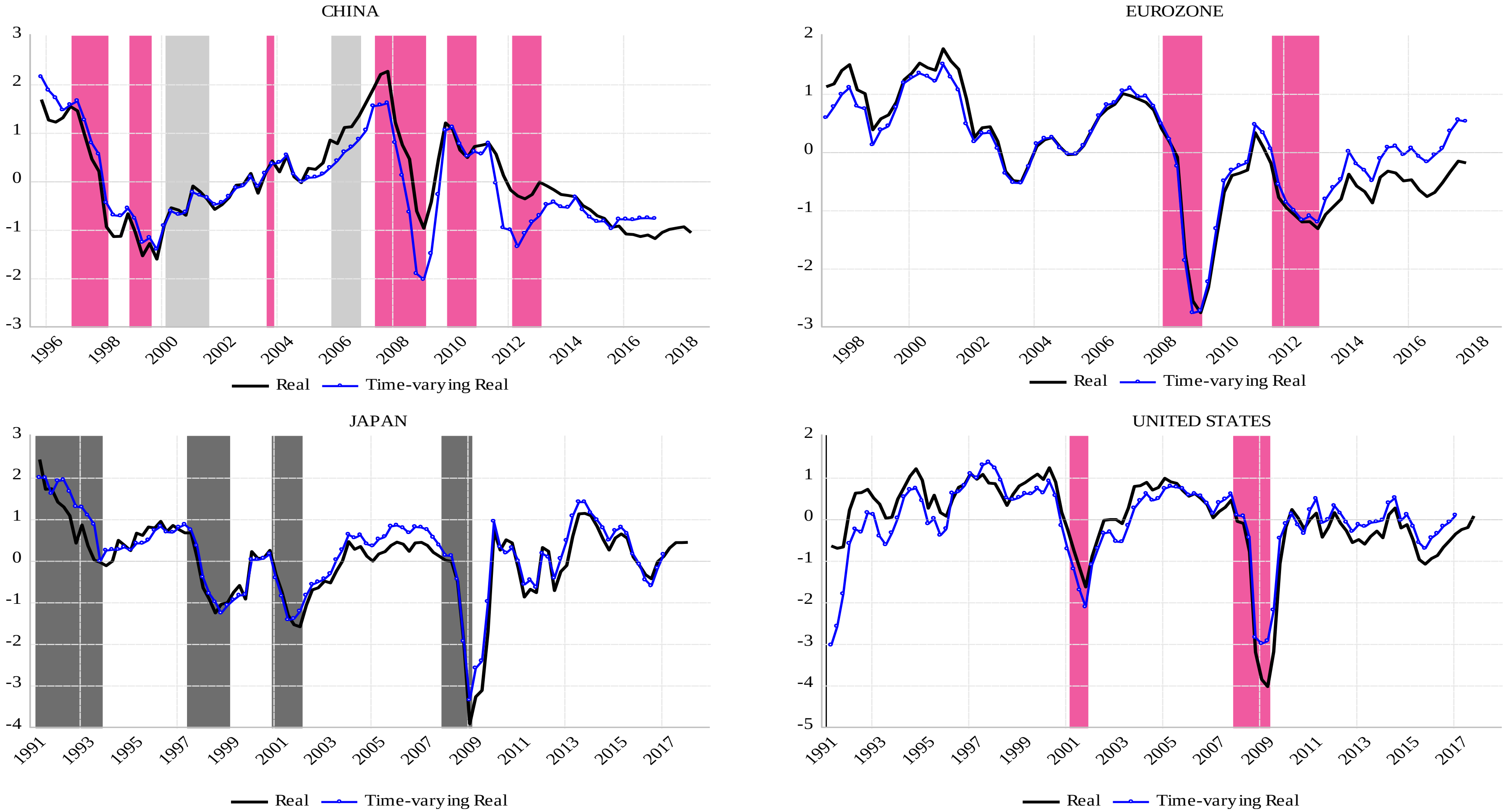

Note: see Table 1 and the text for the definition. The wiring factor ranges between 0 and 1 with 1 indicating complete synchronicity across the various business cycle indicator proxies.

**Figure 2 – Wiring Ratio for Financial Indicators**



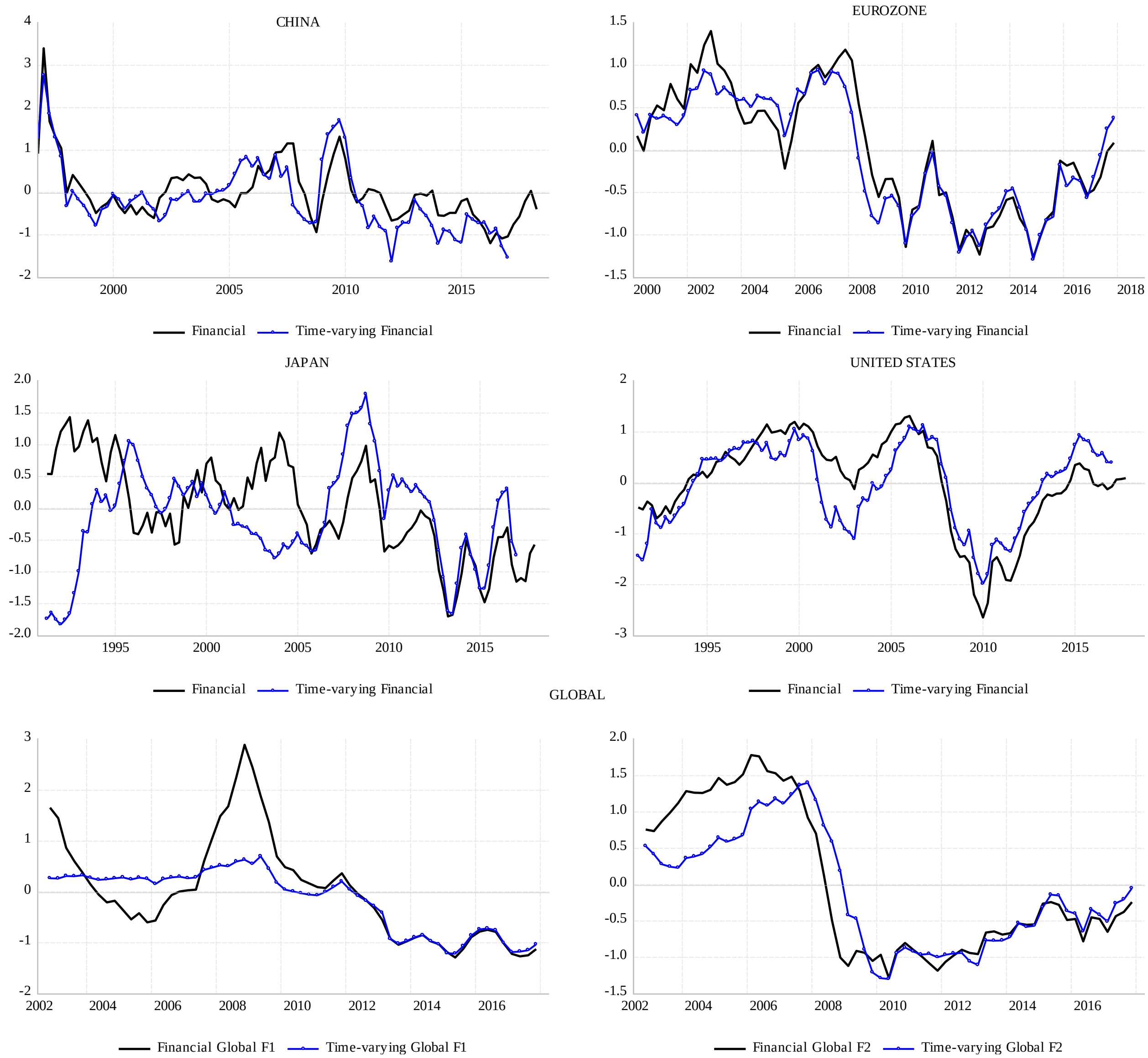

Note: See note to Figure 1.

**Figure 3 – Factor Scores: Real Variables**



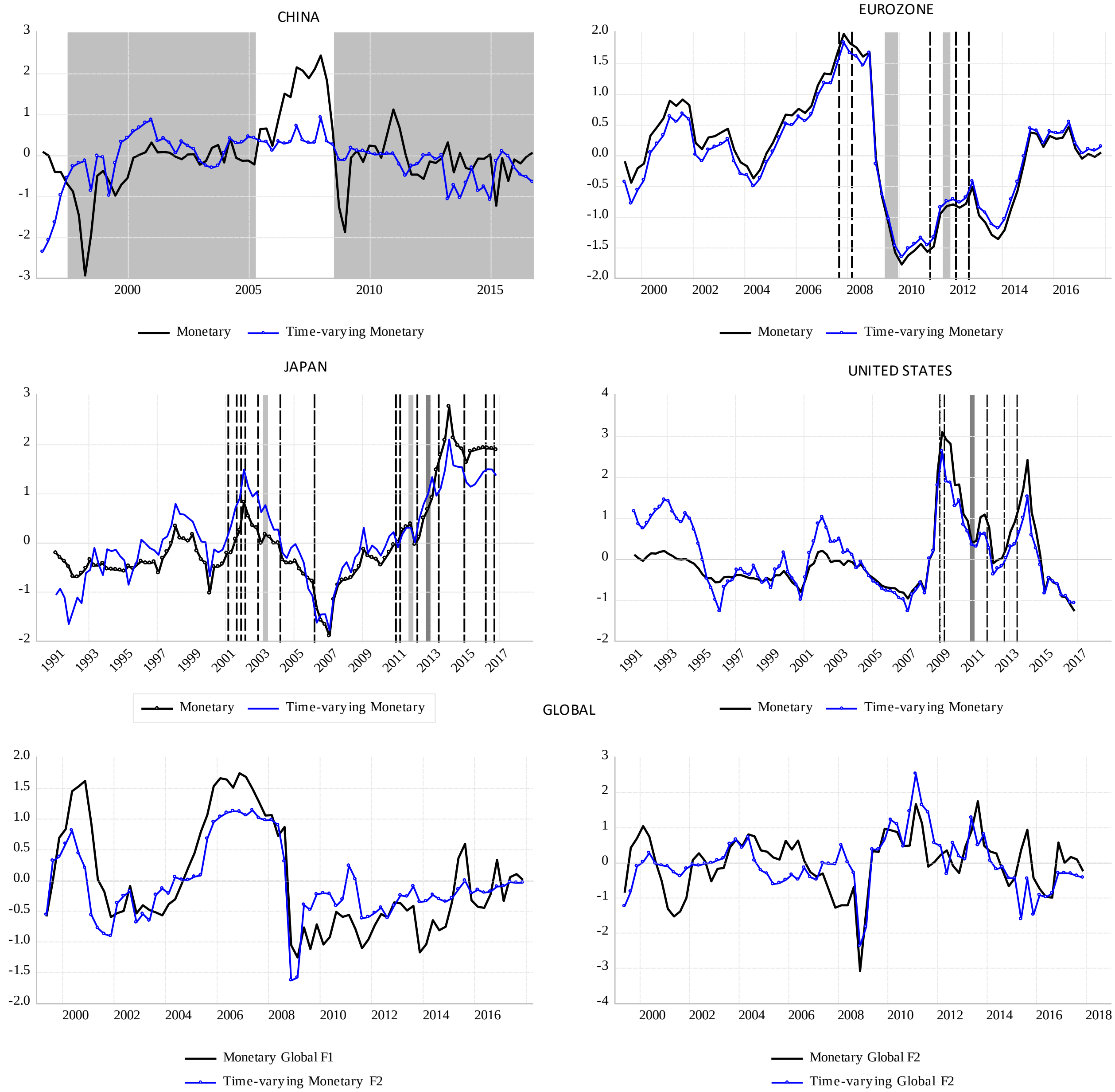

Note: See Table 2A for the series used to generate the principal components. These are estimated via maximum likelihood. In cases where more than one principal component is estimated (labelled F1, F2, and so on) the factor scores are obtained after rotation via the varimax method. All scores are standardized to permit comparisons. The time-varying scores are based on a 10-year rolling sample that is advanced 8 quarters at a time. Overlapping scores are then averaged to obtain the scores plotted above.

