HONG KONG INSTITUTE FOR MONETARY RESEARCH

ASIAN BUSINESS CYCLE SYNCHRONISATION

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HKIMR Working Paper No.06/2011

February 2011

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Abstract

This paper develops a multi-level structural factor model to study international output comovement and its underlying driving forces. Our method combines a structural VAR with a multi-level factor model, which helps us understand the economic meaning of the estimated factors. Using quarterly data of real GDP growth covering nine emerging Asian economies and G-7 countries, we estimate a global supply factor, a global demand factor, and group supply and demand factors for each group of the economies. We find that, while the role of the global factors has intensified over the past fifteen years for most of the economies, output fluctuations in Asia have remained less synchronised with the global factor than those in the industrial countries. The Asian regional factors have become increasingly important in tightening the interdependence within the region over time. Thus while emerging Asian economies cannot "decouple" completely from the advanced economies, they have nonetheless sustained a strong independent cycle among themselves. We also find that synchronised supply shocks contributed more to the observed synchronisation in output fluctuations among the Asian economies than demand shocks. This points to the role of productivity enhancement through vertical trade integration, rather than dependence on external demand, as the primary source of business cycle synchronisation in emerging Asia.

Keywords: Business Cycle Synchronization, Asia's External Dependency, Decoupling, Multi-Level Factor Model, Structural VAR

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* We are grateful to Hans Genberg, Mathias Hoffmann and Philipp Maier for their thoughtful comments and suggestions. We would also like to thank Joshua Aizenman, Jiandong Ju, Heiwai Tang, Eric van Wincoop, and James Yetman for helpful discussions, and Li Cui, Alex Ho, Chunyu Ho, Chang Shu, and Matthew Yiu for their comments on the paper. All remaining errors are ours. Authors' E-Mail Addresses: dhe@hkma.gov.hk; cwliao@hkma.gov.hk

1. Introduction

The accelerated pace of globalisation in the past fifteen years has led to a high degree of economic integration of Asian economies with the rest of the world, particularly through trade of goods and services. At the centre of the globalisation process in East Asia is a rapid development of vertical trade integration in the region, with China becoming a trading hub of manufactured goods after its accession to the WTO in 2001. The East Asian supply chain is particularly dominant in electronic products, as illustrated by Koopman, Wang, and Wei (2008). While increased trade in substitutes can generate resource-shifting effect, leading to more asymmetric business cycles across countries, trade in complements such as vertical trade will have opposite effect and strengthen the output co-movement (Burstein, 2008). Giovanni and Levchenko (2009) and Ng (2010) find that the vertical production linkage is the main channel through which trade synchronises business cycles between economies. Thus, business cycles in East Asia may have become more synchronised as a result of increasing vertical trade integration in the region.

Theoretically, vertical trade integration in a region can affect business cycle synchronisation among the economies in the region through a number of channels. On the demand side, since the regional production network is organised to serve a common market or source of final demand, common demand shocks that originate outside the region may lead to common movement of business cycles in the region. On the supply side, the regional production network implies that producers along the production chain are pushed or pulled together toward the frontier of technology. For instance, a positive supply shock to computer technologies may lead to producers in different countries along the supply chain to move to higher efficiency simultaneously. Such supply side shocks may thus lead to higher synchronisation of business cycles among the economies that form the production network. He and Zhang (2010) argue, for example, that the role of export in promoting economic growth in China should best be appreciated from its effect on the supply side, rather than on the demand side.

Empirically, several papers have investigated business cycle synchronization in East Asia. One strand (e.g., Kim, Lee and Park, 2009) employs a structural VAR model and examines the impact on Asian economies of global shocks and regional shocks. However, the results of SVAR models are in general sensitive to the identification assumptions, and it is not trivial to separate regional shocks from global shocks. Another strand (e.g., Eichengreen and Bayoumi, 1996) assesses bilateral correlations. However, it is not clear whether the observed bilateral correlation is due to global co-movement or regional integration, and business cycle synchronization should conceptually be multilateral. Genberg and Siklos (2010) raised concern about the role of shocks originating from the US (or more broadly, from the rest of the world) when studying the correlation of demand or supply shocks between two economies. They find fewer statistically significant correlations of underlying shocks in Asia once the external effects are considered.

Closest to our work, Kose, Otrok and Whiteman (2003) used a multiple-level factor model to decompose world business cycle co-movement into global, regional and country-specific levels, which has been widely used to study comovement of economic variables. However, such a model is subject to two major challenges. The first challenge is how to deal with multiple factors. The multi-level factor models conventionally assume one single factor at each level. For instance, there is typically only one global factor. As many researchers (e.g.,Harding, 2010) have pointed out, there might be more than one global factor in reality. For a conventional factor model without the hierarchical structure, Amengual and Waston (2007) proposed a way to estimate the number of factors consistently and the multiple factors can be selected using the principal component method. However, for a factor model that has a hierarchical structure, computation is difficult and the estimation of more than one factor at each level would be nontrival. Secondly, the factors do not usually have any economic meaning, making it difficult to understand what are the driving forces of observed co-movement among economic variables.

This paper introduces a new way to tackle these problems. We develop a multi-level factor model with a structural VAR model embeded. The estimation method proceeds in three steps. First we use a SVAR to identify a supply shock and a demand shock for each economy. Then we apply the multi-level factor model to the identified shocks, separating global co-movement from regional co-movement. Finally, we assess the role played by comovement in different structural shocks in explaining output fluctuations at both the global and the group level.

In the first half of the paper, we apply the multi-level factor model directly to real output data, and obtain an overall picture about business cycle synchronization in East Asia. The findings are rich and intriguing. Using a full sample analysis on real GDP, we identified notable roles for both the global factor and regional specific factors in explaining the output fluctuations across sixteen economies. The impact of the factors on each country is heterogeneous, though. For example, China's output fluctuations are mostly explained by its country-specific component.[1] A further investigation using subsamples suggests that the role played by the global factor has intensified over the decades, implying a stronger global business cycle. For both the Asian group and the industrial countries group, on average the variances explained by global factors increased dramatically after mid 90s. However, the influences of the Asian regional factor and the G-7 group factor exhibit very different evolution patterns. The Asian regional factor has played an increasingly important role in strengthening the business synchronization within the group, while the G-7 group economic co-movement has been mainly driven by the global factor.

In the second part of the paper, we use the multi-level structural factor model to disentangle the driving forces behind the pattern of international business cycle synchronization. We decompose the common

[1] As a sensitivity check, we estimate the model using data from 1999 Q1 to 2008 Q2, in which both the 1997 Asian Crisis and the recent global financial crisis are excluded. The results show that the Asian regional factor can explain around 22% of China's output fluctuations in this sub-period. Therefore, China's seemingly delinking from other countries found in full-sample analysis may be due to its resilience in the two crises.

factors into supply factors and demand factors, at both global and group level. The supply factors capture the co-movement among supply shocks, which are assumed to have a long run impact on output growth and can be interpreted as productivity shocks. On the other hand, the demand factors extracted from the demand shocks only affect output temporarily and are conventionally considered to be caused by monetary policy shock or other short-lived shocks. We find that East Asian economies have had a sharply increased degree of synchronisation in terms of supply factors at both the regional level and the global level after 1995, with no significant change in the role played by global and regional demand factors. These findings imply that the more synchronised business cycles among the East Asian economies are largely due to more synchronised productivity shocks.

The paper is organized as follows. We describe the data and the methodology in Section 2 and discuss the empirical results in Section 3. In Section 4 we discuss the policy implications of our results. Section 5 concludes.

2. Methodology and Data

To study Asian regional business cycle synchronization, it is important to separate global effect from regional-specific co-movement. A rising tide lifts all boats, hence the observed co-movement among Asian economies could be partly due to the global trend of synchronization. In order to answer the question how the pattern of Asian regional business cycle co-movement is different from the global trend, we need to look into the regional specific co-movement, netting out the effect of synchronization at the global level.

