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and Iikka Korhonen

China and the World economy:
Wavelet spectrum analysis of
business cycles



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Contents

Abstract.....	4
1 Introduction	5
2 Synchronization of Chinese business cycle with other countries.....	6
3 Wavelet spectral analysis	8
4 Stylized facts of the business cycle in China and selected countries	11
5 Globalization and business cycles in China and G7 economies.....	13
6 Conclusions	14
References	16
Figures and tables	18

Jitka Poměnková, Jarko Fidrmuc and Iikka Korhonen

China and the World economy: Wavelet spectrum analysis of business cycles

Abstract

We employ a wavelet spectrum analysis to study globalization and business cycles in China and G7 countries. The co-movement synchronization between G7 countries and China is shown to have undergone frequent and large changes during our sample period. The co-movements for business cycle frequencies are generally different from those for other frequencies, and synchronization with China's business cycle differs as between G7 countries. In recent years Japan, Germany and Italy seem to have the closest synchronization at business-cycle frequency. We find a significant relationship between the time-varying wavelet measure of synchronization and trade only for business-cycle frequencies. The co-movements at longer frequencies are negatively related to trade, so that the overall co-movements and trade tend not to be significantly related.

Keywords: Globalization, business cycles, synchronization, trade, wavelet analysis.

JEL-Codes: E32, F15, F41.

Jitka Poměnková, Department of Radio-Electronics (DREL), Brno University of Technology, Technická 12, 616 00 Brno, Czech Republic, e-mail: pomenkaj@feec.vutbr.cz.

Jarko Fidrmuc, ZU Friedrichshafen; Institute for East and South-East European Studies, Regensburg, Germany, Austrian Institute of Economic Research (WIFO), Austria, and Charles University Prague, Institute of Economic Studies, Czech Republic. Corresponding address: Zeppelin University Friedrichshafen, Am Seemooser Horn 20, D-88045 Friedrichshafen, Germany.

Iikka Korhonen, Institute for Economies in Transition, Bank of Finland. Postal address: PO Box 160, 00101 Helsinki, Finland. Email: iikka.korhonen@bof.fi.

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1 Introduction

During the past two decades China has become the world's second largest economy and largest exporter. This has increased the influence of China's economy on the rest of the world, while China's economic openness means that other economies also impact China's economic development.

In this paper we assess the business cycles in China and the G7 countries using wavelet analysis, which assesses the contribution of cyclical developments at different frequencies to the overall GDP development. In this, we have several aims. First, we want to document the various forces driving business cycles and their relative strengths in China and the G7 countries, ranging from the very long-run movements in GDP to shorter-run fluctuations. Second, we are interested in the synchronization of business cycle developments at different frequencies in China and the G7 countries. Finally, we seek to determine whether more trade with China leads to more closely aligned business cycle movements, and whether this effect might vary over different frequencies.

Somewhat unsurprisingly, we find that China's cyclical development has been quite different from that of the G7 countries, as in China the longer-term developments have dominated GDP growth. This is natural given China's position as a catch-up country. E.g. the short-term fluctuations that dominate GDP developments in the G7 countries around the 2008–9 economic crisis are much less influential in China. Moreover, synchronization with the Chinese business cycle has decreased for almost all G7 countries and all frequencies. In recent years we have seen somewhat more synchronization at business cycle frequencies with e.g. Germany and Japan, perhaps because of those countries' more extensive trade ties with China. When we regress the cospectra of GDP movements in China and the G7 countries at different frequencies on the intensity of bilateral trade, we find that at business cycle frequencies trade links increase synchronization. However, at longer frequencies the effect is the opposite, possibly indicating China's very different average growth performance during this period. This result is novel to the literature, and affords us an opportunity to reconcile the seemingly opposing views of Krugman (1993) and Frankel and Rose (1998).

The paper is structured as follows. The following section discusses the literature on China's business cycle synchronization. Section 3 introduces the concept of wavelet analysis, and Section 4 discusses the stylized facts of business cycles in G7 countries as

well as China. Section 5 analyzes the determinants of business cycle synchronization at different frequencies, and the last section concludes with suggestions for future research.

2 Synchronization of Chinese business cycle with other countries

A very large literature has evolved reporting correlations between different countries' business cycles and possible explanations. Particular attention has been paid to the role of foreign trade in transmitting shocks across national borders. Krugman (1993), for example, argues that countries should be expected to become increasingly specialized as they become more integrated. Thus, the importance of asymmetric or sector-specific shocks should increase with the degree of economic integration – a relationship perhaps more appropriate here for explaining Chinese business cycles. On the other hand, Frankel and Rose (1998) argue that trade, and more generally economic integration among countries, results in increased synchronization of national business cycles. They contend that trade links provide a channel for transmission of shocks across countries.