# Figure 4 Factor Scores: Financial Variables



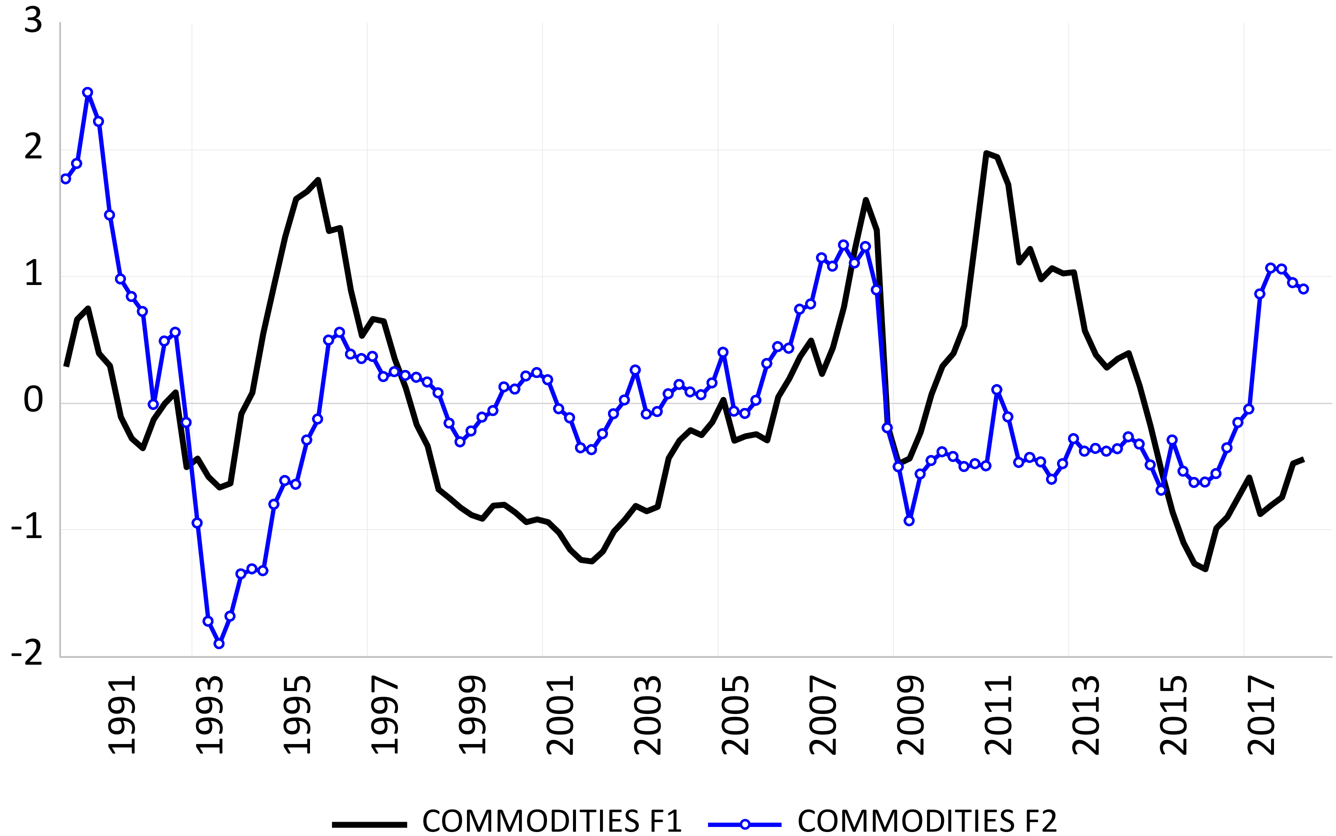

Note: See notes to Figure 3. The global factor is estimated from a factor model where the core variables for each factor across all four economies are included.

**Figure 5 Factor Scores: Monetary Variables**



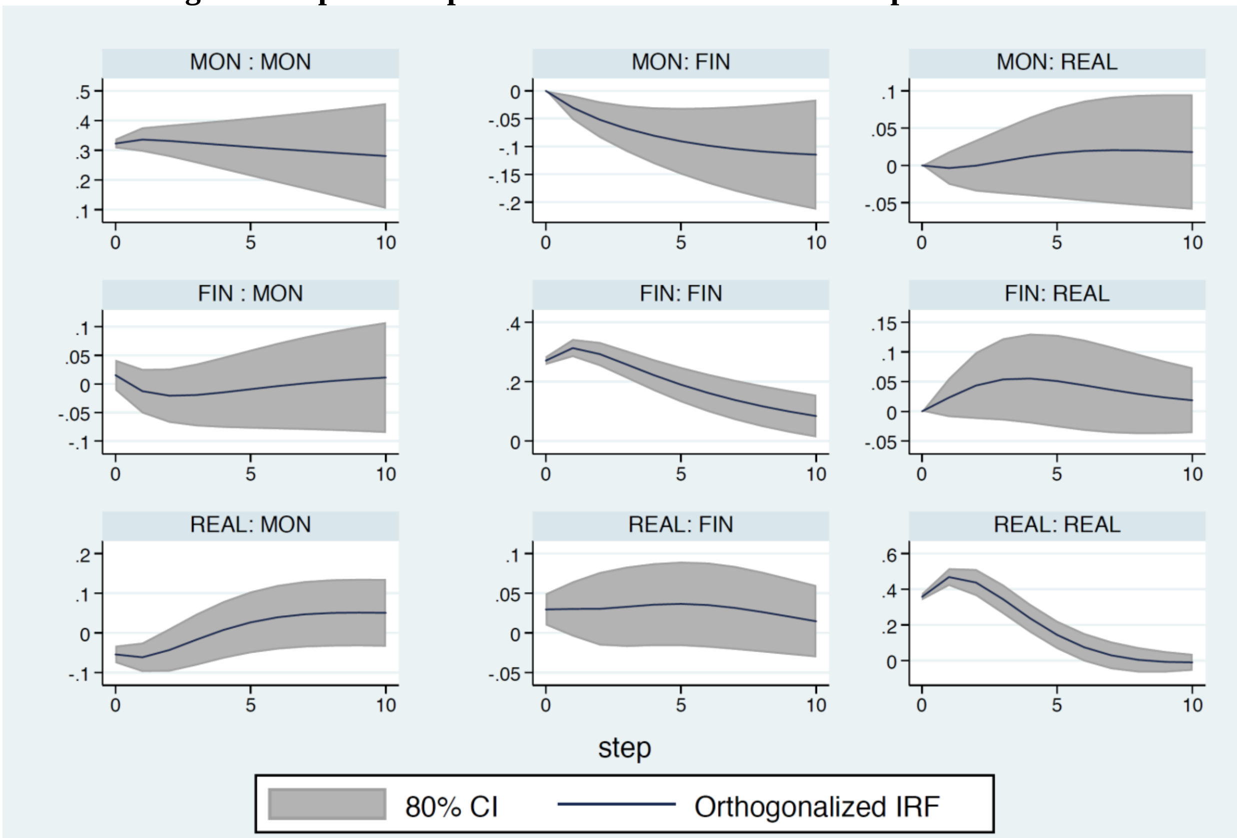

Note: See note to Figure 3. The vertical dashed lines indicate quarters when central banks in the US, the Eurozone, and Japan intervened in the form of unconventional monetary policies (see the appendix (available on request) for details). In the case of China, the shaded areas represent distinct periods when the exchange rate regime was deemed to differ from other periods. See Lin (2016).

**Figure 6 Factor Scores: Commodity Price Variables**



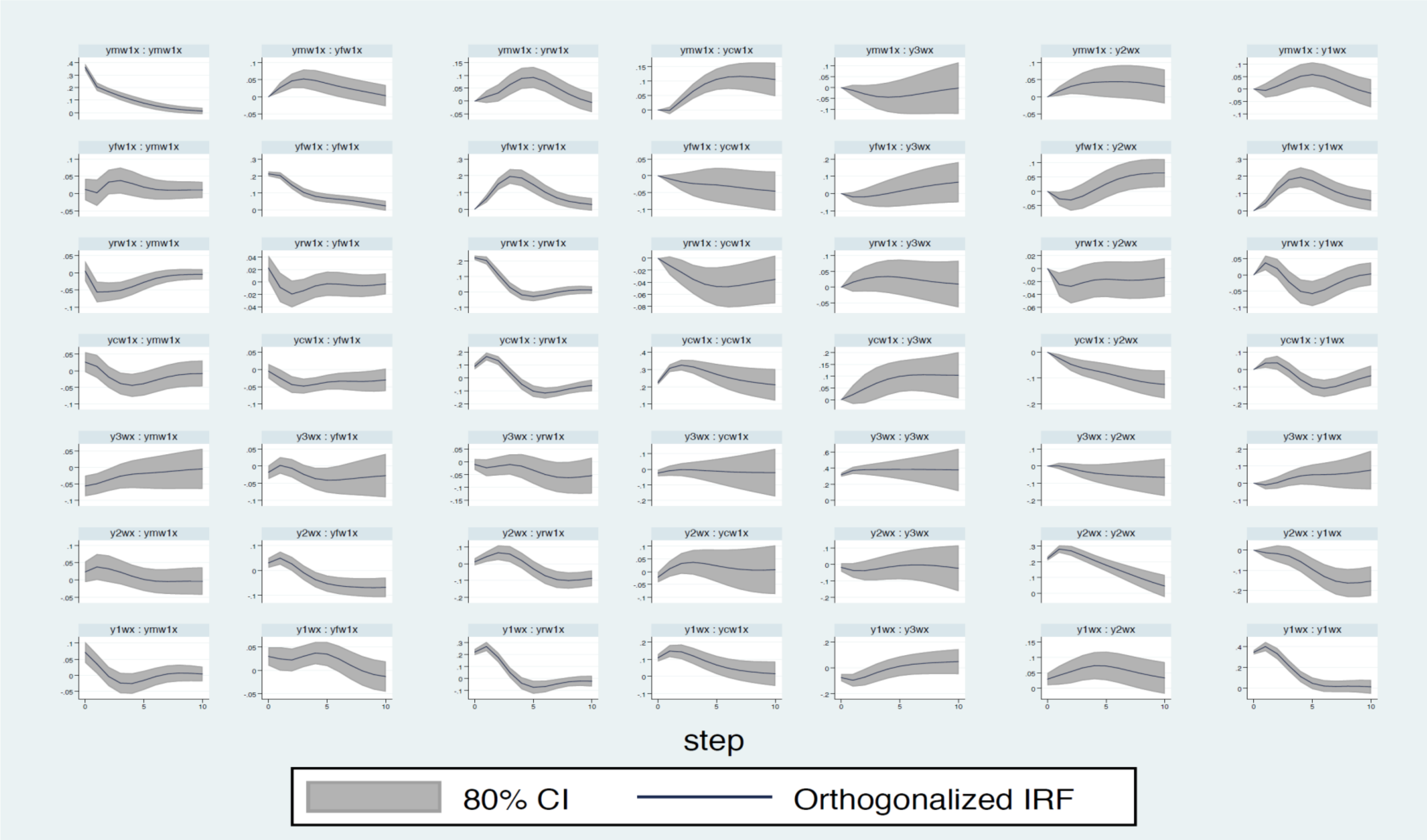

Note: See note to Figure 3.