We adopt a latent factor model with multi-level factors, which is a parsimonious way to deal with commonality among a large dataset. There are many economic fundamentals driving global and regional economic fluctuations. However, it is not clear in which way, for example, linear or nonlinear, they affect business cycle movement and how they should be included in the econometric model. Furthermore, too many explanatory variables would cause problems such as multicollinearity in regression models, while including too few variables leads to the misspecification and omitted variable problem. Instead of explicitly considering all possible observed factors, the latent factor model identifies unobserved factors, which could be interpreted as a combination of various fundamentals that affects the economies, such as technology progress, monetary shocks, oil prices, etc.

Another advantage of the factor models is that it is a multi-lateral approach. Conventionally, bilateral correlations are used to measure co-movement of two time series. Researchers use average pair-wise correlation over a group of countries to gauge synchronization within the group. If one uses a reference country, the results will depend on the selection of the benchmark. Factor models can avoid such problems, and thus have been extensively used to quantify the extent of co-movement among time series.

2.1 The Econometric Model

A latent multi-level factor model can be used to decompose output growth (or any other economic variables) into a world component, a group component, and a country-specific component. For country i which belongs to group k, its output growth at time t, y_{it} , is modelled as follows (Model 1 henceforth)

$$y_{it} = \lambda_i^g g_t + \lambda_i^k f_t^k + u_{it} \tag{1}$$

$$E(u_{it} u_{j,t-s}) = 0, \ for\ i \neq j, and\ s \neq 0 \tag{2}$$

$$E(u_{it} u_{it}) = \sigma_i^2 \tag{3}$$

where g_t is the global factor which captures the world-wide co-movement in output growth, f_t^k is the factor specific to group k which only affects countries in that group, and u_{it} is the country-specific cyclical movement. The impact of latent factors is not homogeneous to all countries. This is captured by the country-specific coefficients or factor loadings λ_i^g, λ_i^k , which measure country i's heterogeneous response to the latent common factors. To complete the econometric model, we use auto-regressive processes to model the dynamics of the factors:

$$g_t = \Phi_g(L) \cdot g_{t-1} + \eta_t^g \tag{4}$$

$$f_t^k = \Phi_k(L) \cdot f_{t-1}^k + \eta_t^k \tag{5}$$

$$E(\eta_t^g \eta_{t-s}^g) = 0 \ \text{ for } \ s \neq 0; \ \ E(\eta_t^g \eta_t^g) = \sigma_g^2 \tag{6}$$

$$E(\eta_t^k \eta_{t-s}^k) = 0 \ \text{ for } \ s \neq 0; \ \ E(\eta_t^k \eta_t^k) = \sigma_k^2 \ \text{ for all } k \tag{7}$$

$$E(\eta_t^k \eta_{t-s}^g) = 0 \ \text{ for all } \ t, s \tag{8}$$

In line with the representation of the model in Stock and Waston (2005), the above system can be conveniently cast into a state-space form:

$$Y_t = \Lambda F_t + u_t \tag{9}$$

$$F_t = \Phi F_{t-1} + G \eta_t \tag{10}$$

where F_t is the collection of current and lagged latent factors, and Y_t is the vector of all countries' current output growth.

The above model can be estimated using the maximum likelihood method with the help of Kalman filter. Due to the large dimension of the parameters, the shape of the likelihood function is rather complicated, making it computationally intensive to find the global maxima by the conventional hill-climbing method. One can either use a Bayesian estimation method (Kose *et al.*, 2003) or use the Expectation-Maximization (EM) recursive algorithm to calculate the MLE (Norrbin and Schlagenhauf, 1996).[2] We will adopt the latter method, and conduct robustness check by trying different starting values, employing several convergence criteria, and increasing the number of iterations to ensure that the outcome from EM algorithm is indeed a global maximum.

The estimated factor F_t, however, lacks economic meaning. In the multi-level factor framework, we can only differentiate the group factor from the global factor, without knowing what those factors are. Also, it is very difficult to allow more than one factor at each level due to the large dimension of the parameters. Here we propose a new method combining the structural VAR with the factor model to tackle such problems. We will use the classic two-variable Blanchard and Quah (1989) model as a way to identify the structural shocks. It should be noted that our method can be readily applied to any SVAR model to accomandate various economic shocks as long as one can effectively identifies them.

The estimation method proceeds in three steps. In the first step, we use long-run restrictions in a structural VAR model to identify the underlying demand and supply shocks for each economy i, following Blanchard and Quah (1989). Let y_{it} and π_{it} be the output growth and inflation for country i at time t. A reduced form VAR is estimated in the first stage,

$$\begin{bmatrix} y_{it} \\ \pi_{it} \end{bmatrix} = B_1 \begin{bmatrix} y_{i,t-1} \\ \pi_{i,t-1} \end{bmatrix} + B_2 \begin{bmatrix} y_{i,t-2} \\ \pi_{i,t-2} \end{bmatrix} + \begin{bmatrix} e_{it}^{y} \\ e_{it}^{\pi} \end{bmatrix} \tag{11}$$

The structural VAR takes the following form,

$$A_0 \begin{bmatrix} y_{it} \\ \pi_{it} \end{bmatrix} = A_1 \begin{bmatrix} y_{i,t-1} \\ \pi_{i,t-1} \end{bmatrix} + A_2 \begin{bmatrix} y_{i,t-2} \\ \pi_{i,t-2} \end{bmatrix} + \begin{bmatrix} u_{it}^{s} \\ u_{it}^{d} \end{bmatrix}, \tag{12}$$

$$where \begin{bmatrix} u_{it}^{s} \\ u_{it}^{d} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \right) \tag{13}$$

2 The EM algorithm iterates between an E-step, where the first two moments of the hidden state vector are calculated conditional on the complete data and the given parameter values, and an M-step, where an expected log likelihood is maximized to yield an update of the parameter estimates. The expected log likelihood in the M-step is fully characterized using the first two moments of the hidden state vector. As proved in Watson and Engle (1983) and Dempster, *et al.* (1977), the EM algorithm always increases the likelihood value in each step towards a local maximum.

The structural shocks u_{it}^s and u_{it}^d are called supply shock and demand shock respectively. Notice that we drop the country index for the coefficient matrices to simplify notation. The supply shock has long run impact on output growth and can be interpreted as productivity shock, whereas the demand shock only affects the output temporarily and is conventionally considered to be caused by monetary policy shock or other short-lived shocks.[3]

We rewrite the reduced form as

$$\begin{bmatrix} y_{it} \\ \pi_{it} \end{bmatrix} = B_1 \begin{bmatrix} y_{i,t-1} \\ \pi_{i,t-1} \end{bmatrix} + B_2 \begin{bmatrix} y_{i,t-2} \\ \pi_{i,t-2} \end{bmatrix} + A_0^{-1} \begin{bmatrix} u_{it}^s \\ u_{it}^d \end{bmatrix}, \tag{14}$$

which implies a moving average representation,

$$\begin{bmatrix} y_{it} \\ \pi_{it} \end{bmatrix} = (I - B_1 L - B_2 L^2)^{-1} A_0^{-1} \begin{bmatrix} u_{it}^s \\ u_{it}^d \end{bmatrix}, \tag{15}$$

where L denotes the lag operator. Because we can identify the reduced form shocks in the first stage VAR regression, the structural shocks are identified as long as the matrix A_0 is identified. Blanchard and Quah (1989) assumed that the supply shock has a long-run effect on both output and price while the demand shock has no long-run effect on output. If we use M to denote the matrix $(I - B_1 - B_2)^{-1} A_0^{-1}$, this amounts to the restriction such that the (1,2)-th element of M is zero. Coupled with the restriction that $A_0^{-1} A_0^{-1'} = var\begin{bmatrix} e_{it}^y \\ e_{it}^\pi \end{bmatrix}$, we are able to uniquely pin down the matrix A_0, and thus the structural shocks are identified.