The conflicting theoretical explanations have given rise to an empirical literature studying the effects of economic integration on business cycle correlations. Whereas the introduction of the euro and subsequent enlargement of the euro area spurred many researchers to investigate business cycle correlations in Europe (see e.g. Bayoumi and Eichengreen, 1997), in Asia there has been somewhat less interest in this topic. China in particular warrants more research given its increased importance in the global economy and rapidly expanding foreign trade.

Kose et al. (2012) compare business cycles of industrial countries and emerging economies and find convergence within both groups, but divergence (decoupling) between the groups of industrial and emerging economies. This decoupling of business cycles between China and developed economies has been confirmed by Akin and Kose (2008).

A number of papers study business cycle correlations within Asia or around the Pacific Ocean, but as our emphasis is on the Chinese business cycle, we will concentrate solely on papers that include China in their analyses. Moneta and Ruffer (2009) look at business cycle correlations among ten Asian countries. They find that generally the Chinese and Japanese business cycles display very low correlations with those of the smaller

Asian economies and with each other, even though exports from all Asian countries seem to move together. Interestingly, Shin and Wang (2004) report that intra-industry trade is related to business cycle correlations among East Asian countries, including China and Japan. However, they also note that *increasing* intra-industry trade did not lead to higher business-cycle correlations. Gong and Kim (2013) conclude that Asian countries' similar links to the outside world lead to higher business-cycle synchronization in the region, but even when this is taken into account increasing regional trade linkages still strengthen the correlations. However, regional financial integration is associated with less business cycle synchronization, which may point to the benefits of financial diversification.

Other approaches to the question seem to confirm the above-mentioned results. For example, He and Wei (2012), using factor analysis, find that overall the Asian countries are less dependent on global cycles than are other large economies. Intra-Asian trade integration has increased the confluence of business cycles. Furthermore, the dependence of China on the identified global and regional factors has actually diminished over time. Artis and Okubo (2012) take a long-term view, using data extending from 1870 to 2006, and they find no evidence of Asian business-cycle correlation, although it is noteworthy that their sample of Asian countries is smaller than those of He and Wei (2012). Using dynamic correlation analysis, Fidrmuc and Korhonen (2010) look at the correlation of Chinese and Indian business cycles with the OECD countries and find that at business-cycle frequencies the correlations are quite low or even negative. But, as many other papers report, more intense trade relations between countries do increase their business-cycle correlations. Fidrmuc et al. (2013) confirm this result for a longer data sample, and also find that those OECD countries trading extensively with China have lower business-cycle correlations with other OECD countries than one would otherwise expect. Lam and Yetman (2013) look at developments in output gaps in the US and countries in the Asia-Pacific region, and conclude that more intense trade ties do lead to greater business-cycle synchronization.

Inclusion of data from the period of financial crisis in 2008–2009 and the subsequent recovery does raise the estimated business-cycle correlations, as all countries were hit hard by the drop in international trade. This result is confirmed by Kim et al. (2011), Lam and Yetman (2013) as well as Fidrmuc and Korhonen (2010).

To sum up, the correlations of Chinese business cycles with the other major economies of the world have been quite low. This result generally holds also for Asian

countries, which have extensive trade ties with China. However, it should be noted increasing trade linkages do raise correlations of business cycles with China. Most of the previous literature looks at relatively simple measures of business-cycle correlation, such as static correlation. Our contribution aims to provide a fuller account of correlation at different frequencies.

3 Wavelet spectral analysis

There are several questions that need to be answered in an analysis of business-cycle synchronization. How does one quantify the degree of synchronization of business cycles among countries; and how does one analyze the evolution of synchronization between different periods? Traditionally, the analysis of co-movement measurements has focused on static correlation. Extensions of this approach include common features (Engle and Kozicki, 1993), common cycles and codependence (Vahid and Engle, 1993 and 1997).

Alternatively, other authors apply the frequency domain techniques, which provide deeper insights into the dynamic properties of time series and their co-movements. This approach, based on spectral and cross-spectral analysis, enables the detailed study of co-movements of time series (Iacobucci, 2003; Iacobucci and Noullez, 2005). Thus, the analysis of co-movement can be based on the coherency, squared coherency denoted as coherence, dynamic correlation, and phase shift methods. Croux et al. (2001) provide a theoretical background and practical application on business cycles in Europe and the USA. They measure business-cycle synchronization via cohesion, measured by a multivariate index of co-movements. Messina et al. (2009) and Marczak and Beissinger (2012) present results derived from both the time and frequency domain to assess co-movements between real wages over the business cycle. In their approach, the frequency domain has the advantage that it allows an assessment of the relative importance of particular frequencies for the behavior of real wages. Furthermore, Fidrmuc and Korhonen (2010) use dynamic correlation to analyze the effects of the global crisis on business cycles in China, India and OECD countries. Fidrmuc et al. (2013) use the same methodology to estimate the determinants of output co-movements between OECD countries.