**Figure 7 Impulse Responses – PVAR: Parsimonious Specification**



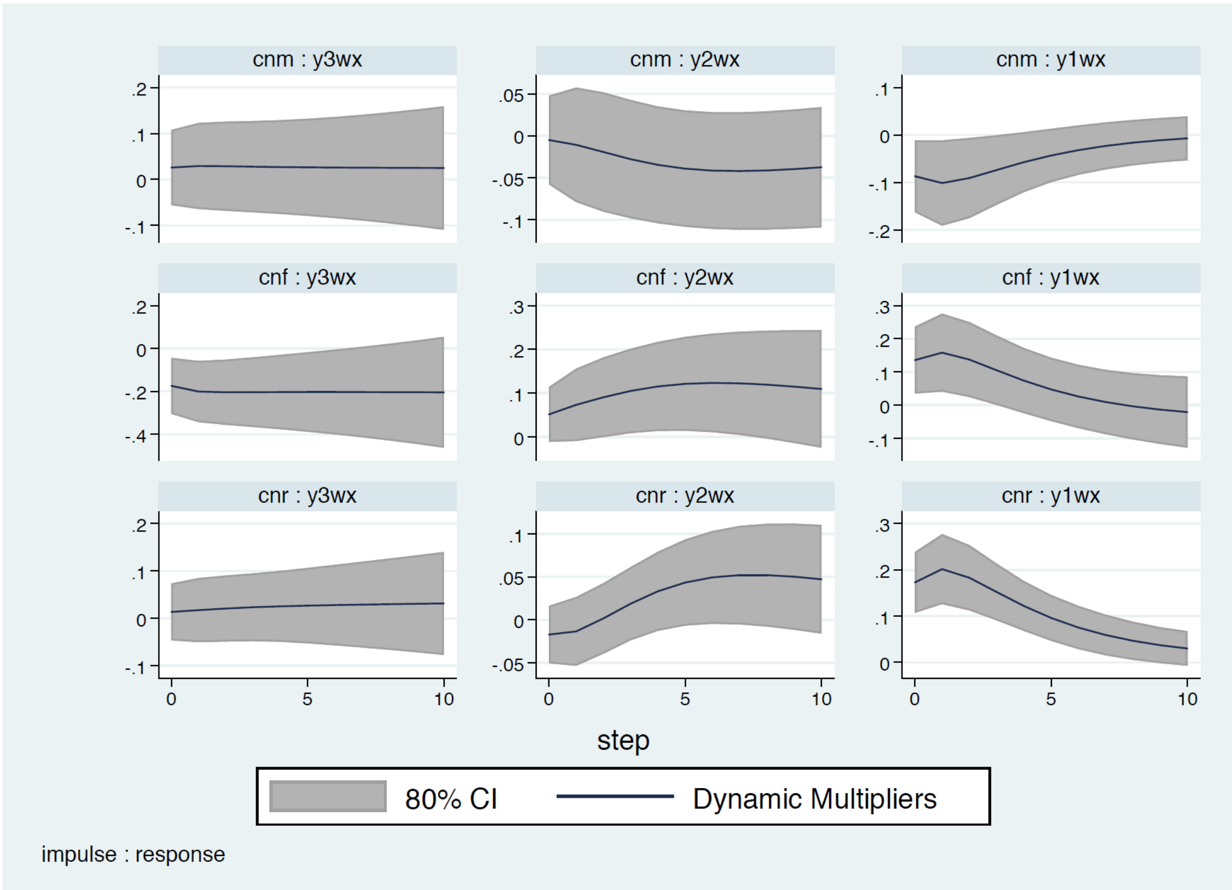

Note: see the text for additional details. The cross-section consists of all four economies (US, China, the Eurozone and Japan) but excludes the commodity factor or any exogenous variables.

**Figure 8A Impulse Responses PVAR: China as an Exogenous Source of Shocks, G3 with China Exogenous**



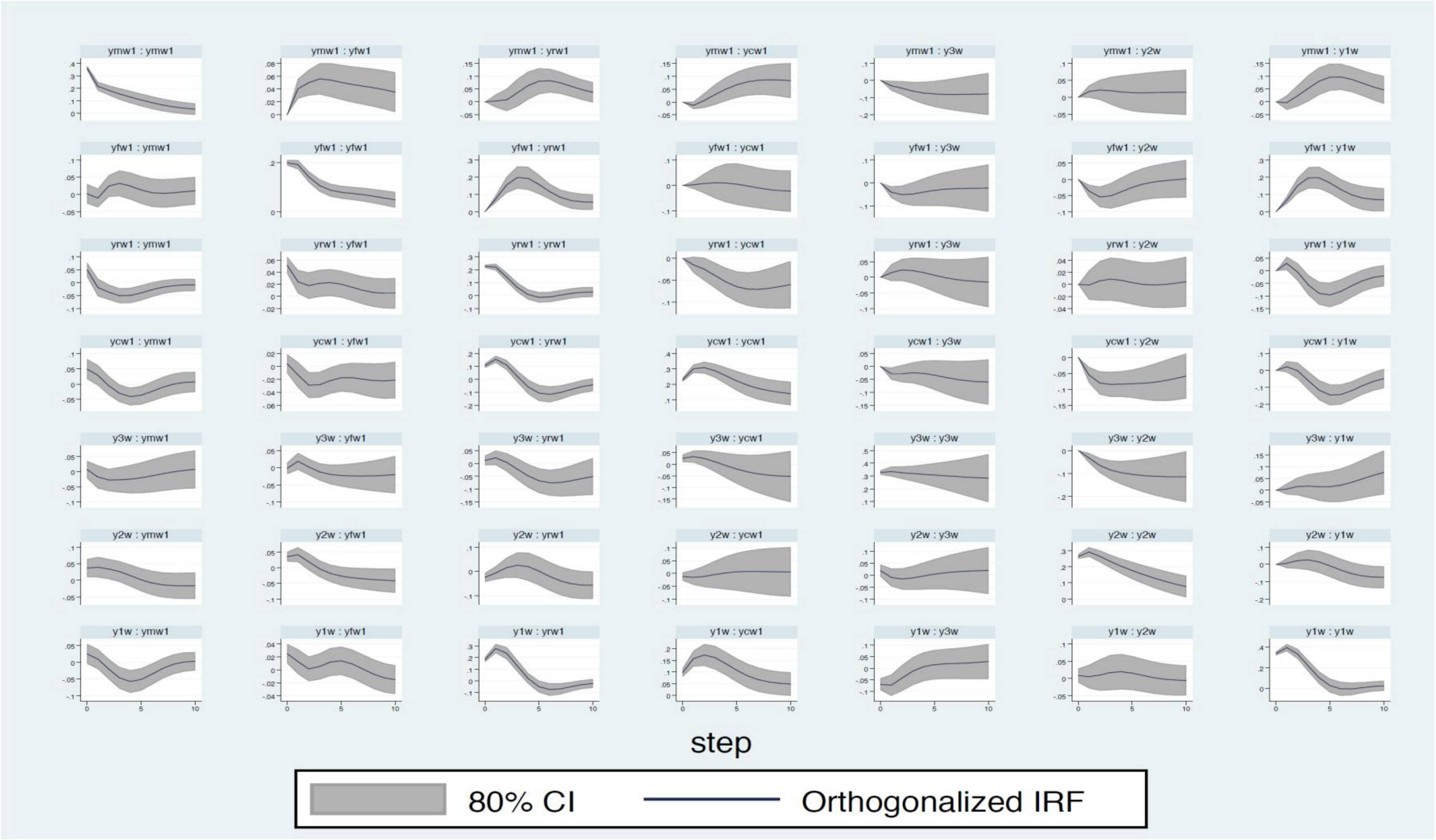

Note: See the text for more details. The cross-sections include the US, the Eurozone and Japan and include the commodity factor and other global factors as endogenous variables. Real, Financial, and Monetary shocks from China are treated as exogenous variables. Legend: y1wx, y2wx, y3wx are, respectively, domestic real, financial and monetary factors. Global real, monetary, financial and commodity factors are, respectively: yrw1x, yfw1x, ymw1x, and ycw1x.

**Figure 8B Dynamic Multipliers:**
**China's Impact on the Other Three Systemically Important Economies**



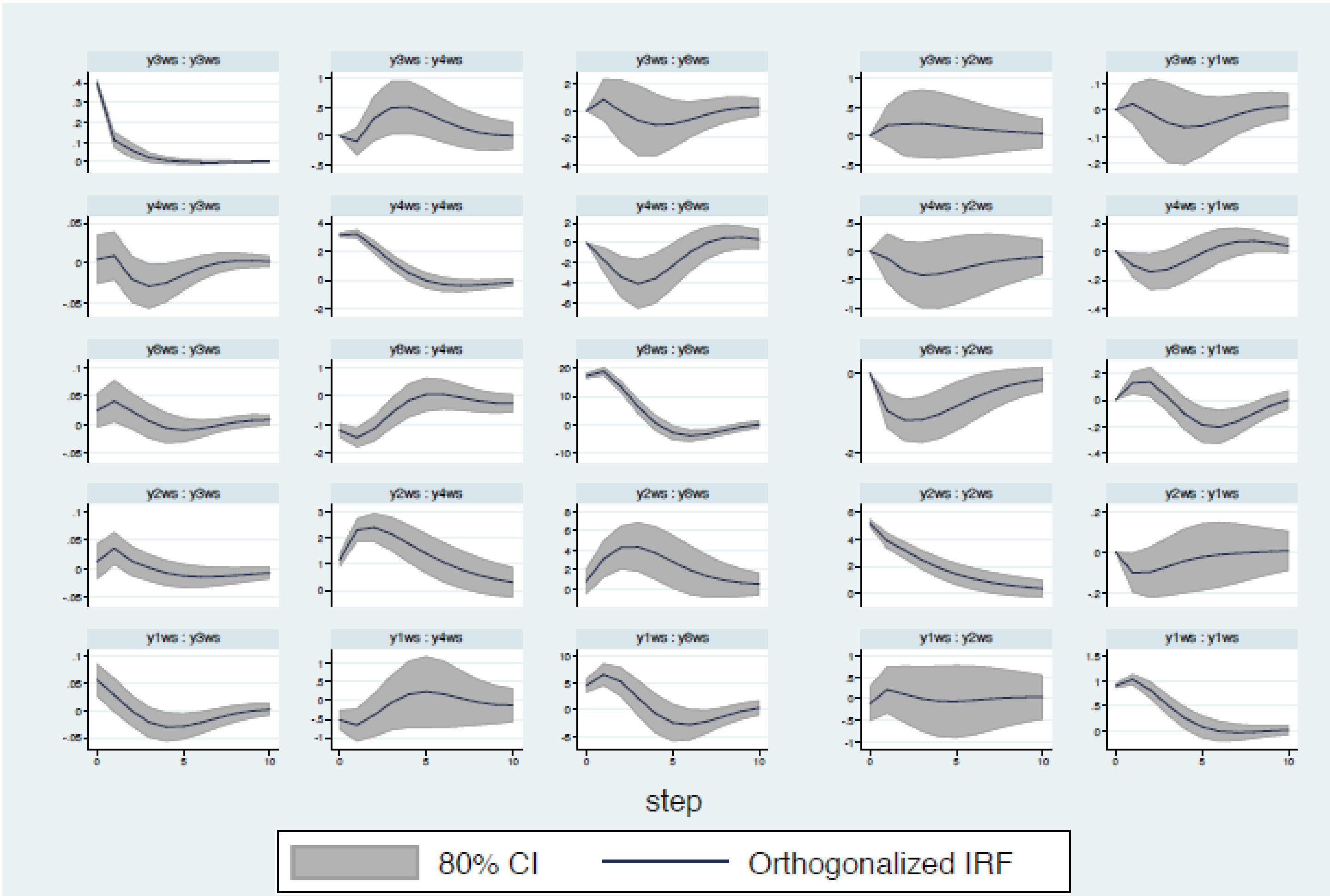

Note: See note to Figure 8A for details.