Next, we use Model 1 to decompose each type of shocks into a world component and a regional component. We estimate the multi-level factor model for supply shocks:

$$u_{it}^s = \gamma_i^{s,g} g_t^s + \gamma_i^{s,k} f_t^{s,k} + \vartheta_{it}^s; i = 1,...N \tag{16}$$

and then for demand shocks:

$$u_{it}^d = \gamma_i^{d,g} g_t^d + \gamma_i^{d,k} f_t^{d,k} + \vartheta_{it}^d; i = 1,...N \tag{17}$$

[3] It should be noted that the shocks we identify from each SVAR model contain both domestic and external components. Our multi-level factor model then allows us to separate the regional co-movement apart from the global co-movement.

where g_t^s is the global supply factor, and g_t^d the global demand factor, which are common to all economies, and $f_t^{s,k}$ is the group-specific supply factor, and $f_t^{d,k}$ the group-specific demand factor, for group k which is common to economies in the k-th group, k =Asian region, or G-7 group.

From equation (15), a Wold representation of y_{it}, is as follows:

$$y_{it} = C(L)u_{it}^s + D(L)u_{it}^d$$

In the third step, we combine the above equation with (16) (17), and get Model 2

$$\begin{aligned} y_{it} &= C(L)(\gamma_i^{s,g} g_t^s + \gamma_i^{s,k} f_t^{s,k} + \vartheta_{it}^s) + D(L)(\gamma_i^{d,g} g_t^d + \gamma_i^{d,k} f_t^{d,k} + \vartheta_{it}^d) \\ &= (C(L)\gamma_i^{s,g} g_t^s + D(L)\gamma_i^{d,g} g_t^d) + (C(L)\gamma_i^{s,k} f_t^{s,k} + D(L)\gamma_i^{d,k} f_t^{d,k}) + (C(L)\vartheta_{it}^s + D(L)\vartheta_{it}^d) \end{aligned} \quad (18)$$

Equation 18 bears a similar structure as equation (1), but decomposes the global factor g_t into distributed lags of the global supply factor g_t^s and the global demand factor g_t^d, and does the same for regional factors. This allows for an investigation of the role played by different structural shocks in explaining output fluctuations at both the global and the group levels. Further augmentation of the number of factors could be easily done through using more complicated SVAR models to identify more structural shocks. Also different from model 1, this is a dynamic factor model instead of a static one, since now y_{it} depends on both the contemporaneous and the lagged terms of the factors.

With the representation of (18), we can now conduct a variance decomposition to analyze the importance of each factor in explaining output fluctuations. For example, the proportion of variance explained by the global supply factor is

$$\frac{Var(C(L)\gamma_i^{s,g} g_t^s)}{Var(y_{it})} \quad (19)$$

However, it is nontrival to calculate the value of the above ratio, due to the fact that y_{it} now depends on the infinite lags of each factors. We describe the variance decomposition method in the Appendix in detail.

2.2 The Data

We use quarterly data instead of annual data as in most other related research. This enables us to study the characteristics of business cycle synchronisation after 1980 at quarterly frequency, which may not be captured at annual frequency. In addition, since the econometric model has a large-dimension of parameters-to-be-estimated and requires relatively long time series to achieve accurate estimation, with quarterly data for almost three decades, we can slice the sample into two sub periods, with mid 90s as the dividing point. The subsample analysis helps examine the evolution of both world and region business cycle synchronizations over the last three decades.

We collect quarterly data for 16 economies from 1981Q1 to 2008Q4. The list includes nine emerging Asian markets, namely Hong Kong, China, Indonesia, South Korea, Malaysia, Philippine, Singapore, Taiwan, and Thailand.[4] We also cover G-7 countries in the industrial group. Most GDP, and CPI data are downloaded from the International Financial Statistics CD-Rom and CEIC data base. Data for several Asian countries are taken from other estimation in existing research since the available data series are too short. Series are seasonally adjusted using Census X-12. Output growth and inflation are calculated as the log difference.[5] All the time series used in the econometric model passed the unit root test and are stationary.

3. Empirical Results

3.1 Output Co-Movement

As a starting point, we first apply Model 1 to output growth to study business cycle co-movement. Using the updated quarterly data covering the most recent crisis, we obtain a big picture of global and regiona business cycle synchronization, and compare our results with what has been found in the existing literature to see how the data freqency and different sample period may affect the conclusion. In a second step, we will use the structural factor model to disentangle the different roles played by underlying structural shocks in the globalisation process.

We estimate the multi-level factor model (Model 1) for the output growth data. We then split our sample into two groups: the emerging East Asia and the industrial country group (G-7); hence we have three factors: the global factor which drives global economic fluctuations, and two group factors which capture

4 We choose the nine Asian emerging markets following Williamson (1996), who argued that the nine economies should adopt a common basket peg.

5 West Germany and Germany united in 1990. The IFS data combine the GDP for the two regions starting 1991Q1, thus there was a large jump in the output for Germany in one quarter. To take into account this break, we follow Engel and West's (2006) method to smooth out the jump.

the co-movement within the respective group. By assumption, the global factor is orthogonal to the two group factors.

3.1.1 Full Sample Analysis

We first estimate the model using the full sample, 1981Q2 to 2008Q4. The estimated factor loadings are reported in Table 1, along with the standard errors. Table 2 reports the autocorrelation coefficients of the three factors. The Asian regional factor is more persistent than the industrial countries' group factor, and the global factor is the most persistent among the three factors. The variances of the economy-specific components which could not be explained by either the global factor or the regional factor are shown in Table 3. By model assumption, the country-specific cycles which are represented by the residuals are mutually orthogonal, and thus the covariance matrix R is diagonal. The estimated global factor and the two group factors are depicted in Figure 1. The dotted line is the Asian factor, and it picks up the 1997 crisis. The solid line is the global factor, and it plummets deeply at the end of this sample, a reflection of the global financial crisis.

For the industrial group, we notice that Canada and the US respond to the industrial factor in the opposite direction from the other industrial countries on our list, while the European countries respond to it positively, as indicated in Table 1. This suggests that the US and Canada might form a North America group, different from the other industrial countries. However, the industrial countries in our sample are only used to help identify the global factor, so that we can study the Asian region-specific factor independently from the global trend. Thus we do not go further to estimate the North American factor, but instead treat Canada and the US as members of our industrial group.

To measure business cycle synchronization, we conduct variance decomposition, and calculate the relative contributions to its total economic fluctuations by different factors for each country. Recall the growth rate of country i can be written in the following form:

$$y_{it} = \lambda_i^g g_t + \lambda_i^k f_t^k + u_{it}$$

Therefore

$$var(y_{it}) = (\lambda_i^g)^2 var(g_t) + (\lambda_i^k)^2 var(f_t^k) + var(u_{it}) \qquad (20)$$

The contribution of the global factor to country i's GDP growth volatility is

$$\frac{(\lambda_i^g)^2 var(g_t)}{var(y_{it})}$$

The contribution of the regional factor to country i's GDP growth volatility is

$$\frac{(\lambda_i^k)^2 var(f_t^k)}{var(y_{it})}$$

The variance decomposition results are shown in Table 4. We find a strong world business cycle, which on average can explain 18% of output volatility. However, the global factor is less influential on Asian countries, explaining 9.5% percent output fluctuations on average, while it contributes nearly 29% of G-7's output volatility. There is some evidence supporting the argument that China is de-linked from other countries, in the sense that both Asian regional factor and global factor can only explain a small portion of its GDP volatility. However, the variance decomposition here is conducted using the full sample without considering the possible time-varying structure of business cycle co-movement, thus we will further investigate the evolution of the business cycle synchronization in subsamples.

3.1.2 Subsample Analysis

The above full sample estimation assumes that the factor structure and the loadings stay the same over the whole sample period. However, East Asia has been experiencing rapid economic growth and structural changes in many aspects, such as China's joining the WTO in 2001, and the 1997 Asian financial crisis, etc. The possibility of time-varying synchronization pattern may lead to misleading results.