However, these methods share the fault that they are unable to define a truly time-varying measure of synchronization, although they can be applied to different subperiods. Therefore, new research directions have emerged during the last decade that attempt to

merge the time and frequency domains. The time-frequency domain analysis provides a more efficient means of statistical analysis. Consequently, both frequency analysis and time-frequency analysis of time series and processes have long been used in analyses in different fields. These have been applied in engineering (speech processing and communications), natural sciences (medicine, climatology, geophysics), and in the social and economic sciences. Accordingly, a wide range of applications can be found for time-frequency analysis, higher order spectra analysis, and frequency filtering.

Estimation of the time-frequency representation of a signal/time series can be done via four basic methods: wavelet analysis (Yogo, 2008), the multiple window method using Slepian sequences (Xu et al., 1999), time-frequency varying autoregressive (AR) process spectrum estimation, or time-frequency Fourier transform estimation (Proakis et al., 2002). These approaches make it possible to capture the time and frequency varying features of co-movement within a unified framework.

Several applications of time-frequency analysis have already been done in economics. Woźniak and Pacziński (2007) estimate the spectrum using a time-varying autoregressive process through appropriate filter order and study the patterns of co-movement via time-frequency coherences between economic cycles in the euro area and some of the European Union member states. Hughes Hallett and Richter (2011) examine the time-frequency framework in a way that allows accommodating structural breaks and non-stationary variables. They estimate a measure of time-frequency coherence for Hungary, Poland, Germany and France. More interestingly from the point of view of our analysis, Hughes Hallett and Richter (2009) use time-varying spectral methods to examine the links between China, USA and four open Asian economies. They find that the Asian economies' links with the USA have been weakening since the 80s, and that Taiwan is more closely synchronized with the Chinese business cycle than with that of Hong Kong.

Wavelet analysis affords a promising approach for time-frequency analysis in economics, as it provides a continuous measure of synchronization. Rua (2010) measures co-movements among Germany, France, Italy and Spain by means of the cross-wavelet spectrum. Jiang and Mahadevan (2011) extend this approach to the wavelet power spectrum, wavelet cross-spectrum, and wavelet coherence and significance tests. Ge (2008) presents significance tests for the wavelet cross spectrum and for wavelet linear coherence. Aguiar-Conraria and Soares (2011) use wavelet analysis to study business-cycle synchronization across the EU-15 and Euro-12 countries. They analyze the wavelet power spec-

trum, wavelet coherency, and phase-differences. Crowley (2007) discusses more examples of using wavelets to analyze business cycles.

Extending this literature, we apply the continuous wavelet transform (CWT) of time series $s(t)$ with respect to the mother wavelet $\psi(t)$, which is defined as

$$S_{CTW}(a, b) = \int_{-\infty}^{\infty} s(t) \frac{1}{\sqrt{b}} \psi\left(\frac{t-a}{b}\right) dt, \quad b > 0, a \in R, \quad (1)$$

where a is the time position (time shift), and b is the parameter of dilatation (scale) of the mother wavelet $\psi(t)$. The CWT transforms input time series from time representation to the time-scale domain. Jiang and Mahadevan (2011) argue that the wavelet transformation provides superior results, because it uses short windows for higher frequencies compared to the Fourier transformation. The time series may contain sharp edges or discontinuities that require more spectral coefficients in the classical spectra, while the wavelet representation can represent the same information with sufficient accuracy with only a small number of spectral components.

The mother wavelet is assumed to have the following properties:

$$\begin{aligned} i) & \int_{-\infty}^{\infty} \psi(t) dt = 0, \\ ii) & \int_{-\infty}^{\infty} \psi^2(t) dt = 1, \\ iii) & 0 < C_{\psi} = \int_0^{\infty} \frac{|\hat{\psi}(\omega)|^2}{\omega} d\omega < \infty; \quad \hat{\psi}(\omega) = \int_{-\infty}^{\infty} \psi(t) e^{-i\omega t} dt, \end{aligned} \quad (2)$$

where $\hat{\psi}(\omega)$ is the Fourier transform of $\psi(\omega)$. These conditions mean that the mother wavelet is mutually orthogonal, has a zero mean value, and is limited to finite time values. Then, the inverse wavelet transformation is defined as

$$s(t) = \frac{1}{C_{\psi}} \int_0^{\infty} \int_{-\infty}^{\infty} \psi\left(\frac{t-a}{b}\right) S_{CWT}(a, b) da \frac{db}{b^2}. \quad (3)$$

To satisfy the assumptions for the time-scale analysis, the waves must be compact in time and frequency representation. We employ here Morlet wavelet models (Gençay et al., 2002).