**Figure 9 Impulse Responses, PVAR: G4 Economies**




Note: See notes to Figure 8. China is included in the cross-section of economies.

**Figure 10 Standard PVAR Based on Observable Time Series**




Note: The standard PVAR consists of all cross-sections with the variables entering in the following order: real GDP growth (y1ws), real credit growth (y2ws), the rate of inflation in real oil prices (y8ws), the rate of change in the real exchange rate (y4ws), and the monetary factor as previously estimated (y3ws). The one year ahead forecast in real GDP growth, the rate of change in real property prices, and a dummy variable capturing UMP and exchange rate regimes as shown in Figure 5 are exogenous variables.

## APPENDIX – VARIABLES EMPLOYED[1]

### A. China

| Real economy | Financial | Monetary Policy |
|---|---|---|
| Consumer price index (2005Q1=100) | Foreign exchange reserves (mn US dollars) | REER (2010=100) Broad BIS index |
| Business Climate Leading Index (1996=100) | Stock market index (Shanghai/Shenzhen) | M2 – monetary aggregate (bn RMB) |
| Real GDP Growth 2010 prices | Property prices RMB/Sq m. | Required reserve ratio percent |
| Energy consumption (KwH bn) | Total Loans (bn RMB) | Central Bank Benchmark Interest Rate: 3 Month or Less percent |
| Real GDP growth Forecast[2] -Consensus Calendar year - % change | Interbank Offered Rate: Weighted Avg percent | Central Bank Benchmark Interest Rate: 1 Year percent |
| Inflation forecast -Consensus Calendar year - % change | Deposit interest rate (3m) percent | M0 – monetary aggregate (bn RMB) |
| Current account balance/ GDP percent | Overnight rate percent | Central Bank Assets/GDP percent |
| Oil price inflation – CEIC data YoY % change | CHIBOR 21d (China Interbank Offer Rate) percent | |
| Consumer Confidence | | |

[1] Note: In bold the series used to derive factors. All the variables for factor analysis are stationary. If the original time series is in levels and 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. Unless otherwise noted the data are in percent or an index. Recession indicators are [0,1] dummies with recession =1. YoY means that the rate of change is evaluated on a year by year basis.

[2] 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.

| | | |
|---|---|---|
| point | | |
| Industrial Production<br>Cement, oil, iron, coal, pharmaceutical, gas, rice, iron, steel (Ton th) | | |
| Economic Policy Uncertainty Index | | |

B U.S.

| **Real economy** | **Financial** | **Monetary Policy** |
|---|---|---|
| Real GDP<br>2012 prices | Stock market index<br>（S&P500, Wilshire 5000） | Shadow federal funds rate[3]<br>Wu-Xia<br>Krippner |
| Personal consumption expenditures Implicit Price Deflator (2009=100) | Total Credit to Private Non-Financial Sector (billions) | Effective Federal Funds Rate[4]<br>percent |
| Real GDP Forecast<br>- Consensus<br>Calendar year - % change | Domestic Banks Tightening Standards for Loans<br>index | Excess reserves (millions) |
| Inflation forecast<br>-Consensus<br>Calendar year - % change | Long-Term Government Bond Yields: 10-year<br>percent | REER (2010=100)<br>Narrow BIS index |
| Unemployment Rate<br>percent | 3-Month Treasury Bill<br>percent | Central Bank Assets/GDP<br>percent |
| Oil price inflation – WTI ($ per b) | All-Transactions House Price<br>1980Q1=100 | Monetary Policy Uncertainty |
| NBER Recession Indicator | National Financial Conditions index | |
| Economic Policy Uncertainty<br>index | Debt/GDP ratio<br>percent | |
| Industrial Production (2012 = 100) | Total Commercial Loans (mn) | |
| Current Account/GDP<br>percent | Commercial Paper Rate<br>percent | |

[3] From 2009Q1 to 2016 q4.

[4] From 1990Q1 to 2008 q4.

C. Eurozone

| **Real economy** | **Financial** | **Monetary Policy** |
|---|---|---|
| Real GDP Forecast<br>- Consensus<br>Calendar year - % change | Money Market Rate<br>percent | Central Bank Policy Rate (MRO)[5]<br>percent |
| Inflation forecast<br>-Consensus<br>Calendar year - % change | Domestic credit<br>(mn euro) | European Central Bank shadow rate[6]<br>Wu-Xia<br>Krippner |
| Consumer price inflation (HICP, 2015=100) | Euribor 1-year<br>percent | Discount rate<br>percent |
| Real GDP<br>2010 prices | Euro area 10-year Government Benchmark bond yield<br>percent | REER (2010=100)<br>Narrow BIS index |
| Unemployment<br>perccnt | Residential Property Prices (2010=100) | M3 - Monetary aggregate<br>(mn euro) |
| oil price inflation – Brent ($ per b) | Total Loans and Securities<br>(mn euro) | Central Bank Assets/GDP<br>-Germany (29.2%)<br>-France (20.5%)<br>-Italy (15.4%)[7] |
| Industrial Production (1999Q1=100) | Stock market index<br>- Germany (DAX)<br>- France (CAC40)<br>- Italy (Milan) | Monetary Policy Uncertainty |
| Economic Policy Uncertainty index | Bank lending survey<br>Supply (Backward/Forward looking)<br>Demand (Backward/Forward looking) | |
| CEPR Recession Indicator | | |

[5] Main refinancing operations.

[6] 2004Q3 to 2016 q4.

[7] Size of economies relative to Eurozone (19 countries) in 2017. Used as weights in calculating Eurozone average.

D. Japan

| **Real economy** | **Financial** | **Monetary Policy** |
|---|---|---|
| Real GDP<br>2011 prices | Stock market index<br>(Nikkei 225 Stock) | Monetary Base<br>(100 million ￥) |
| Consumer Price Index<br>(2015=100) | JGB Bonds Yield (10 years)<br>percent | Uncollateralized overnight call rate |
| Current Account/GDP<br>percent | JREI Home Price Index<br>Jan. 2000=100 | Shadow rate[8]<br>Imabuko-Nakajima<br>Krippner |
| Unemployment Rate<br>Percent | JGB Bonds Yield (3 months)<br>percent | REER (2010=100)<br>Narrow BIS index |
| Real GDP Forecast<br>-Consensus<br>Calendar year – % change | Assets: Loan: Financial Institutions (bn ¥) | Policy Rate<br>percent |
| Inflation forecast<br>-Consensus<br>Calendar year - % change | Money Market Rate<br>percent | Central Bank Assets/GDP<br>percent |
| Oil price inflation – WTI<br>YoY % change | Government debt<br>(bn ￥) | Monetary Policy<br>Uncertainty |
| Industrial Production (2010=100) | TANKAN Survey<br>– diffusion index<br>-Large enterprises<br>-Medium enterprises<br>-Small enterprises | |
| Diffusion Index: Leading Series | Foreign exchange reserves<br>(bn ¥) | |
| Economic Policy Uncertainty index | Money Market Rate<br>percent | |

[8] Full sample

E. Commodity Factor

| Component Members of Commodity Price Groups | |
|---|---|
| ENERGY | Coal, natural gas, petroleum[1] |
| FOOD | Butter, fish, rice, sugar, coffee[1] |
| SEEDS | Barley, wheat, maize, soybean[1] |
| INDUSTRIALS | Cotton, wool, pulp, rubber, timber (logs & hardwood), softwood, plywood[1] |
| LIVESTOCK | Lamb, beef[1] |
| METALS | Aluminium, copper, gold, iron ore, nickel, potash, silver, zinc, lead, tin[1] |

[1] Indicates that global pricing may be sourced in more than one location (e.g., coffee in New York, Brazil, and Uganda). All raw price data denominated in USD.

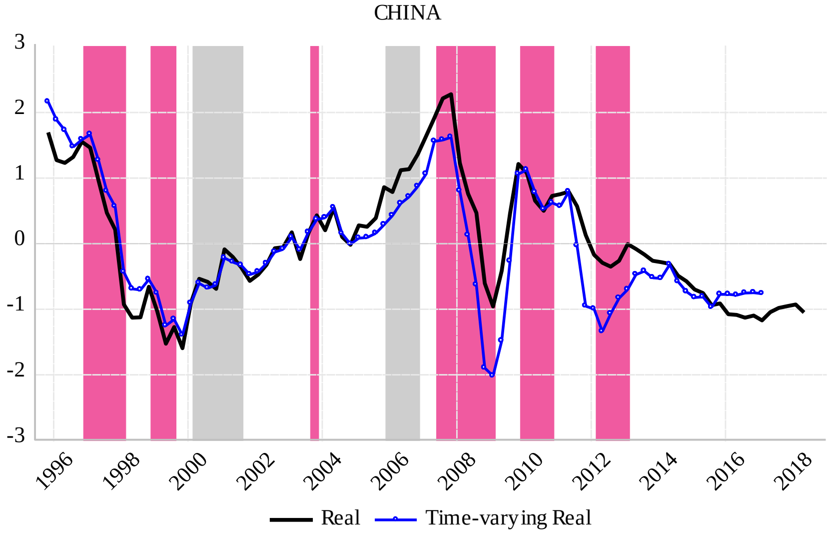
F. Global Factor (alternative – not used in the paper)

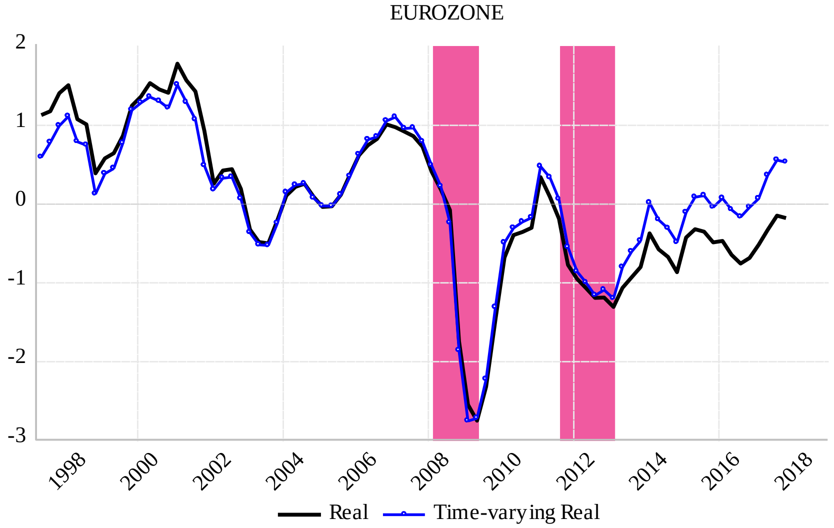
| Economy | Series |
|---|---|
| China | VIX – VXFXI/Cross-border claims[2] |
| Eurozone | VIX – Stoxx 50/ Cross-border claims |
| Japan | VIX – JPX JGB/ Cross-border claims |
| U.S. | VIX/ Cross-border claims |
| All | Baltic dry index<br>OECD industrial production indicator |