To study the time-varying property of business cycle synchronization, we conduct a preliminary subsample analysis by dividing the entire sample into two subsamples: 1981Q2 -- 1994Q4, 1995Q1 -- 2008Q4. Lane and Milesi-Ferretti(2007), and Fujiki and Terada-Hagiwara (2007) both documented an accelerated financial openness around the middle of 90s worldwide. In terms of trade openness, East Asian countries have negotiated 25 free trade agreements (FTAs) since the mid-1990s. Since it also requires long enough time series to consistently estimate the model parameters given such a complex structure of the model, we slice our sample into two subsamples, with 1995Q1 as the break point. For each subsample, we independently re-estimate the whole model. Figure 2 depicts the estimated factors for the sub-period of 1981Q2 to 1994Q4. Table 5 collects the results from variance decomposition, which measures the degree of synchronization in outputs. Figure 3 and the Table 6 are the counterparts for the second subsample, 1995Q1 to 2008Q4. Table 7 shows the evolution of synchronization over the two sub-periods.

We summarize the findings as follows.

First, the role played by the global factor intensified over the two subsamples. For both the Asian group and the industrial countries group, on average the variances explained by the global factor increase by a significant amount over time (from 7% to 20.4% for the Asian group, while from 13% to 43% for the G-7). This suggests an increasingly stronger global business cycle in the past 15 years.

Secondly, the Asian regional factor and the G-7 group factor show different patterns. The contribution of the regional factors increased from 12% to near 19.9% (on average) for East Asian countries, while the G-7 factor's influence weakened substantially, from 24.6% in the first subsample to only around 5% in the later subsample. This is a very intriguing finding and would not have been obvious without analyzing the multi-level factor structure.

Suppose we do not separate the group factor from the global factor, we will find that a common factor (a combination of group and global factors) can account for 19% in Asian output growth fluctuation and 38% for the G-7 group during 1981 to 1995, while the numbers become 40% and 49% respectively in the second subsample. Those numbers are provided in Table 7. The G-7 group still exhibits a higher degree of business cycle synchronization than the East Asian group does in both subsamples. However, by looking into the different influences of the global factor and the group factors, the picture changes to a great extent. The global factor's impact almost tripled for both groups from the first period to the second period, while Asian economies show a much tighter regional interdependence than the G-7 group does. This finding indicates that there is some unique underlying driving force within the East Asian region, apart from the common driving force towards greater globalisation.

Thirdly, there is a significant degree of heterogeneity in how synchronised each individual Asian economy has been with the global and the regional common factors. Since the mid-1990s, Singapore has had the highest synchronisation with the global factor, and Malaysia has had the highest synchronisation with the Asian regional factor. In the case of China, contrary to the common perception that the Mainland economy has been heavily dependent on external demand, the role of both global factor and regional factor has diminished significantly, accounting for only 7.5% and 3% respectively after 1995, a drop from 18% and 6.6% respectively during 1981-1994. While this finding is consistent with our view that shocks hitting the Chinese economies are largely domestic and idiosyncratic, the very low contribution by the global and regional factors may be a reflection of data issues, in that only production-based GDP numbers are available at quarterly frequency in China, and they tend to be much smoother than expenditure-based quarterly GDP.

Another possible explanation of the low degree of synchronization between China and the both the world and regional cycles is that China's resilience against the adverse external shocks. As a sensitivity check, we re-estimate the model using data from 1999 Q1 to 2008 Q2, in which both the 1997 Asian Crisis and the recent financial crisis are excluded. The results are reported in Table 8. Indeed, we find that including the crisis period will result in a higher level of global synchronization of output, for both Asian economies and the G-7 countries. The results also show that the Asian regional factor can now explain around 22% of China's output fluctuations during 1999 Q1 to 2008 Q2 (crisis periods are exclude), while the global factor still plays a very insignificant role. Such a finding suggests that China may have stronger interaction with the Asian region during normal time while its seemingly delinking from other countries found in full-sample analysis may be also partly due to its resilience in the two crises.

How do our results compare with the findings in the earlier literature? Using annual data, Kose, Otrok and Prasad (KOP, 2008) found that the average contribution of the global factor to output growth fluctuations was 7% during 1985-2005, while we find a much higher number 18% for 1981 to 2008. The reason that we find a stronger global co-movement is that we cover the periods of the recent crisis. If we drop the data after 2005Q4, the number decreases to 6%, which is close to what KOP (2008) found. Similarly, we also find larger average contribution of the global factor within each group (9.5% versus 4% in KOP in the case of emerging markets, and 29% versus 9% in the industrial group), due to the same reason. Once the data after 2005 are dropped, our results are also close to their estimation (our 4.6% versus KOP's 4% for emerging markets, and 7.6% versus 9% for industrial group). Without including the recent financial crisis data, they found a much weaker global factor and dominate group-specific factors for each group, and concluded that there was evidence supporting the decoupling conjecture. As a sensitivity check, we estimate the model using data from 1999 Q1 to 2008 Q2, in which both the 1997 Asian Crisis and the recent financial crisis are excluded. We find a weaker global factor than in the sample including the crisis period, as expected. However, the global factor is still stronger (explaining a higher share of output volatility) in the recent years than in the earlier period (before middle 90s).

3.2 Structural Factors

In this section we estimate Model 2 to investigate the underlying driving force of the observed global and regional output co-movement as described above, and help us better understand the economic meaning of the unobserved factors. As with the estimation of Model 1, we proceed first with a full sample analysis, and then re-estimate the model using two sub-samples.

3.2.1 Full Sample Analysis

Figure 4 and Figure 5 show the estimated demand and supply factors. Again, the solid line represents the global factor; the dotted line describes the Asian regional factor: and the dashed line is the estimated G-7 group factor. Table 9 reports the variance decomposition results for all economies in our sample.

Overall, we find that the global supply and demand factors play almost equally important roles in driving international business cycle. On average, the global supply factor can explain 18.6% of output flucutations in the sample economies, and the global demand factor can account for 19% of such fluctuations. However, their relative roles differ significantly across the two groups of economies. The global supply factor makes a larger contribution to the synchronisation of cycles in emerging Asia than the global demand factor does, with the global supply factor explainning 11.4% of growth fluctuations in the region and the global demand factor explaining 3.4% of such fluctuations. In contrast, the global demand factor was the major driving force behind G-7 business cycle synchronisation, acounting for 39% of the output fluctuations on average in those countries.

At the regional level, the group supply factor is more important than the group demand factor in explaining growth flucutations in emerging Asia. The group supply factor accounted for 18% of output movements and the group demand factor only explained 6.8% of such movements in emerging Asia. In the G-7 group, we do not see significant difference in the roles of the supply and demand factors (12.5% and 11.2% respectively).

Overall, the full sample analysis reveals that output comovement in G-7 was mainly driven by global factors (from both the supply and demand side). The emerging Asian group does exhibit its distinct pattern of business cycle syncrhonisation. Regional common supply shocks were more important for output growth co-movement in emerging Asia. As argued earlier, this observation can be explained by the common productivity enhancement as a result of vertical trade integration in the region.

3.2.2 Subsample Analysis

In this section, we conduct subsample analysis and re-estimate Model 2 for the two sub-periods, 1981Q2 to 1995Q4, and 1996Q1 to 2008Q4 respectively. The results are collected in Table 10 and Table 11. We find that the contribution by global and regional common supply shocks was significantly higher in the second period in explaining business cycle syncronization in emerging Asia. The explanatory power of the global supply factor increased from 3% to 30%, and the regional supply factor from 5% to 30%, over the two sub-periods. On the other hand, the contribution of both the global and regional demand factors remained very stable over the two. As a sensitivity check, we also conduct a subsampe analysis for 99Q3 to 08Q2, excluding both the 1997 Asian crisis and the most recent global crisis. The evolution patterns of common supply factors remained broadly the same (Table 12).

In contrast, the pattern is very different for the G-7 countries. The importance of the global factors dramatically increased over time, while the importance of the regional factors greatly declined. The contribution of the global supply factor rose from 8.7% to nearly 40%, and that of the global demand factor increased from 18.9% to 33.9%. However, the contribution of the regional supply factor fell from 20% to 9% , and that of the regional demand factor dropped from 16.7% to 9.2%.