To analyze relations between two time series, for example y_1 and y_2 , in frequency domain, one can perform cross spectral analysis. The wavelet cross spectrum between two inputs, $s_1(t)$ and $s_2(t)$, for their time-scale representation $S_{CWT-1}(a,b)$ and $S_{CWT-2}(a,b)$ can be defined as

$$S_{12} = SO\left(S_{CWT-1}(a,b)S_{CWT-2}(a,b)\right), \quad (4)$$

where SO is the smoothing operator (Jiang and Mahadevan, 2011).

The cospectrum is measured on the y-axis for specific periods (x-axis) and periodicities (z-axis). The figure shows a two-dimensional projection of three-dimensional charts. The intensity of each contour represents the relative importance of the different periodicities and time.

4 Stylized facts of the business cycle in China and selected countries

We use seasonally adjusted quarterly data on gross domestic production (GDP) in constant prices from IMF International Financial Statistics, 1995:1 to 2012:1. All variables are in first differences of logarithms.

As official data for China are unavailable for a sufficiently long period, we chain data from different national and international sources, including the National Bureau of Statistics of China, the Hong Kong Monetary Authority, and the Bank of Finland database. We used national quarterly GDP data in current prices deflated by the CPI¹ and seasonally adjusted via the US Census Bureau's X12 ARIMA procedure. This allows us to assess the effects the recent global financial crisis and subsequent recovery on the business-cycle correlations. We test all variables for unit roots by the Augmented Dickey-Fuller test and obtain clear rejections of the null of unit root for first differences of output for all the countries (see Table A.1).

As in most studies, we distinguish among three components of the aggregate correlation. First, the long-run movements (over 8 years) correspond to a cycle length of 32 quarters or more (denoted by P32 in the figures below). Given that we use only relatively short time series, we do not use estimated spectra and cospectra for cycle lengths of more

¹ The GDP deflator is not available for the earliest years of the sample.

than 16 years (P64). Second, the traditional business cycles (with periods between 6 and 32 quarters) belong to the middle part of the figure between P6 and P32. Finally, the short-run movements are defined by a cycle length less of than 6 quarters (P6). Although it is common practice to neglect these developments in the literature, we consider them here as the short-run dependences of economic development, which may be important in the case of China.

Figure 1 presents estimated wavelet spectra. In general, the long-run and business-cycle frequencies dominate the spectra of all G7 countries, although in Japan the shorter business-cycle frequencies seem more prevalent than elsewhere, perhaps at the expense of long-run growth. The recent financial crisis increased the importance of relatively short cycles. The spectrum estimated for China also shows the dominance of the long-run business cycle frequencies, but their importance is less pronounced than for the G7 economies. Also, during the financial crisis of 2008 and 2009 the shortest frequencies seem to be less important for China than for G7 countries.

Given the differing characteristics of national business cycles in G7 economies versus China, the relatively low degree of synchronization is not surprising. Figure 2 presents wavelet cospectra for business cycles in China versus G7 economies over the period studied. We see that cycles in China and selected economies vary significantly over the frequencies and different time periods. For example, we can see that the degree of synchronization between China and the USA was relatively high at the beginning of the 1990s. However, it was surprisingly volatile: periods of business-cycle synchronization were followed by periods of diverging business cycles. At the same time there was a general tendency to less business cycle confluence, which is referred as decoupling in the literature. In this period the co-movements were observed mainly in relatively long cycles (with lengths of 32 quarters or even more). However, starting in about 2006 we find that there is also a tendency to an increasing degree of synchronization of relatively short cycles (with lengths of about 20 quarters).

This pattern can be found for all G7 economies. The initial synchronization was mainly due to long business cycles, but this synchronization diminished between 1995 and 2005. After that, we notice an increasing synchronization of classical business-cycle frequencies. This new synchronization with China was especially strong in Japan, Italy and Germany. For Japan and Germany, we can easily explain this by stronger trade links over time.