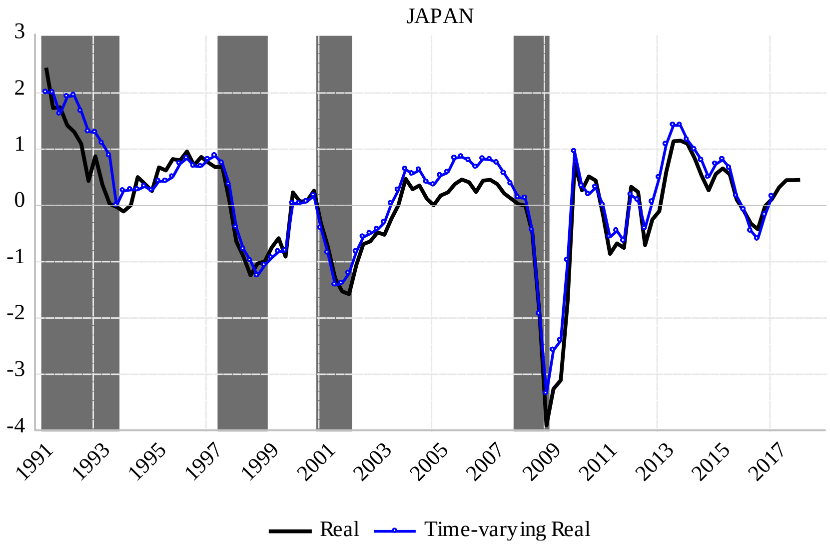
[2] BIS, Consolidated banking Statistics, All instruments, amounts outstanding, Millions of USD. Cross-border and total claims.