Overall, our results show that the observed synchronised business cycles within the emerging Asian economies have been attributable more importantly to synchronised shocks from the supply side. These findings are consistent with the theoretical prediction that the vertical trade linkage will tighten the co-movement of supply shocks across economies, given that vertical trade integration has intensified in east Asia since middle of 1990s.

4. Policy Implications

Our findings have rich policy implications. First, they cast doubt on the hypothesis that the emerging Asia has been excessively dependent on external demand and, in order to make future growth more self-sustainable, the region needs to switch to a domestic demand-led growth model. On the basis of the findings of this paper, we can argue that the Asian economies are not as dependent on external demand as headline numbers appear to suggest, and share a strong region-specific business cycle as we find in this paper. There is a need to appreciate the role of productivity enhancement through vertical trade integration, rather than excessive dependence on external demand, as a primary source of business cycle synchronisation in emerging Asia. A drive to reduce the openness of Asian economies will deprive the region of the opportunity of further productivity enhancements through active participation in global production networks (He *et al*., 2007).

The analysis in the paper is expected to enrich the debate on “decoupling”, i.e., whether emerging Asian economies can rely on themsevles rather than the advanced economies in sustaining their growth momentum. The debate has been complicated by the observation that while emerging Asia can be affected severely by shocks originating from the advanced economies, they have also demonstrated a significant degree of resilience. This is amply clear from the recent experience during the global financial crisis of 2007-2009. The analytical framework in this paper allows us to interprete Asia’s experience in new light. Thus, while emerging Asian economies cannot “decouple” completely from the advanced economies, they have nonetheless formed a strong independent cycle among themselves, reflecting both demand and supply factors specific to the region itself.

Our findings also shed light on the desirability of monetary and exchange rate policy coordination within the East Asian region. Mundell’s (1961) "optimal currency area" suggests that business cycle synchronization is a crucial consideration in choosing optimal exchange rate regimes. Regarding Emerging Asia, a number of proposals have also been made, mainly but not exclusively from academic circles, regarding cooperation on exchange rate policy (e.g., Ogawa and Ito, 2002). Although our estimation shows that Asian regional factors play a more important role after the middle 1990s, it also suggests that observed increase in the Asian business cycle synchronization has been greatly due to the region's integration into the world economy, and the overall degree of synchronization has still been lower than in G-7 group in the recent years. The study on underlying shocks delivers the same message. Since the Asian economies are exposed to more asymmetric shocks than the G-7 countries overall, exchange rate coordination among the Asian economies may encounter difficulties. This is consistent with the arguments in Genberg and He (2009).

On the other hand, our findings lend support to policy initiatives to enhance regional financial cooperation and to set up arrangements for mutual emergency liquidity assistance, such as the Chiang Mai Initiative. Such schemes of crisis insurance are most effective if the underlying shocks affecting different economies are uncorrelated. If the shocks were significantly correlated then all economies would tend to need to borrow from each other at the same time, which would make the insurance schemes unworkable. Our analysis on structural shocks shows that the underlying shocks are still more asymmetric in Emerging Asia, measured by the total portion of output co-movement explained by the global and regional shocks. This suggests that a regional crisis insurance scheme have a positive role to play, since overall the underlying shocks are more asymmetric in Asian economies than in the G-7 group. For example, we find that China's growth performance has been resilient against either regional or global shocks, which may suggest that China can serve as a stabilising force when other Asian economies are hit by crises.

5. Conclusions

In this paper we have developed a multi-level structural factor model to study Asian business cycle synchronisation. Our method combines a structural VAR with a multi-level factor model, which helps us to understand the economic meaning of the estimated unobserved factors. We then use the model to study international output comovement and its underlying driving forces.

As a starting point, we first use the conventional multi-level factor model to identify a global factor and two group factors using quarterly data of sixteen economies' real GDP growth. We find that the effects of these factors on output fluctuations in individual Asian economies have been rather heterogeneous. While the role of the global common factor has intensified over the past fifteen years for most of the economies, output fluctuations in emerging Asia have remained less synchronised with the global common factor than the industrial countries. The Asian regional factor has become increasingly important in tightening the interdependence within the region over time, while the co-movement among the G-7 economies has been mainly driven by the global factor.

Then employing the structural factor model, we decompose the common factors into supply factors and demand factors, at both the global and group levels. The supply factors capture the co-movement among supply shocks, which are assumed to have long run impact on output growth and can be interpreted as productivity shocks. On the other hand, the demand factors are extracted from the demand shocks which only affects output temporarily and are conventionally considered to be caused by monetary policy shock or other short-lived shocks. We find that synchronised supply shocks contributed much more to the observed synchronization in output fluctuations among the Asian economies than demand shocks. This points to the role of productivity enhancement through vertical trade integration, rather than dependence on external demand, as the primary source of business cycle synchronisation in emerging Asia.

While these findings are fresh, interesting and have rich policy implications, they also leave many questions remaining to be answered. In particular, we need to understand better the transmission mechanisms through which different structural factors drive output fluctuations in individual economies. How important were oil price shocks in driving output fluctuations in Asia? Were such shocks demand shocks or supply shocks? What is the relative importance of trade linkages as compared to financial market linkages in driving business cycle synchronisation in the region? Has China become an independent growth engine for the Asia region? These are important questions for future research.

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Table 1. Factor Loadings for Model 1, Full Sample

	Global Factor	Asian Regional Factor	Industrial-country Factor
HKSAR	0.2332	0.35	0
	(0.07)	(0.073)	
China, Mainland	0.1477	0.0994	0
	(0.0633)	(0.0733)	
Indonesia	0.1433	0.4414	0
	(0.0763)	(0.075)	
Korea	0.2455	0.379	0
	(0.0745)	(0.073)	
MYS	0.1652	0.4783	0
	(0.0784)	(0.0767)	
PHL	0.0594	0.1007	0
	(0.0618)	(0.0726)	
SGP	0.2911	0.3991	0
	(0.0734)	(0.0716)	
TWN	0.2506	0.2193	0
	(0.0645)	(0.0704)	
THA	0.1102	0.342	0
	(0.0696)	(0.0704)	
JAP	0.2187	0	0.4316
	(0.0786)		(0.1061)
FRA	0.3297	0	0.4911
	(0.0849)		(0.1165)
DEU	0.2292	0	0.3833
	(0.074)		(0.1175)
ITA	0.3213	0	0.4203
	(0.0762)		(0.1172)
GBR	0.3833	0	0.0694
	(0.0579)		(0.1038)
CAD	0.4344	0	-0.2992
	(0.063)		(0.1117)
USA	0.4146	0	-0.2058
	(0.0599)		(0.1051)

Note: Standard errors are shown in the parentheses below the estimators

Table 2. The Persistence of Factors, Measured by their Autocorrelation

Global Factor	Asian Regional Factor	Industrial-country Factor
0.8788	0.7352	0.3947
(0.0692)	(0.0857)	(0.1716)

Note: Standard errors are shown in the parentheses.