5 Globalization and business cycles in China and G7 economies

The findings of the previous sections show that business cycles in China and in the OECD countries are decoupled, although there is also a trend towards synchronization, at least for some lengths of business cycles. Furthermore, the intensity of economic links with China differs substantially across the G7 countries (Bussière and Mehl, 2008). Therefore, we focus our analysis on the business-cycle correlations between the G7 countries and China. In particular, we estimate the traditional relationship of business-cycle synchronization, following Frankel and Rose (1998), for individual cycle lengths:

$$cs_{it}(\lambda) = \gamma_1(\lambda) + \gamma_2(\lambda)x_{it} + \varepsilon_{it}, \quad (5)$$

where cs is the cospectrum between China and country i at cycle length λ , and x_i denotes the bilateral share of trade with China in GDP of country i . Using again IMF data (International Financial Statistics and Direction of Trade Statistics), we compute quarterly trade intensity between 1995:1 and 2012:1.

Typically, equations similar to (5) are estimated for cross-sectional static correlation between OECD countries. By contrast, we estimate (5) for each country using a time-varying measure of business-cycle synchronization and quarterly bilateral trade data.

The detailed results for different cycle lengths are reported in Figure 3 and Table 1. We see that the estimated coefficients are positive for all business cycles. The closest relationship between business cycle confluence and degree of trade integration occurs at a cycle length of about 23 quarters. Therefore our results lend support for the view that increased trade integration between G7 countries and China has also led to higher business-cycle correlations. However, it seems that, as the length of the cycle increases, the effect of trade integration also changes and becomes negative. This explains the fact that on average trade has no significant effects on the relatively long business cycle frequencies (4 to 8 years) in Japan, UK and USA (see Table 1), while Figure 3 shows that there is a positive relationship between trade and relatively short business-cycle frequencies (close to a period length of 6 quarters).

One can imagine that in the long-run countries will adjust to various shocks by e.g. changing the composition of their capital stocks, and they will return to their long-run

growth potential, but in the short-run shocks in one country are transmitted to other countries through trade linkages.

6 Conclusions

The emergence of China as the second largest economy and the largest trading nation in the world has rendered an understanding of its business cycle behavior highly important. It is also important to understand the degrees of synchronization of China's business cycle with those of other countries.

Our paper makes three main contributions. First, we use wavelet analysis to analyze China's GDP growth and find that China's growth is less dominated by traditional business-cycle frequencies than is growth in the G7 countries. Instead, China's GDP development seems to be driven more by longer-run developments, which may be associated with China's position as a catching-up economy.

Second, we find that overall synchronization of China's GDP growth with the G7 countries is quite low, but the degree of synchronization varies at different frequencies. Moreover, there was a general tendency to less business cycle confluence, which can be seen as evidence for the so-called decoupling hypothesis. Interestingly, we also find evidence for more synchronization during the financial crisis of 2008–9 with respect to GDP developments in Germany, Italy and the UK. Moreover, synchronization with Japan increases drastically at the shortest frequencies, perhaps owing to the two countries' positions within the same production networks.

Third, we test whether more bilateral trade with China increased the G7 countries' business-cycle synchronization with China. We find that the answer very much depends on the frequency examined. For the business-cycle frequencies, more trade leads to more synchronization, which is consistent with the hypothesis advanced by Frankel and Rose (1998). On the other hand, at long-run frequencies the effect is negative, which may explain why it is sometimes difficult to ascertain the Frankel-Rose hypothesis empirically. It can be that China's trend growth has been so much faster during the period that at longer frequencies the correlation is necessarily negative.

Therefore, as China's importance in the global economy continues to increase, and trade with China continues to expand, it is likely that other countries' economic developments will also be more influenced by China. However, our results show that the effect