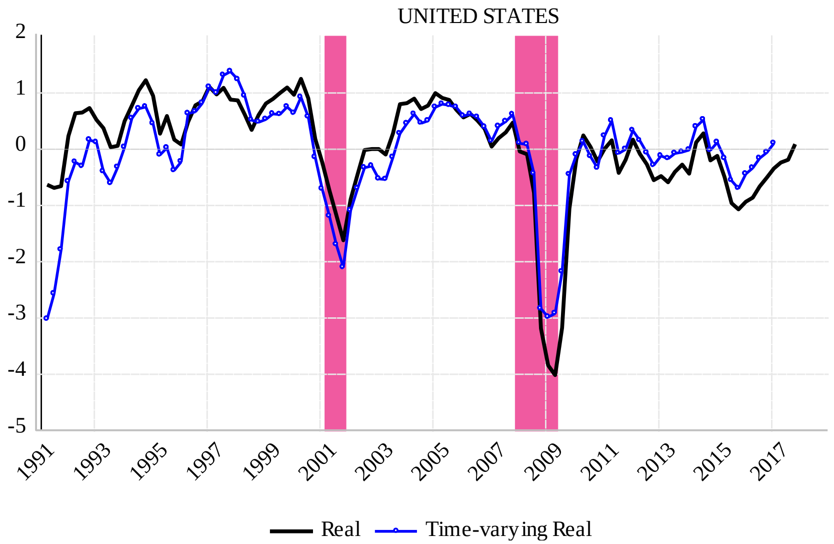
Factor Scores – Selected Graphs

## Real economy

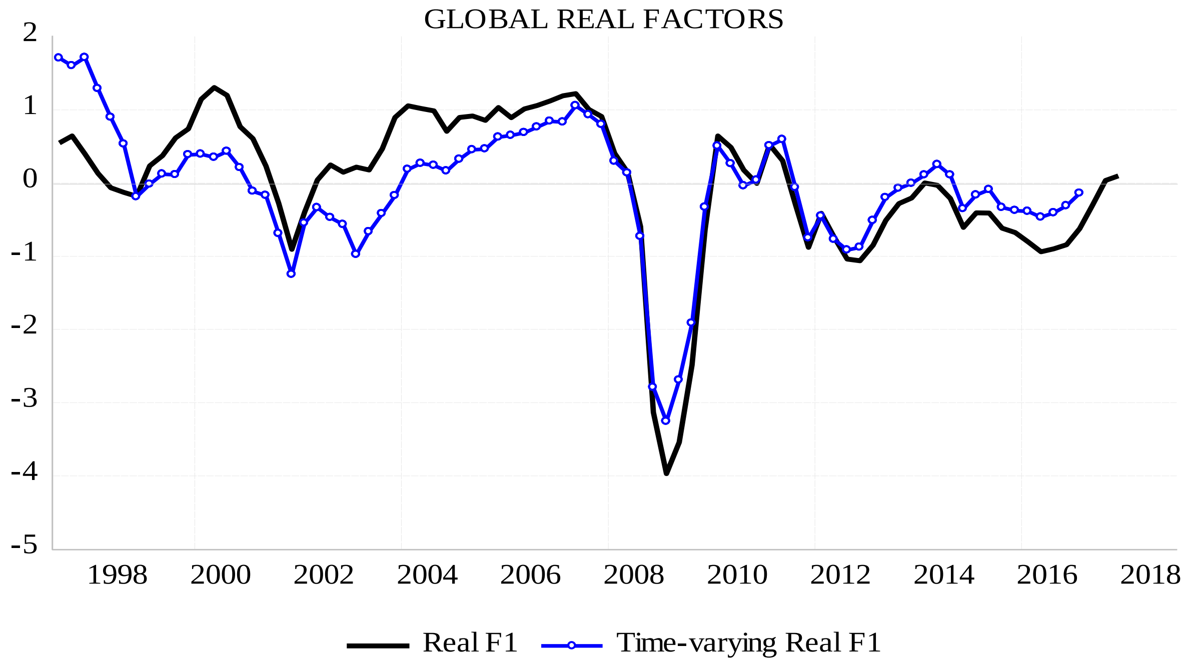


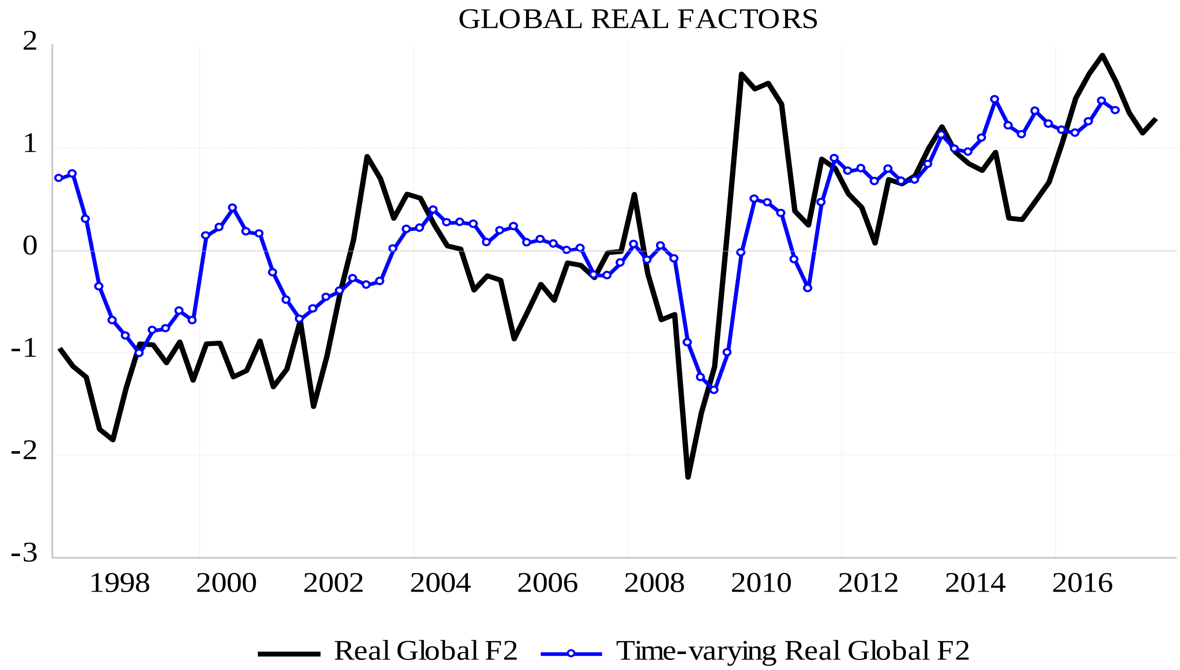



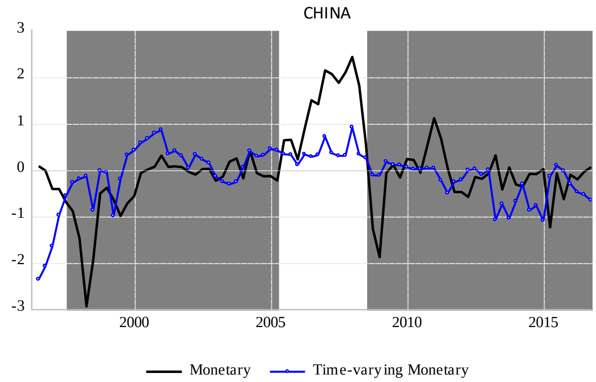



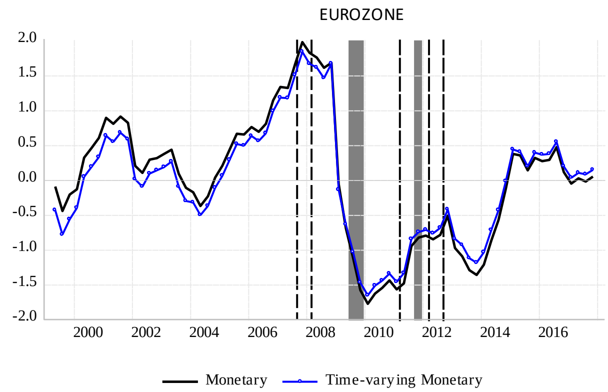
Real economy – Global

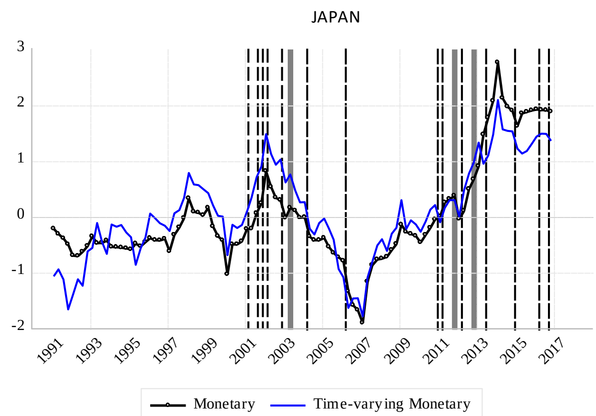


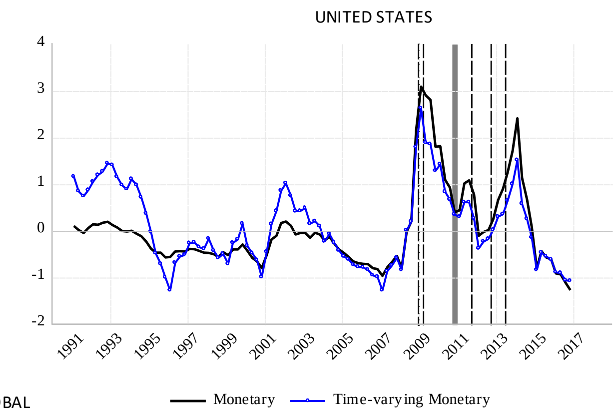



# Monetary

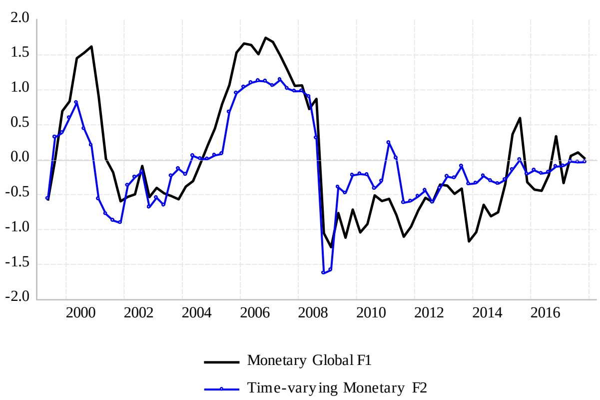


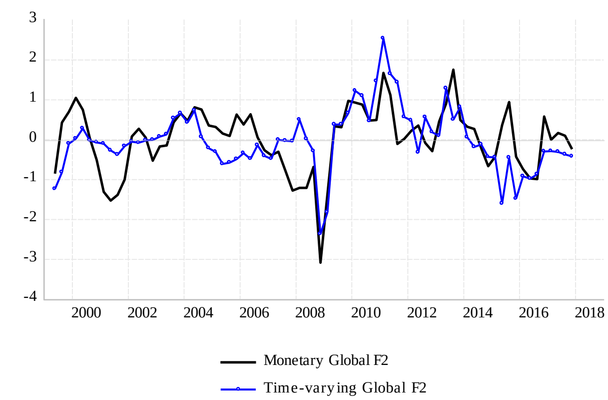



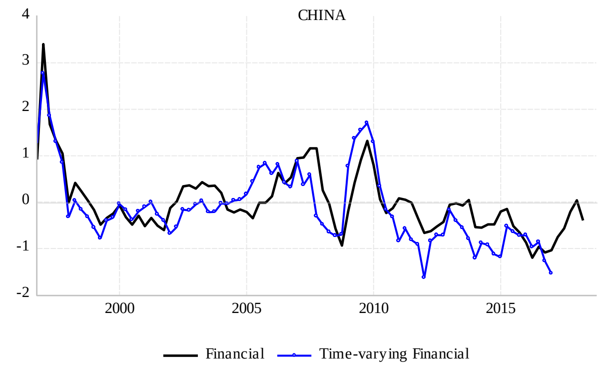



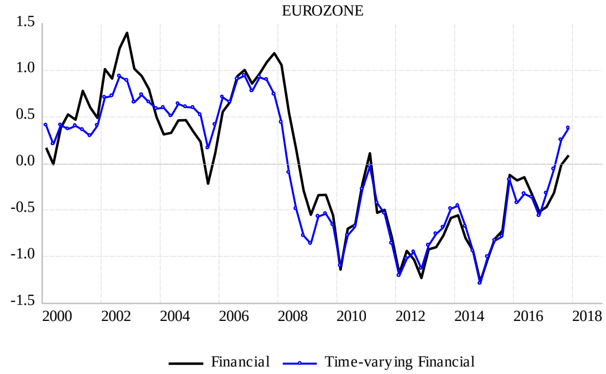

GLOBAL

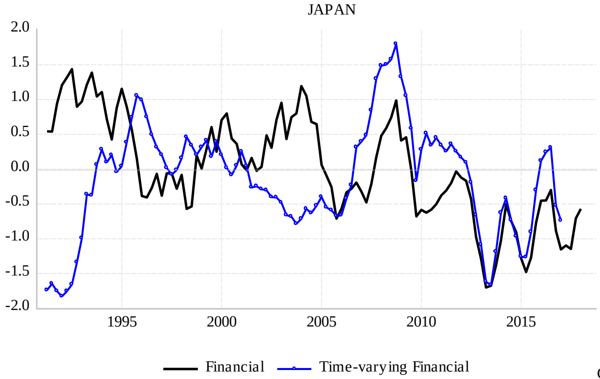


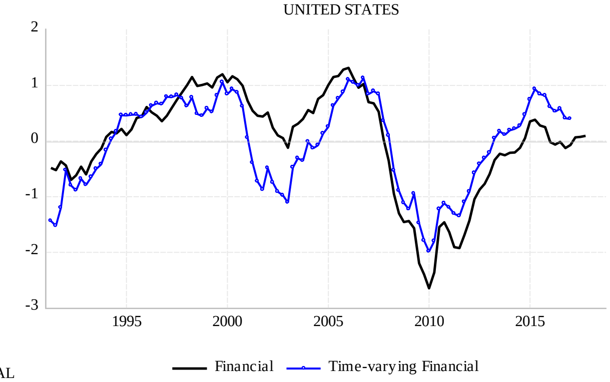



# Financial

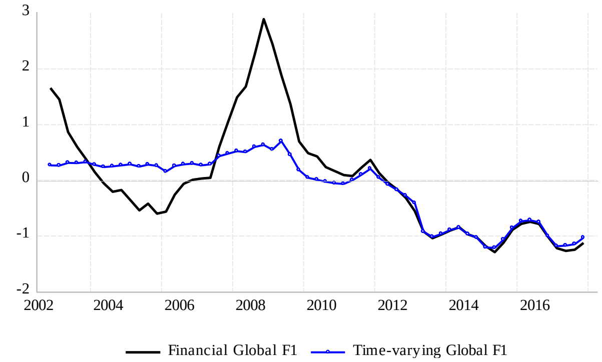


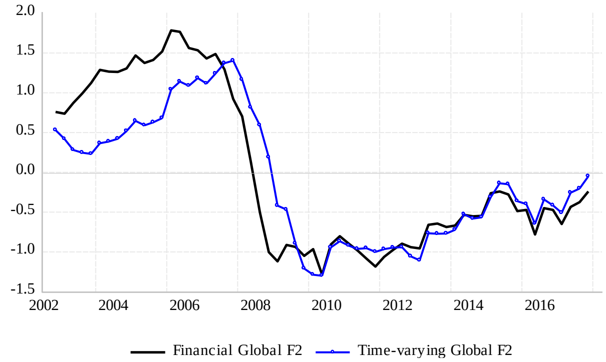



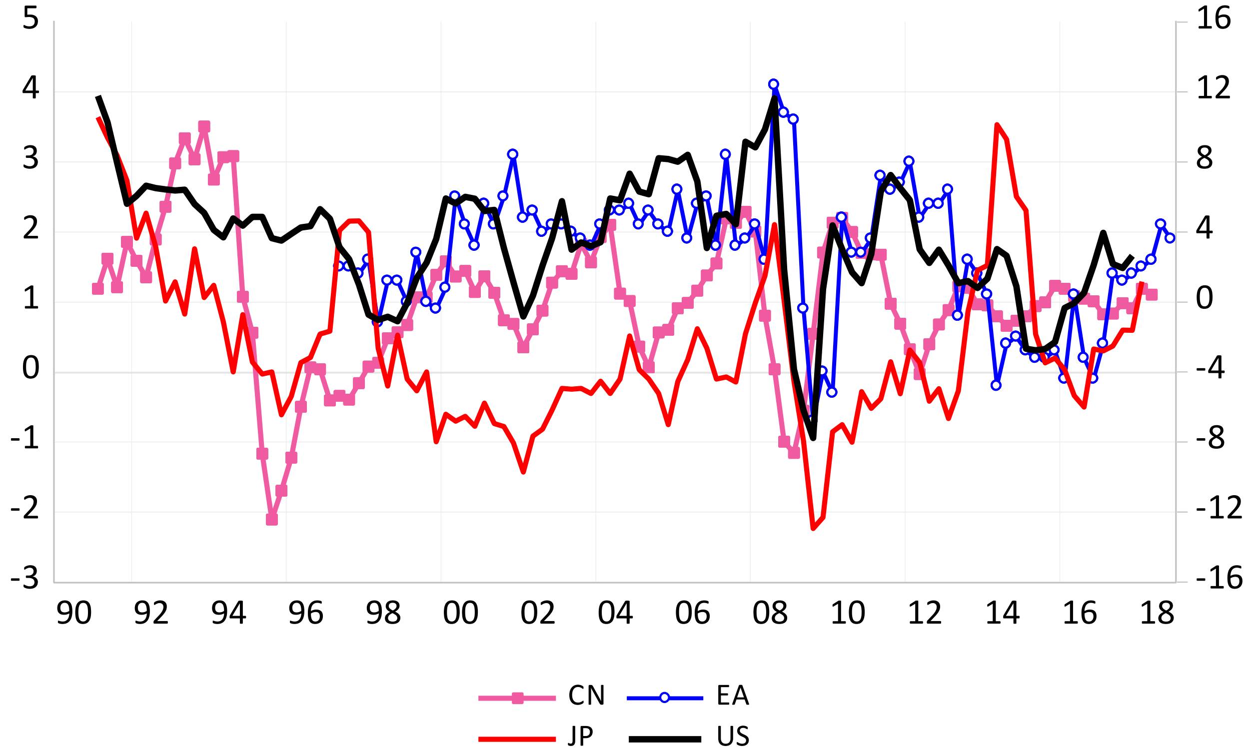



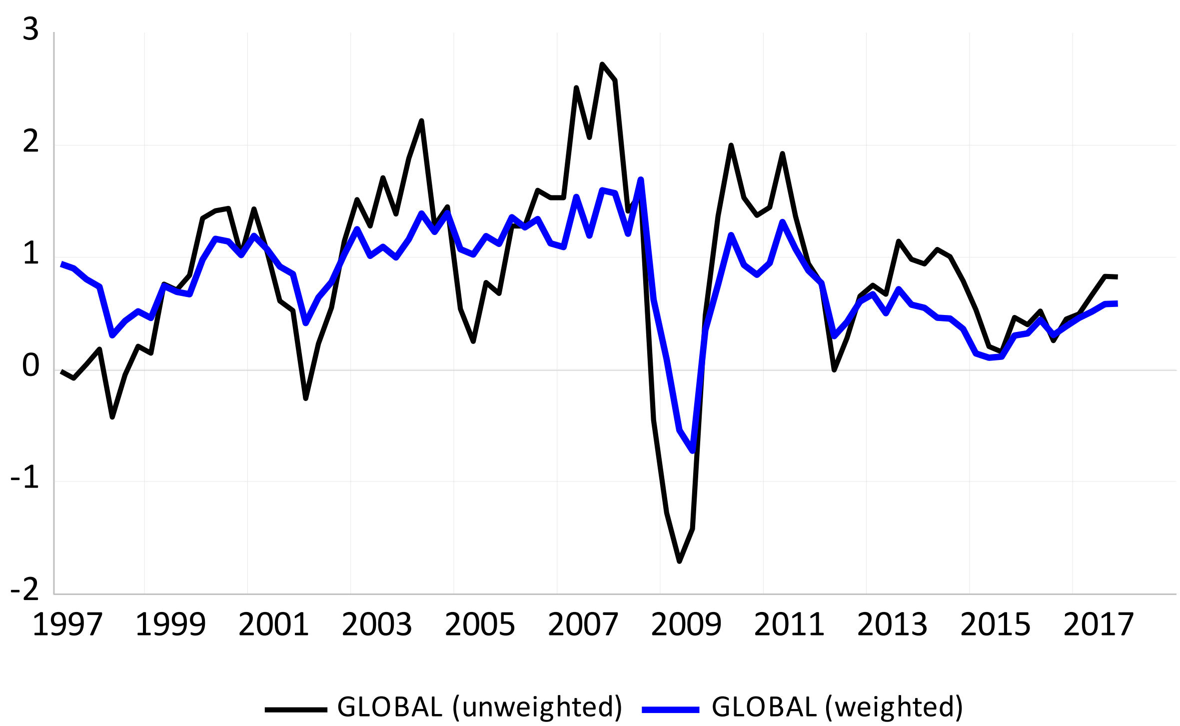

GLOBAL



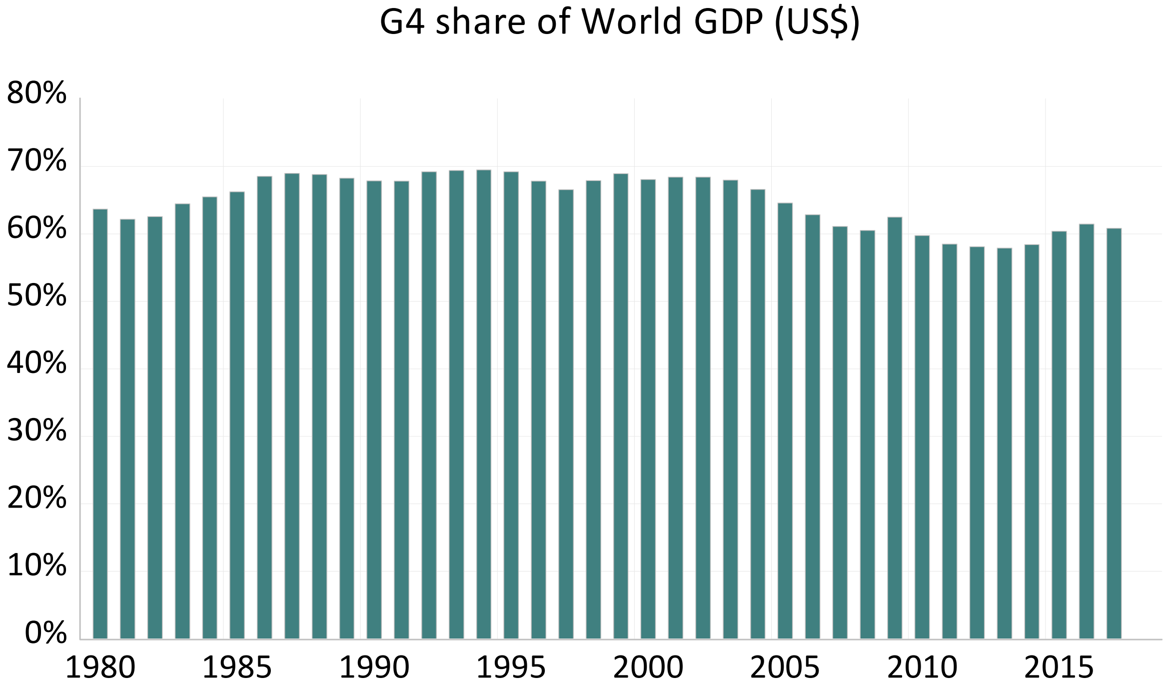



Inflation – By Country and Global

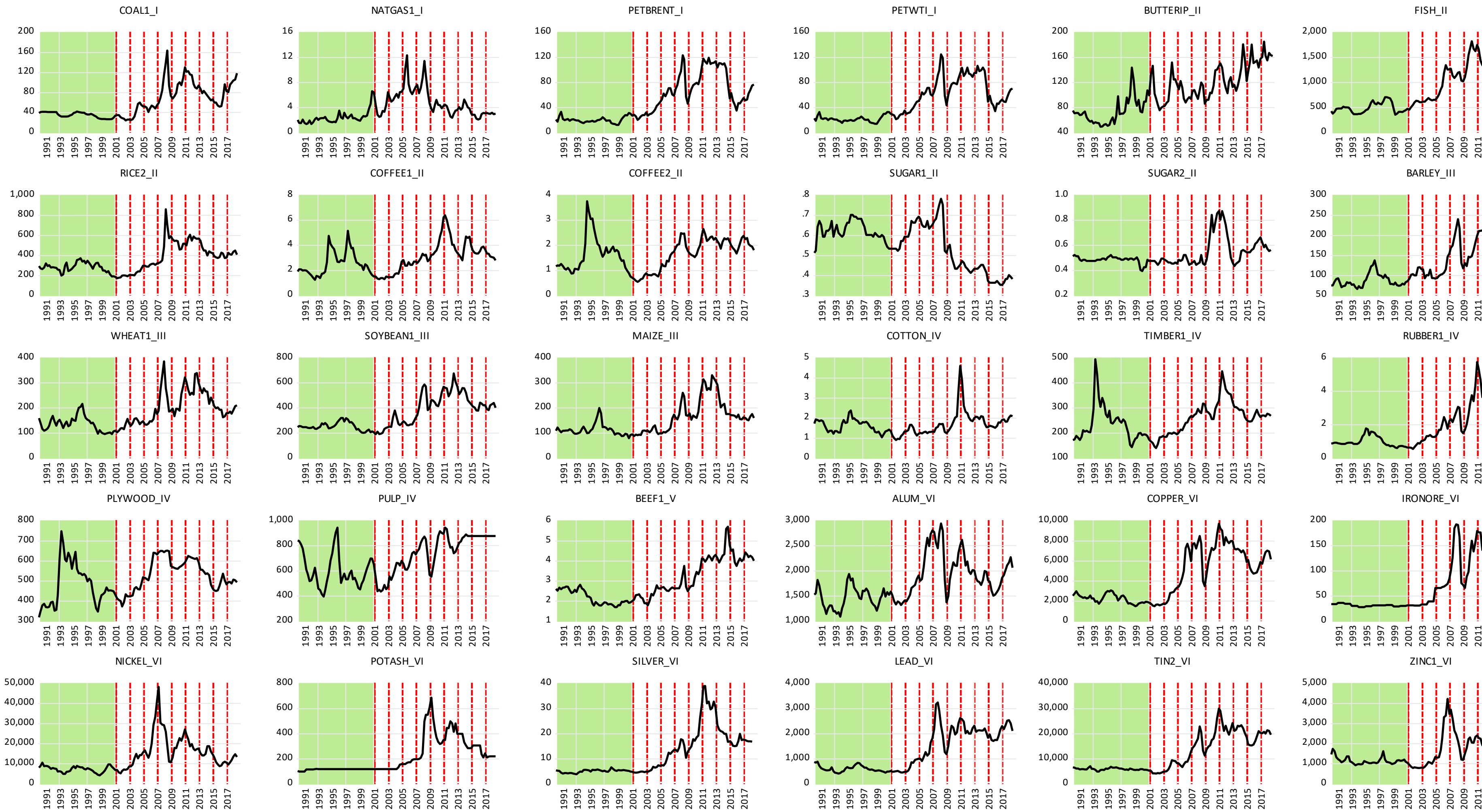


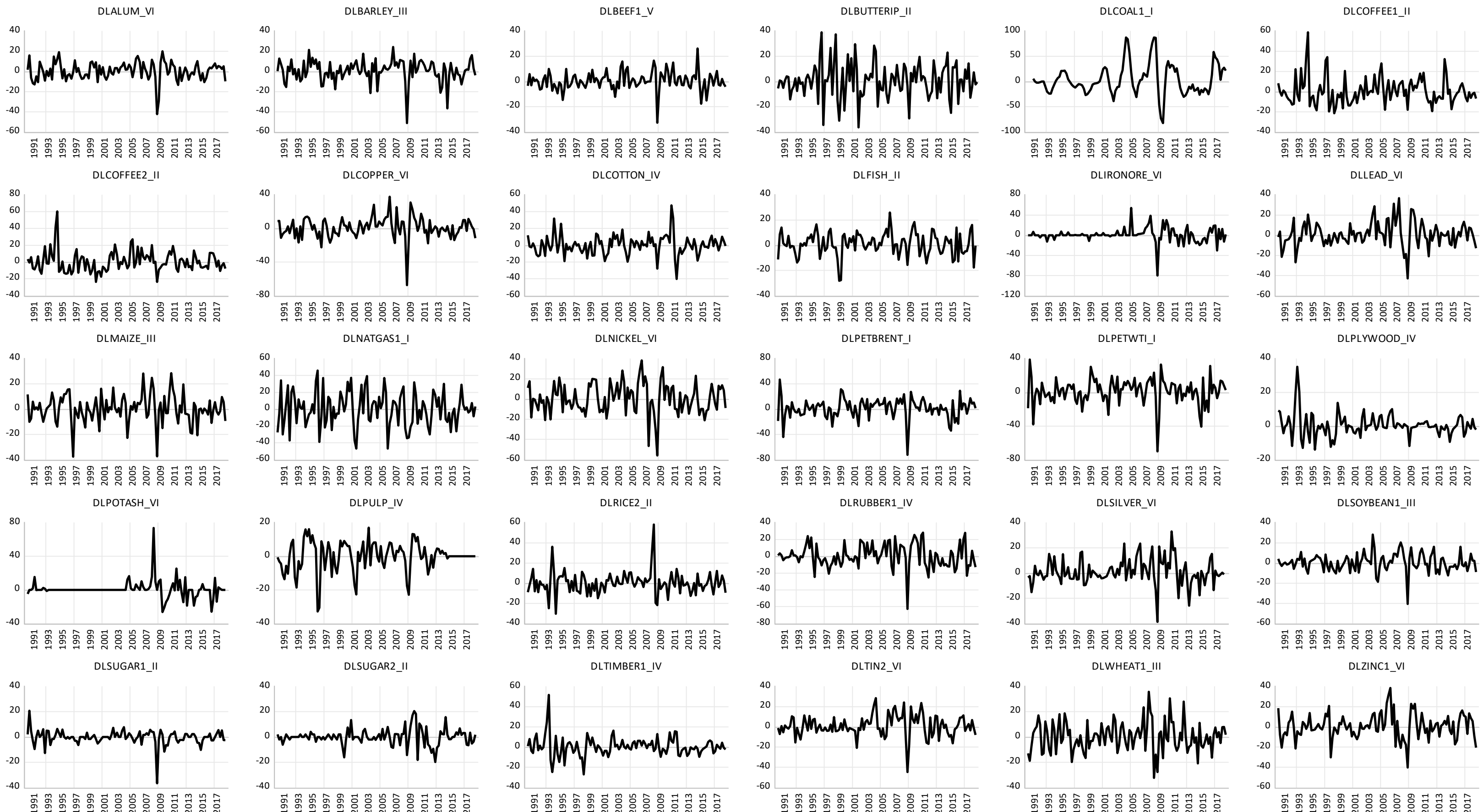
G4 Share of Global GDP



## Commodity Prices - Levels



Commodities – 100 times first log difference



Commodities – Factor Scores

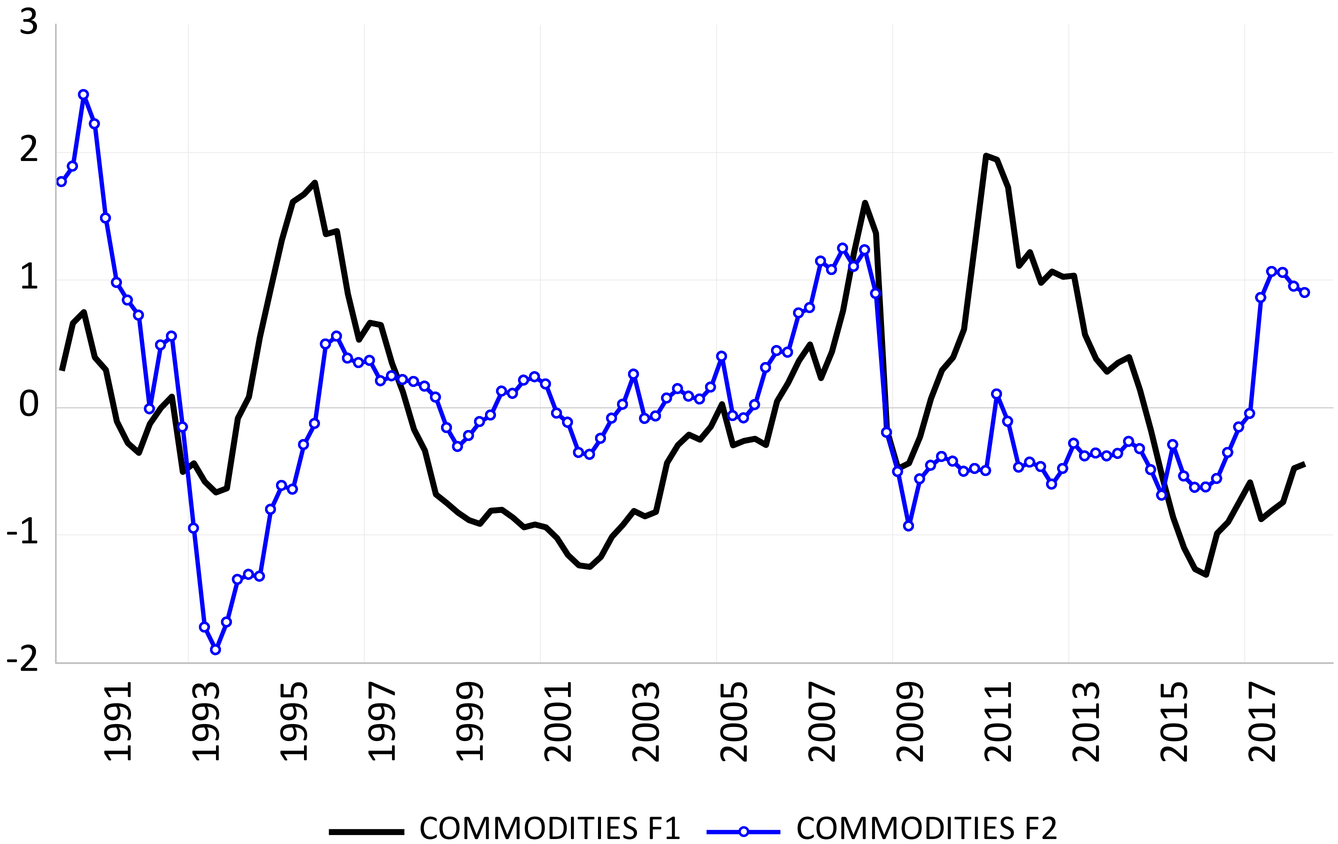


**Table 4 – Forecast Error Variance Decompositions (from WP version of the paper)**

Forecast-error variance decomposition

| Response variable and Forecast horizon | Impulse variable y1w | y2w | y3w | ycw1 | yrw1 | yfw1 | ymw1 |
|---|---|---|---|---|---|---|---|
| y1w | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | .9829727 | .0000551 | .0000243 | 8.21e-07 | .0058261 | .0059449 | .0051762 |
| 3 | .9570854 | .0002707 | .0001888 | .0000737 | .0190214 | .0069416 | .0164184 |
| 4 | .9313856 | .0006374 | .0009839 | .0002865 | .0287556 | .0065097 | .0314415 |
| 5 | .8929819 | .0010796 | .00298 | .0004212 | .0313338 | .0216637 | .0495398 |
| 6 | .8371977 | .0015021 | .0060917 | .0004292 | .0295471 | .0571816 | .0680505 |
| 7 | .7789037 | .001845 | .009552 | .0004069 | .0272737 | .0972968 | .0847218 |
| 8 | .7343015 | .0020999 | .0126647 | .0004241 | .025783 | .1258652 | .0988616 |
| 9 | .7074274 | .00227 | .0151408 | .0006612 | .0248892 | .1393027 | .1103086 |
| 10 | .6935515 | .0023549 | .0169518 | .0014966 | .0244034 | .1425478 | .118694 |
| y2w | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | .0046383 | .9953617 | 0 | 0 | 0 | 0 | 0 |
| 2 | .004725 | .9889129 | .004722 | .000314 | 1.30e-06 | .0009195 | .0004052 |
| 3 | .0059483 | .9716049 | .0127519 | .0021288 | .0035437 | .0037388 | .0002836 |
| 4 | .0084949 | .941709 | .023121 | .0054227 | .0128739 | .0080466 | .0003319 |