Table 3. The Variance Matrix R

	Variance of the country cycles	Standard Error
HKSAR	0.66	0.0974
China, Mainland	0.9235	0.1256
Indonesia	0.5813	0.0924
Korea	0.6101	0.091
MYS	0.506	0.0846
PHL	0.9655	0.1302
SGP	0.5316	0.0838
TWN	0.768	0.1073
THA	0.7453	0.1075
JAP	0.6617	0.11
FRA	0.4427	0.0956
DEU	0.6929	0.1077
ITA	0.527	0.092
GBR	0.5773	0.086
CAD	0.3194	0.0753
USA	0.4337	0.0742

Table 4. Variance Decomposition (Full Sample, 1981 Q2 to 2008 Q4)

	Global Factor	Asian Factor	Industrial Factor
HKSAR	0.134361	0.20784	0
China, Mainland	0.053874	0.01676	0
Indonesia	0.050741	0.33057	0
Korea	0.148865	0.24369	0
MYS	0.067456	0.38808	0
PHL	0.008727	0.01719	0
SGP	0.209354	0.27023	0
TWN	0.155146	0.08157	0
THA	0.030008	0.19842	0
JAP	0.118146	0	0.148223
FRA	0.26864	0	0.191863
DEU	0.12976	0	0.116887
ITA	0.255106	0	0.140516
GBR	0.363086	0	0.003836
CAD	0.466184	0	0.071234
USA	0.424718	0	0.033711
World Average	0.180261		
Asian group average	0.095392	0.194928	
G-7 Group average	0.289377		0.100896

Table 5. Variance Decomposition, Subsample 1 (81 Q2 to 94 Q4)

	Global Factor	Asian Factor	Industrial Factor
HKSAR	0.081861	0.027737	0
China, Mainland	0.178682	0.066211	0
Indonesia	0.080448	0.102722	0
Korea	8.49E-06	0.003558	0
MYS	0.068604	0.255522	0
PHL	0.038203	0.115668	0
SGP	0.186469	0.365573	0
TWN	0.012371	0.008046	0
THA	0.01075	0.12733	0
JAP	0.160566	0	0.134769
FRA	0.327157	0	0.247338
DEU	0.11471	0	0.142327
ITA	0.114548	0	0.338226
GBR	0.004476	0	0.205225
CAD	0.10444	0	0.355556
USA	0.095647	0	0.295648
World Average	0.098684		
Asian group average	0.073044	0.119152	
Industrial Group average	0.131649		0.245584

Table 6. Variance Decomposition, Subsample 2 (Subsample 95 Q1 to 08 Q4)

	Global Factor	Asian Factor	Industrial Factor
HKSAR	0.324226	0.271917	0
China, Mainland	0.07529	0.033866	0
Indonesia	0.071715	0.407365	0
Korea	0.281181	0.237885	0
MYS	0.186563	0.420745	0
PHL	0.028385	0.050892	0
SGP	0.449832	0.155649	0
TWN	0.382041	0.022914	0
THA	0.039861	0.192248	0
JAP	0.463136	0	0.159249
FRA	0.491234	0	0.009361
DEU	0.378824	0	0.009651
ITA	0.350352	0	0.0187
GBR	0.660945	0	0.002592
CAD	0.333564	0	0.146754
USA	0.381905	0	0.03132
World Average	0.306191		
Asian group average	0.204344	0.199276	
Industrial Group average	0.437137		0.053947

Table 7. The Contribution of Regional and Global Factors

		1981Q2 – 1994Q4	1995Q1 – 2008Q4	1981Q1 – 2008Q4
Asian group average,	global	0.073044	0.204344	0.095392
	regional	0.119152	0.199276	0.194928
	Total	0.192196	0.40362	0.29032
Industrial group average,	global	0.131649	0.437137	0.289377
	Regional	0.245584	0.053947	0.100896
	Total	0.377233	0.491084	0.390273

Table 8. The Crisis versus Non-Crisis Period

	1981Q2 to 1994Q4		95Q1 to 08Q4		99Q1 to 08Q2 (excluding crisis period)	
	Global	Regional	Global	Regional	Global	Regional
China	0.1787	0.0662	0.0753	0.0339	0.0923	0.2167
Asian Average	0.0730	0.1192	0.2043	0.1993	0.1234	0.1883
G-7 Average	0.1316	0.2456	0.4371	0.0539	0.2881	0.1364
World Average	0.0987		0.3062		0.2009	

Table 9. Variance Decomposition for Model 2 (Full Sample: 82Q1 to 2008Q4)

	global supply	regional supply	global demand	regional demand
HKSAR	0.157373151	0.102472592	0.036986	0.009803887
China, Mainland	0.040257424	0.073549183	0.191325	0.078630742
Indonesia	0.054996235	0.463140888	0.002168	0.345051895
Korea	0.281117298	0.307319754	0.029822	0.052840877
MYS	0.090671423	0.470918174	0.006852	0.080344385
PHL	0.001341619	0.000791985	0.003507	6.53E-05
SGP	0.191659381	0.104185749	0.000994	0.011782268
TWN	0.182068548	0.020939599	0.001294	0.0280032
THA	0.024268473	0.071791647	0.035509	0.002786834
JAP	0.314069306	0.096116023	0.01601	0.011607165
FRA	0.602295959	0.035517323	0.684797	0.035663612
DEU	0.059547968	0.183390493	0.022153	0.009068982
ITA	0.424231944	0.102346674	0.050952	0.064803025
GBR	0.191830964	0.000804945	1.162419	0.476147892
CAD	0.225901899	0.334077059	0.396964	0.134254556
USA	0.130243001	0.122975933	0.395475	0.054224426
World Average	0.185742162		0.189827	
Asian group average	0.113750395	0.179456619	0.034273	0.067701041
G-7 Group average	0.278303006	0.125032636	0.389824	0.112252808

Table 10. Variance Decomposition for Model 2 (Subsample 1: 82Q1 to 1995Q4)

	global supply	regional supply	global demand	regional demand
HKSAR	0.028969	0.042651	0.02982	0.018178
China, Mainland	0.003601	0.023518	0.259066	0.636873
Indonesia	0.010899	0.25086	6.33E-05	0.11447
Korea	0.05928	0.051662	0.031778	0.064082
MYS	0.038594	0.00632	0.000837	0.068959
PHL	0.002781	0.000392	0.008604	0.008377
SGP	0.069637	0.015599	4.27E-03	0.037282
TWN	0.02553	2.15E-02	0.00048	0.014071
THA	2.64E-02	0.042497	0.014858	0.004035
JAP	0.328121	0.023039	0.016846	0.01305
FRA	0.090332	0.106732	0.198974	0.183116
DEU	0.022241	0.005239	1.75E-05	0.032633
ITA	0.104126	0.021848	0.296064	0.442093
GBR	0.00495	0.094319	0.791115	0.134199
CAD	0.038336	0.580802	0.001715	0.232411
USA	0.017858	0.596444	0.020822	0.12884
World Average	0.054478		0.104708	
Asian group average	0.02952	0.05055	0.038864	0.10737
G-7 Group average	0.086566	0.20406	0.189365	0.16662

Table 11. Variance Decomposition for Model 2 (Subsample 2: 96 Q1 – 08 Q4)

	global supply	regional supply	global demand	regional demand
HKSAR	0.348545	0.122636	0.008989	0.004295
China, Mainland	0.146166	0.027172	0.038236	0.03482
Indonesia	0.197878	0.73187	0.000813	0.066036
Korea	0.457685	0.639806	0.021314	0.001875
MYS	0.305296	0.847848	0.045711	0.803279
PHL	0.01058	0.015478	0.001226	0.000235
SGP	0.778103	0.062831	8.68E-05	0.000166
TWN	0.477916	7.78E-05	0.013333	0.001996
THA	4.13E-07	0.203534	0.085153	0.000388
JAP	0.577446	0.024714	0.033848	0.093632
FRA	1.045859	0.007413	0.633773	0.326845
DEU	0.143404	0.000596	0.02487	0.014377
ITA	0.738428	0.002742	0.179777	0.067576
GBR	0.245012	0.069981	0.417838	0.016329
CAD	0.03743	0.384393	0.463533	0.116064
USA	0.000626	0.133117	0.617347	0.011033
World Average	0.344398		0.161615	
Asian group average	0.302463	0.294584	0.023873	0.101455
G-7 Group average	0.398315	0.088994	0.338712	0.092265