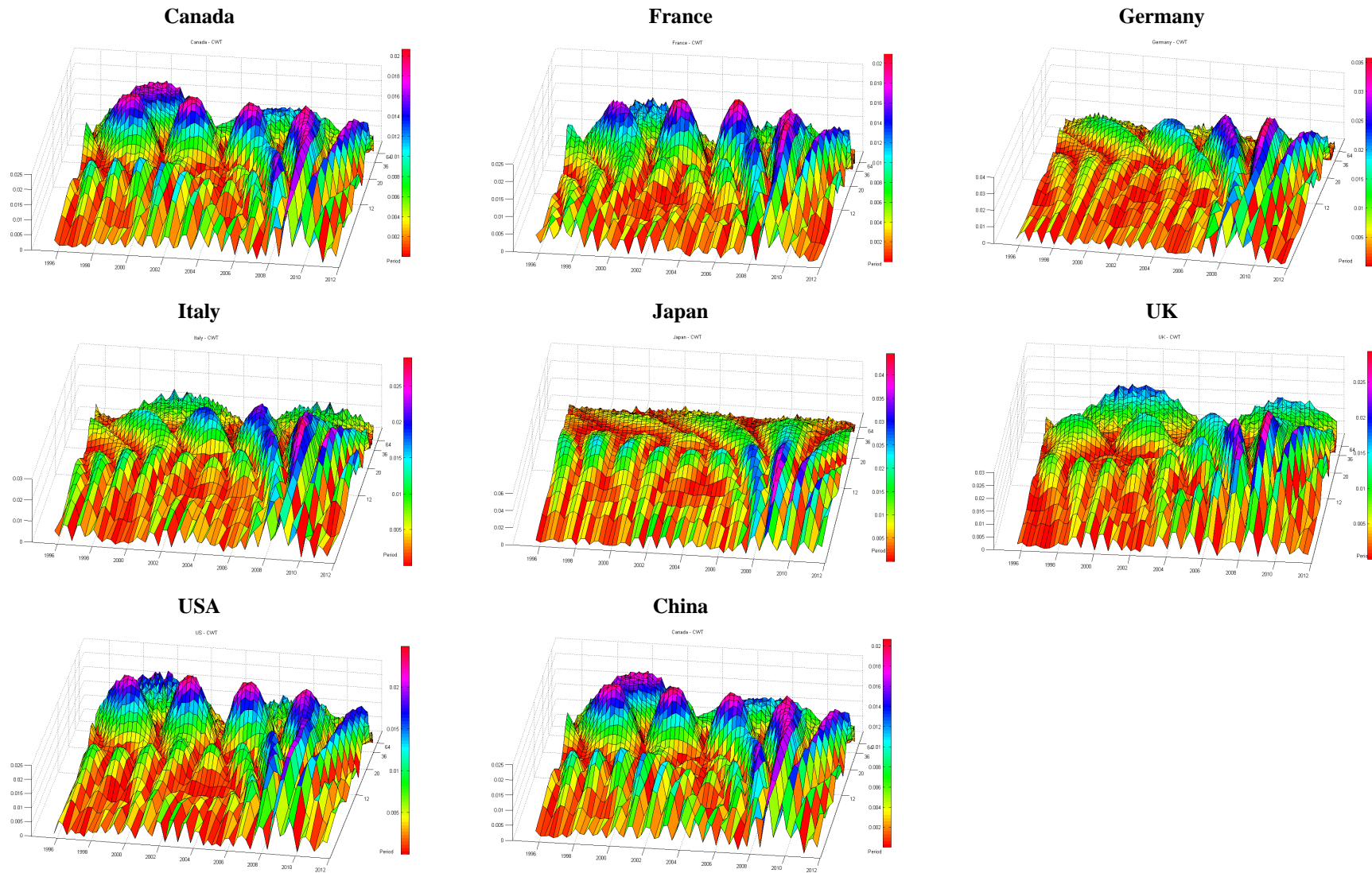
is not simple and straightforward: At business-cycle frequencies synchronization may increase, but at long-run frequencies the effect can be very different, which is a novel result in the literature – with obvious policy implications.