| 5 | .0119369 | .9021125 | .0353334 | .0102453 | .0277519 | .0119608 | .0006593 |
| 6 | .015554 | .8564895 | .048794 | .0168778 | .0465334 | .0143267 | .0014246 |
| 7 | .0186366 | .8069776 | .0627618 | .0256784 | .0682576 | .0150762 | .0026118 |
| 8 | .0207569 | .7545581 | .0763552 | .0368648 | .0926695 | .0147139 | .0040815 |
| 9 | .0218067 | .6997908 | .0886391 | .0504194 | .119945 | .0137664 | .0056327 |
| 10 | .021904 | .6433217 | .0987563 | .0660997 | .1502594 | .0125845 | .0070744 |
| y3w | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | .0277347 | .0019615 | .9703038 | 0 | 0 | 0 | 0 |
| 2 | .028878 | .0012735 | .9621423 | .0025311 | .0015569 | .0005903 | .003028 |
| 3 | .0243712 | .0013079 | .9522648 | .0083471 | .0035062 | .0023605 | .0078423 |
| 4 | .0191751 | .0012589 | .9383398 | .0171059 | .0054511 | .005494 | .0131751 |
| 5 | .0152962 | .0011704 | .9203255 | .0284713 | .0074758 | .0091906 | .0180702 |
| 6 | .01297 | .0010919 | .8996039 | .0420221 | .0100413 | .0122369 | .0220339 |
| 7 | .0118059 | .0010451 | .8773865 | .0572895 | .0137324 | .0139121 | .0248285 |
| 8 | .0113566 | .0010428 | .8539202 | .073874 | .0191207 | .0142617 | .0264241 |
| 9 | .0112871 | .001098 | .8287804 | .0915211 | .0266205 | .0137535 | .0269393 |
| 10 | .0113772 | .0012283 | .8013998 | .1101308 | .0364139 | .0128639 | .0265861 |
| ycw1 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | .0018058 | .002825 | .0000308 | .9953384 | 0 | 0 | 0 |
| 2 | .0024745 | .0013344 | .0000352 | .979578 | .0080653 | .0009845 | .007528 |
| 3 | .0020062 | .0016755 | .0002893 | .9544817 | .0297234 | .0012926 | .0105314 |
| 4 | .0014802 | .0043575 | .0006256 | .9214609 | .0592734 | .0011014 | .011701 |
| 5 | .0011948 | .0089879 | .000869 | .8823157 | .0941804 | .0008694 | .011583 |
| 6 | .0010995 | .0147923 | .000959 | .8396394 | .1316248 | .0011446 | .0107403 |
| 7 | .0010774 | .0209991 | .0009081 | .7955871 | .1696466 | .0022753 | .0095064 |
| 8 | .0010479 | .0270055 | .0007731 | .7517973 | .2069755 | .0042589 | .0081416 |
| 9 | .0009785 | .0324045 | .0006373 | .7094209 | .242925 | .0068085 | .0068252 |
| 10 | .0008701 | .0369635 | .000594 | .6692477 | .2771267 | .0095385 | .0056594 |
| yrw1 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | .0101481 | .0006836 | .0056053 | .0178599 | .965703 | 0 | 0 |
| 2 | .0132127 | .0003963 | .003822 | .0144865 | .9467413 | .0012355 | .0201057 |
| 3 | .0124596 | .0003853 | .0029772 | .0246802 | .9362403 | .0091911 | .0140663 |