Table 12. Variance Decomposition for Model 2 (Non-Crisis Period: 99 Q3 – 08 Q2)

	global supply	regional supply	global demand	regional demand
HKSAR	0.161078	0.178662	0.013842	0.126124
China, Mainland	0.050364	0.289232	0.104523	0.000418
Indonesia	0.022538	0.028597	0.032223	0.018946
Korea	0.124494	4.10E-05	0.005872	0.007042
MYS	0.068388	0.015199	0.001244	0.022094
PHL	0.055674	0.000519	0.001347	0.000824
SGP	0.397939	0.50903	0.008014	0.077704
TWN	0.280594	0.199763	0.000221	0.038681
THA	0.274507	0.016598	0.004541	0.096806
JAP	0.059844	0.075655	0.079418	1.11E-05
FRA	0.227891	0.152392	0.111624	0.774471
DEU	0.005319	0.072159	0.0053	0.045232
ITA	0.039159	0.248519	0.000346	0.144438
GBR	0.128089	0.033419	0.129523	0.015746
CAD	0.201444	0.002991	0.013459	0.409469
USA	0.235062	0.024129	0.053732	0.204864
World Average	0.145774		0.035327	
Asian group average	0.159508	0.137516	0.019092	0.043182
G-7 Group average	0.128116	0.087038	0.0562	0.227747

Figure 1. The Estimated Factors (Full Sample, 1981 Q2 to 2008 Q4)

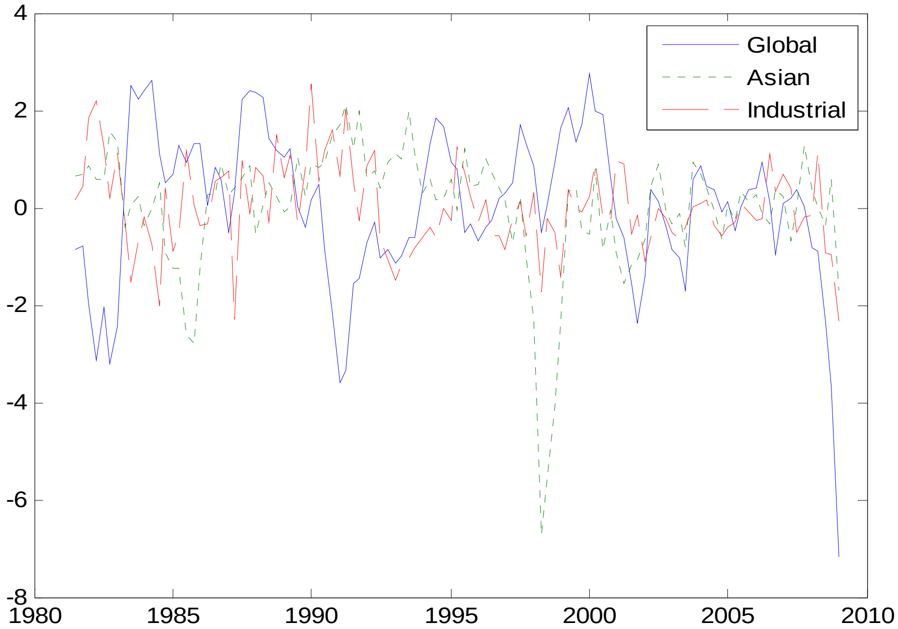


Figure 2. The Estimated Factors (Subsample 1981 Q2 to 1994 Q4)

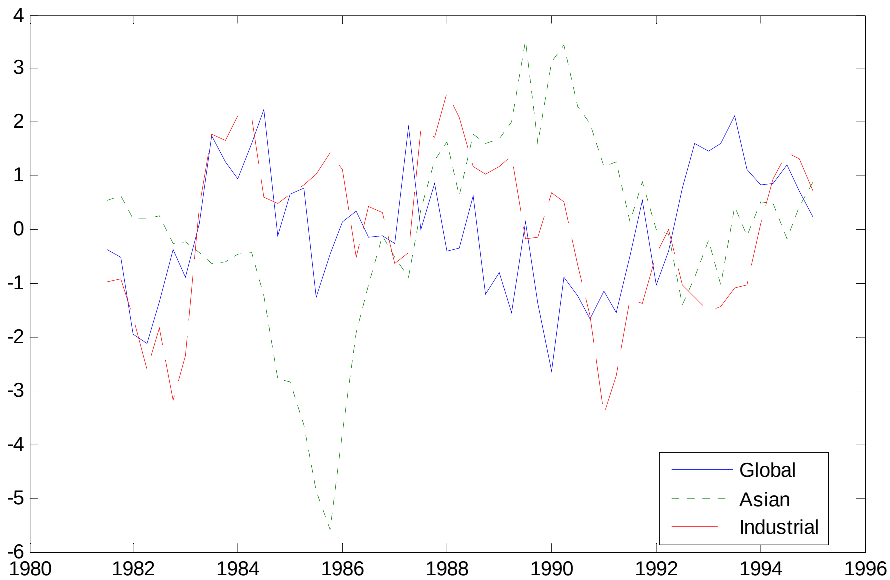


Figure 3. The Estimated Factors (Subsample 1995 Q1 to 2008 Q4)

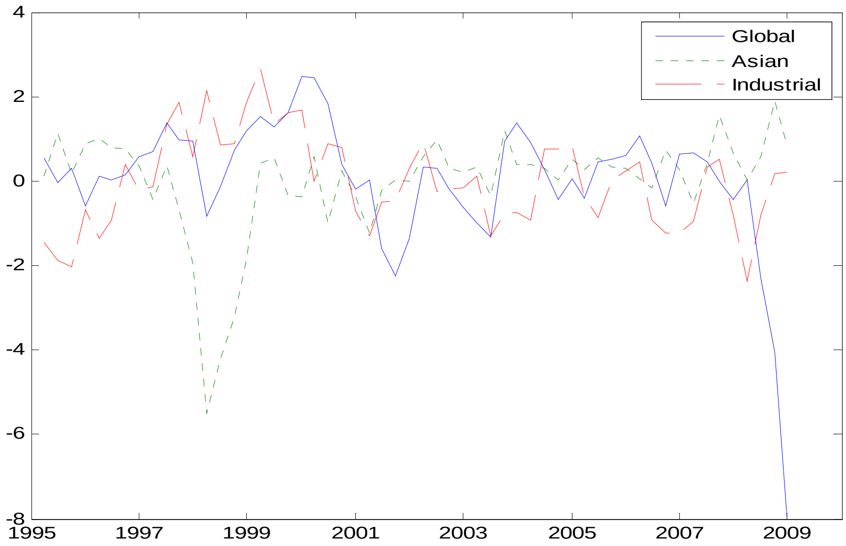


Figure 4. The Estimated Demand Factors (Full Sample)