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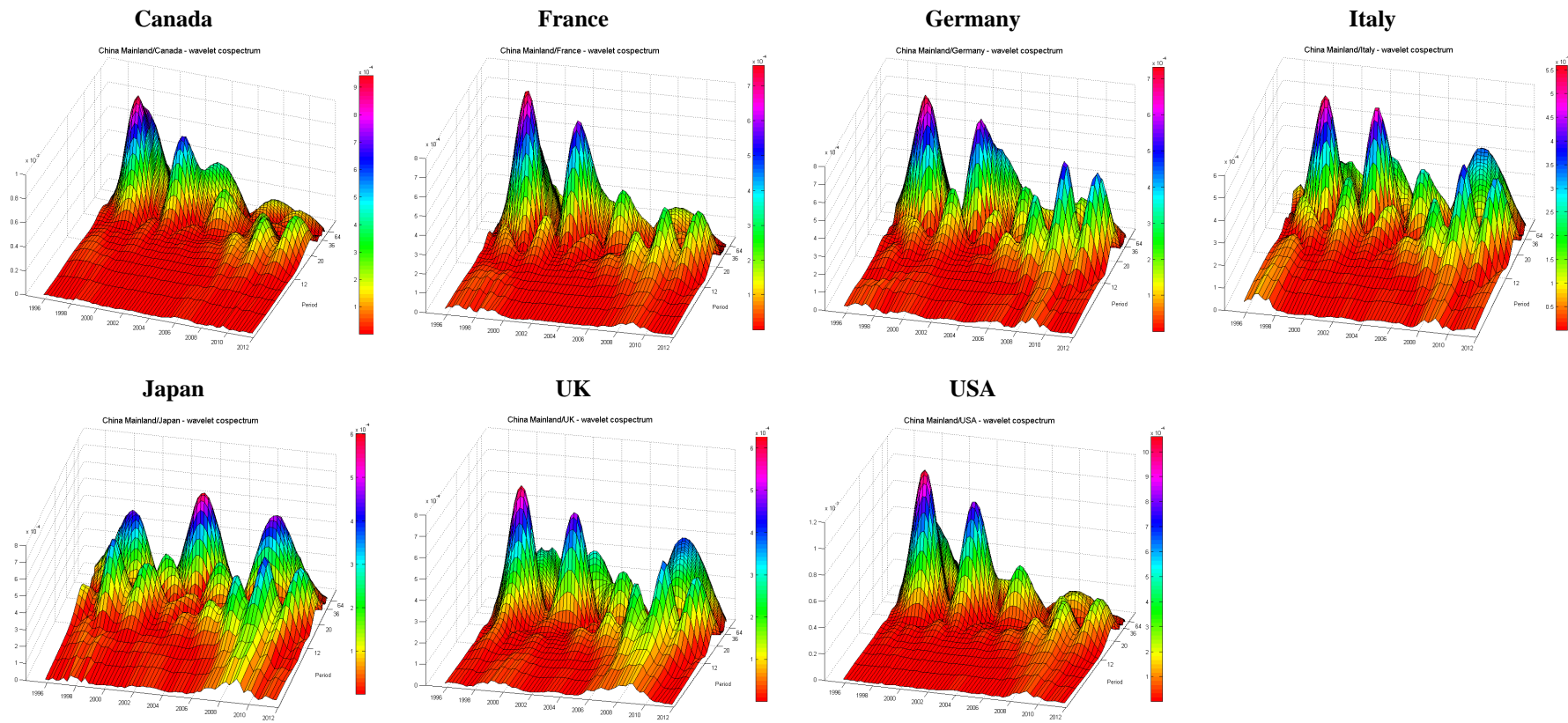
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Figure 1 Estimated wavelet spectra for selected countries



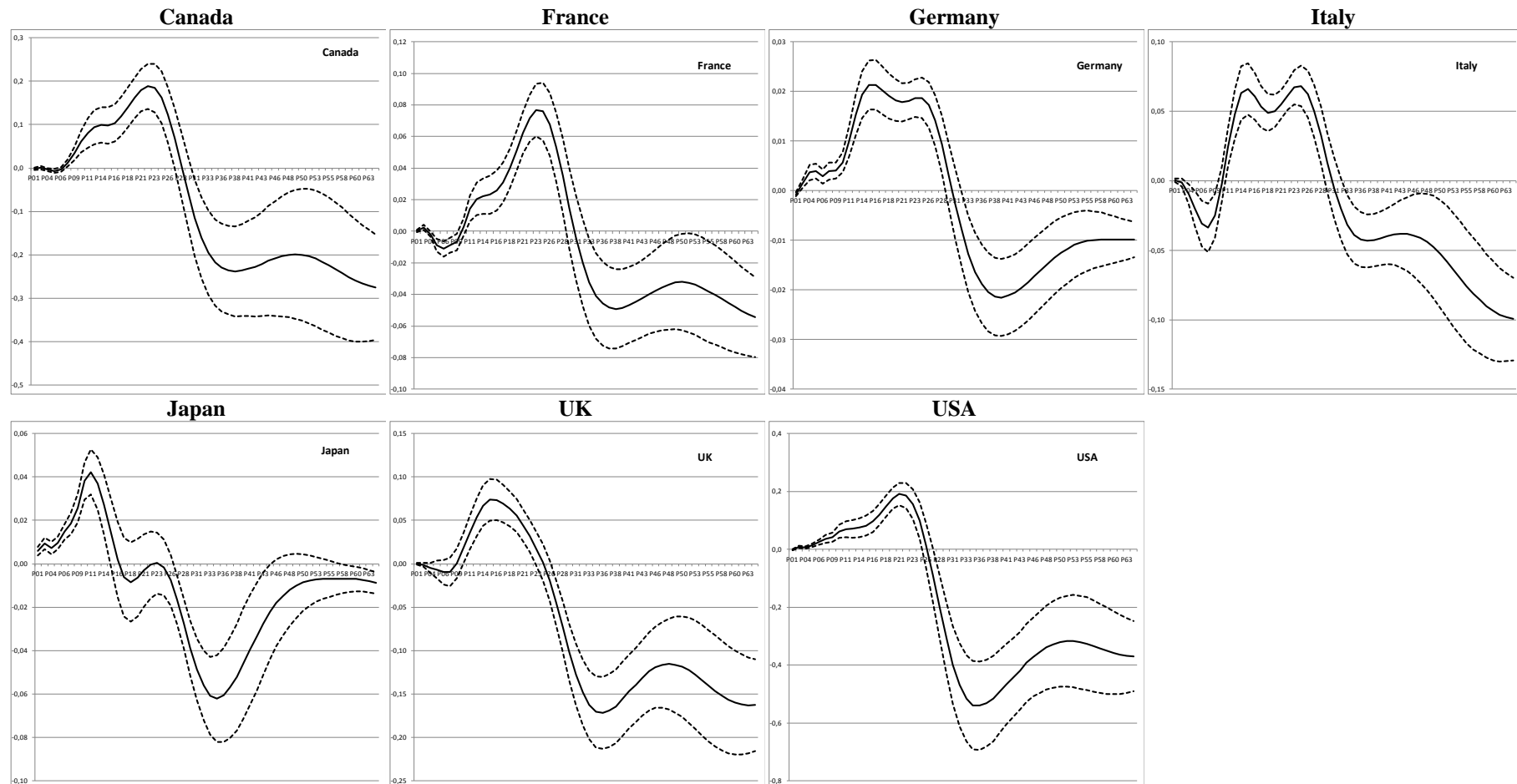
The spectrum is denoted on the y-axis for specific periods (x-axis) and periodicities (z-axis).
Source: Own estimations.