| 4 | .0095441 | .0002785 | .0027986 | .0473721 | .9102926 | .0197526 | .0099615 |
| 5 | .0069875 | .0002662 | .0029672 | .0777788 | .8750982 | .0293703 | .0075319 |
| 6 | .0056138 | .0005143 | .0034305 | .1110816 | .8377533 | .0354216 | .006185 |
| 7 | .0051843 | .0010858 | .0041744 | .1439621 | .8027435 | .0375083 | .0053415 |
| 8 | .0052548 | .0019743 | .0051813 | .1745656 | .7717568 | .0366117 | .0046555 |
| 9 | .0054883 | .0031357 | .0064054 | .2021237 | .7447543 | .0340846 | .0040082 |
| 10 | .0056975 | .0045135 | .007781 | .2265786 | .721023 | .0310159 | .0033905 |
| yfw1 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | .0009264 | .0019426 | .0000561 | .0620014 | .0454023 | .8896712 | 0 |
| 2 | .0011114 | .0012017 | .0025528 | .0338915 | .1171284 | .83807 | .0060444 |
| 3 | .0038411 | .0009868 | .0034446 | .0259607 | .1433321 | .8003513 | .0220835 |
| 4 | .0068976 | .0009171 | .0034663 | .0273064 | .1543687 | .7668467 | .0401972 |
| 5 | .0088071 | .0008692 | .0032918 | .0367598 | .1564104 | .737365 | .0564968 |
| 6 | .009105 | .000944 | .0033554 | .0548527 | .1533265 | .7123389 | .0660776 |
| 7 | .0087151 | .0014027 | .0036998 | .079358 | .1479682 | .6901366 | .0687196 |
| 8 | .0085868 | .0024844 | .0040826 | .1064114 | .1437091 | .6672771 | .0674487 |
| 9 | .0088144 | .0042771 | .0042896 | .1327064 | .144297 | .6408964 | .064719 |
| 10 | .0090204 | .0066974 | .0042644 | .1562101 | .1523848 | .6099722 | .0614506 |
| ymw1 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | .0440766 | .0044108 | 4.71e-06 | .0186638 | .0480949 | .0351123 | .8496369 |
| 2 | .0470284 | .0119312 | .0017227 | .025567 | .034704 | .0303469 | .8486997 |
| 3 | .0421119 | .015433 | .0037424 | .0366561 | .0334786 | .0266666 | .8419114 |
| 4 | .0369225 | .0161561 | .0054856 | .0564157 | .0500627 | .0241469 | .8108105 |
| 5 | .0325893 | .015045 | .00668 | .0823313 | .0834126 | .021811 | .7581308 |
| 6 | .0288199 | .0132518 | .0073001 | .1119792 | .1317858 | .0192173 | .687646 |
| 7 | .0252091 | .0116141 | .0073875 | .1431955 | .1880733 | .0167765 | .6077438 |
| 8 | .0216823 | .0106096 | .0070287 | .1743248 | .2453082 | .015322 | .5257244 |
| 9 | .0183583 | .0104042 | .0063387 | .2039735 | .2985712 | .0152917 | .4470624 |
| 10 | .015371 | .0109504 | .0054604 | .2310175 | .3456109 | .016391 | .3751989 |

Note and Legend: The decomposition is for the PVAR shown in Figure 9. Y1W, Y2W, Y3W are, respectively, the time-varying real, financial, and monetary factors. YCW1, YRW1, YFW1, and YMW1 are, respectively, the global commodity, real, financial, and monetary factors.