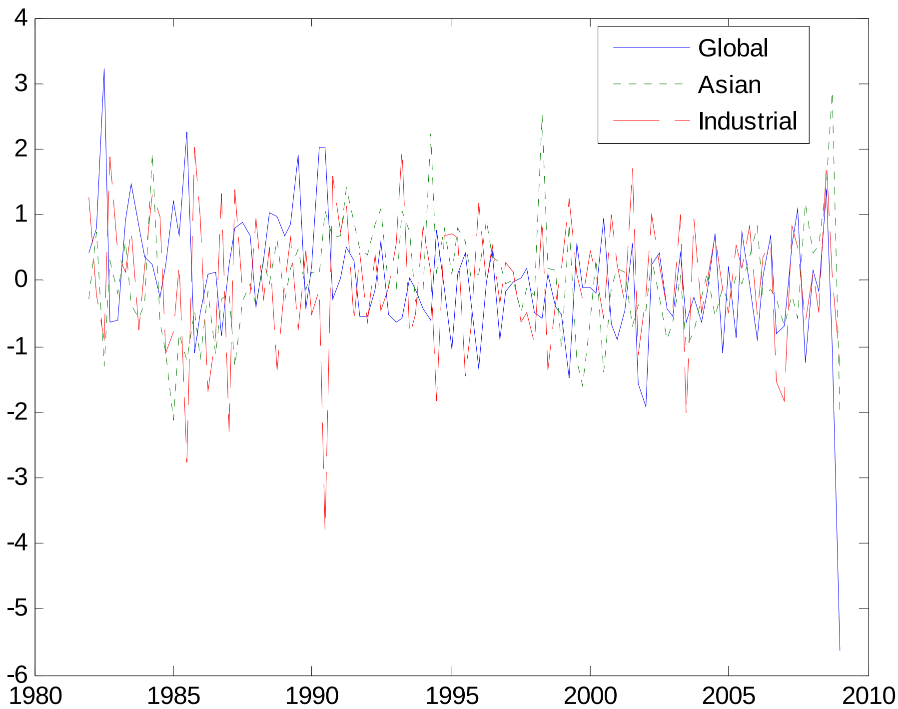
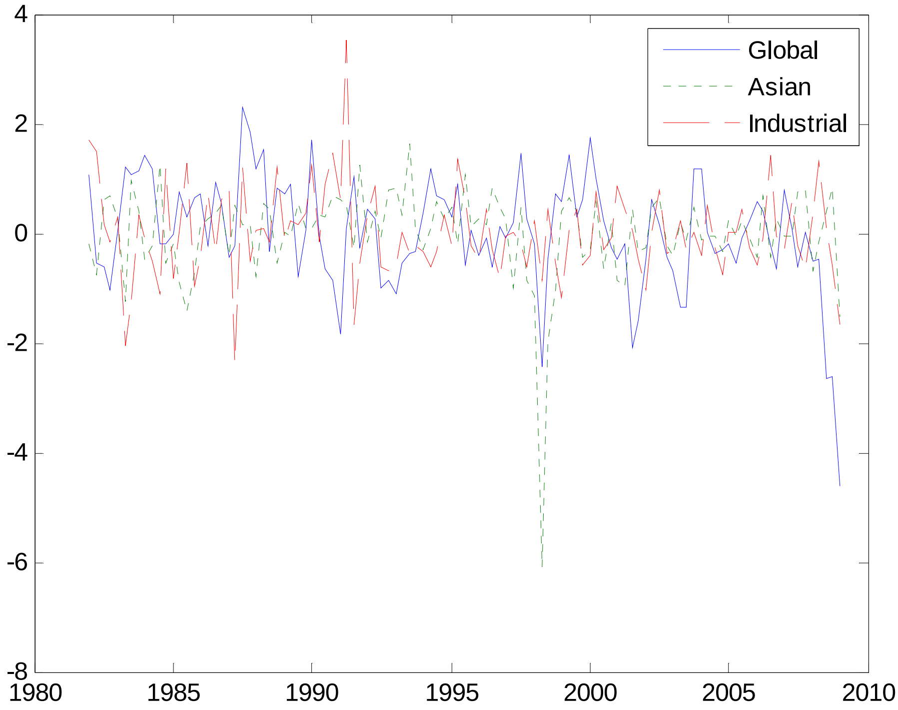


Figure 5. The Estimated Supply Factors (Full Sample)



Appendix

Model 2 shows

$$y_{it} = C(L)\gamma_i^{s,g} g_t^s + D(L)\gamma_i^{d,g} g_t^d + C(L)\gamma_i^{s,k} f_t^{s,k} + D(L)\gamma_i^{d,k} f_t^{d,k} + C(L)\vartheta_{it}^s + D(L)\vartheta_{it}^d$$

The percentage of output fluctuations in the ith economy which can be explained by the movement of the global supply factor g_t^s is

$$\frac{Var(C(L)\gamma_i^{s,g} g_t^s)}{Var(y_{it})} \tag{21}$$

We will show how to calculate the value of (21) as an example, and the procedure would be the same for other factors, for any country.

The $MA(\infty)$ representation of our SVAR model is

$$Y_t = \begin{bmatrix} y_{it} \\ \pi_{it} \end{bmatrix} = (I - B_1 L - B_2 L^2)^{-1} A_0^{-1} \begin{bmatrix} u_{it}^s \\ u_{it}^d \end{bmatrix} \tag{22}$$

Rewrite $(I - B_1 L - B_2 L^2)^{-1} A_0^{-1}$ into a block matrix form

$$(I - B_1 L - B_2 L^2)^{-1} A_0^{-1} = \begin{bmatrix} C(L) & D(L) \\ M(L) & N(L) \end{bmatrix} \tag{23}$$

Hence

$$y_{it} = C(L)u_{it}^s + D(L)u_{it}^d \tag{24}$$

Where

$$u_{it}^s = \gamma_i^{s,g} g_t^s + \gamma_i^{s,k} f_t^{s,k} + \vartheta_{it}^s ; i = 1,...N \tag{25}$$

$$u_{it}^d = \gamma_i^{d,g} g_t^d + \gamma_i^{d,k} f_t^{d,k} + \vartheta_{it}^d ; i = 1,...N \tag{26}$$

Define

$$Z_t = \gamma_i^{s,g} g_t^s \tag{27}$$

Thus

$$\tilde{Z}_t = \begin{bmatrix} C(L) & D(L) \\ M(L) & N(L) \end{bmatrix} \begin{pmatrix} Z_t \\ 0 \end{pmatrix} \tag{28}$$

And the value of (21) is the $(1,1)th$ element of $Var(\tilde{Z}_t)$.

For the dynamics of g_t^s, we will assume a simple AR(1) process, just for illustration purpose. More general case $g_t^s = \Phi_g(L) \cdot g_{t-1}^s + \eta_t^g$ would be easily handled by the same method.

$$g_t^s = \phi_g^s \cdot g_{t-1}^s + \eta_t^g \tag{29}$$

Define

$$A_g = \begin{bmatrix} \phi_g^s & 0 \\ 0 & 0 \end{bmatrix} \tag{30}$$

Thus

$$\begin{pmatrix} Z_t \\ 0 \end{pmatrix} = A_g \begin{pmatrix} Z_{t-1} \\ 0 \end{pmatrix} + \begin{pmatrix} \gamma_i^{s,g} \eta_t^g \\ 0 \end{pmatrix} \tag{31}$$

$$\tilde{Z}_t = (I - B_1 L - B_2 L^2)^{-1} A_0^{-1} (I - A_g L)^{-1} \begin{pmatrix} \gamma_i^{s,g} \eta_t^g \\ 0 \end{pmatrix} \tag{32}$$

From which we can obtain

$$\tilde{Z}_t - (B_1 + A_0^{-1} A_g A_0)\tilde{Z}_{t-1} - (B_2 - A_0^{-1} A_g A_0 B_1)\tilde{Z}_{t-2} + (A_0^{-1} A_g A_0 B_2)\tilde{Z}_{t-3} = A_0^{-1} \begin{pmatrix} \gamma_i^{s,g} \eta_t^g \\ 0 \end{pmatrix} \tag{33}$$

Define

$$W_t = \begin{pmatrix} \tilde{Z}_t \\ \tilde{Z}_{t-1} \\ \tilde{Z}_{t-2} \end{pmatrix} \quad (34)$$

We can rewrite (33) into the following form AR(1) process

$$W_t = AW_{t-1} + V_t \quad (35)$$

Where

$$A = \begin{pmatrix} B_1 + A_0^{-1}A_g A_0 & B_2 - A_0^{-1}A_g A_0 B_1 & -A_0^{-1}A_g A_0 B_2 \\ I_{2\times2} & 0 & 0 \\ 0 & I_{2\times2} & 0 \end{pmatrix} \quad (36)$$

And

$$V_t = \begin{pmatrix} A_0^{-1}\begin{pmatrix} \gamma_i^{s,g}\eta_t^g \\ 0 \end{pmatrix} \\ 0_{2\times2} \\ 0_{2\times2} \end{pmatrix} \quad (37)$$

From (35), we get

$$Var(W_t) = A * Var(W_t) * A' + \begin{pmatrix} A_0^{-1}\begin{bmatrix} var(\gamma_i^{s,g}\eta_t^g) & 0 \\ 0 & 0 \end{bmatrix} A_0^{-1} & 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & 0 & 0_{2\times2} \end{pmatrix} \quad (38)$$

We can input any initial value for $Var(W_t)$, then iterate until it converges. The value of (21) is the $(1,1)th$ element of $Var(W_t)$.