Figure 2 Wavelet cospectrum between China and G7 countries, 1995 to 2012



The cospectrum is denoted on the y-axis for specific periods (x-axis) and periodicities (z-axis).
Source: Own estimations.

Figure 3 Regression results by frequencies, trade and comovements for G7 countries and China



Note: The dependent variable is the average value of wavelet cospectrum over selected periodicity. The explanatory variable is the bilateral share of trade with China in GDP of selected countries. Constant is not reported. X-axis measures cycle periods from 1 to 64 quarters. Business-cycle frequencies correspond to the area between P06 and P32 (1.5 to 8 years). Short-run (long run) frequencies are the frequencies with period length less (more) than 6 quarters (32 quarters). Cross-spectra and estimations are based on quarterly data for 1995:Q2 to 2012:Q1. The bands show the 95% confidence intervals (± 2 standard errors).

Source: Own estimations.

Table 1 Estimation results for average wavelet cospectrum over selected frequency intervals, trade and comovements for G7 countries and China

	short-run frequencies		business cycle fr. (6-16 quarters)		business cycle fr. (17-32 quarters)		long-run frequencies	
Canada	-0.003	*	0.064	***	0.077	***	-0.227	***
	(0.002)		(0.013)		(0.024)		(0.060)	
France	-0.002	***	0.009	***	0.043	***	-0.227	***
	(0.001)		(0.003)		(0.008)		(0.060)	
Germany	0.002	***	0.012	***	0.013	***	-0.014	***
	(0.001)		(0.001)		(0.002)		(0.003)	
Italy	-0.008	***	0.019	***	0.041	***	-0.014	***
	(0.003)		(0.006)		(0.006)		(0.003)	
Japan	0.008	***	0.024	***	-0.018	*	0.008	***
	(0.001)		(0.004)		(0.010)		(0.001)	
UK	-0.003		0.034	***	-0.018	*	-0.014	***
	(0.002)		(0.009)		(0.010)		(0.003)	
US	0.007	***	0.062	***	-0.029		-0.014	***
	(0.002)		(0.011)		(0.033)		(0.003)	

Note: The dependent variable is the average value of wavelet cospectrum over selected periodicity. The explanatory variable is the bilateral share of trade with China in GDP of selected countries. Constant is not reported. Heteroscedasticity robust standard errors in parentheses. Business-cycle frequencies are the average of dynamic correlations for period lengths of 6 to 32 quarters. Short-run (long run) frequencies are the frequencies with period length less (more) than 6 quarters (32 quarters). Wavelet cospectra and regressions are estimated using quarterly data between 1995: 1 and 2012:1. ***, **, and * denote significance at 1, 5, and 10 percent level, respectively.

Table A.1 Augmented dickey-fuller test for GDP of selected countries, 1995:1–2012:1

	Levels	Differences	
Canada	-1.525	-4.015	***
	(0.811)	(0.002)	
France	-0.933	-4.939	***
	(0.946)	(0.000)	
Germany	-2.738	-5.653	***
	(0.225)	(0.000)	
Italy	-0.879	-4.512	***
	(0.952)	(0.001)	
UK	-0.6878	-3.204	**
	(0.970)	(0.024)	
USA	-1.641	-4.833	***
	(0.766)	(0.000)	
China	-1.937	-6.546	***
	(0.620)	(0.000)	

Note: Lag structure determined according to Schwarz information criterion. *** and ** denote significance at 1 and 5percent level, respectively.

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