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MEASUREMENT AND PATTERNS OF INTERNATIONAL SYNCHRONIZATION: A SPECTRAL APPROACH

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Measurement and Patterns of International Synchronization: A Spectral Approach

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Abstract

This paper examines the issue of international synchronization of cycles. Using spectral methods we analyze the pattern of co-movement (coherences) of growth rate cycles between countries across frequency bands and overtime. We also examine the lead-lag structure (phase shifts) of country cycles obtained from spectral methods and evaluate these against the reference chronology given by the Economic Cycle Research Institute (ECRI) based on the NBER methodology. These parameters are studied across three frequency bands, growth rate cycle frequency, low and high frequency. We also report partial coherences and confidence intervals based on Gaussian approximations to the distribution of the sample coherence which follows a complex Wishart distribution.

To characterize growth rate cycles, the paper uses the growth rate of the coincident index of economic activity[2] given by ECRI, a composite of variables that represent current economic activity for various countries and country groups over the period 1974 to 2010. We also evaluate how the character of co-movements has changed overtime by analyzing the sample over two periods, 1974-1990 and 1991-2010.

We find high feedback effects between country cycles, and that average partial coherences are higher during the period 1991-2010 over that in 1974-1990 in at least one frequency band. During the period 1991-2010, for almost all paired comparisons, these have risen in the growth rate cycle frequency. Additionally, for some pairs, coherences rise for longer cycles (low frequency) while for others, they increase in the higher frequency band. Average phase shifts over growth rate cycle frequency indicate that the synchronization is faster in the latter period. Finally, in assessing spectral results against the reference chronology of growth rate cycles given by ECRI, we find that both methodologies yield comparable results.

Keywords: Business cycles, spectral analysis, partial coherence
JEL Classification: C14, E32

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1. Introduction

In the global world order, with high inter-nation linkages through trade, capital and financial flows, economic circumstances in one country cannot be seen in isolation from those in the rest of the world. Thus, cyclical conditions originating in one country have transmission repercussions for others rooted in these channels.

From the intensification of the current phase of globalization in the early 1990s to the recent financial meltdown in the US economy spreading to other economies, world economic history is dotted with episodes where economic circumstances in one country have moved systematically in tandem with those in others. This, while providing empirical support to the international character of business cycle fluctuations, has also kindled renewed interest in the issue. Research on the issue has looked at issues ranging from measurement of correlation/synchronization to locating the proximate factors causing country cycles to move together. Inferences from empirical studies on the issue of synchronization far elude consensus in cycle literature. While some concede that the global era has witnessed higher, rather than lower co-movement, others (e.g. Stock and Watson (2003), Heathcote and Perri (2002) among others) conclude that there has been a decoupling or a divergence in the country cycles. More recent studies have shown that the degree of co-movement of country business cycles is asymmetric across phases of the business cycles, exhibiting more correlatedness in the recessionary phases than otherwise with Hamilton (2005) arguing that recessions are fundamentally different from “normal” times.

The empirical dimension of the question of international synchronization of cycles has been addressed in a variety of ways. Time domain studies have used vector autoregressive empirical frameworks, but recently nonlinear specifications have received significant attention, distinguishing between the expansion and the recession phases. Important among these have been autoregressive threshold models, SETAR models, regime switching models and dynamic factor analysis. An alternative way of capturing international comovement is the Economic Indicator Analysis, used to date peaks and troughs in business cycles. Business cycle transmission has also been studied in the frequency domain using spectral and cross-spectral estimates.

We study international synchronization of growth rate cycles using spectral techniques in the frequency domain, by addressing two aspects of the issue, one of examining the co-movement across countries and second, the sequencing in terms of leads and lags of cycles vis-à-vis each other. The pattern of co-movement of growth rate cycles across countries is analyzed using spectral estimates across frequency bands and overtime. The lead-lag structure of country cycles obtained from spectral methods is evaluated against the reference chronology given by the Economic Cycle Research Institute (ECRI) based on the NBER methodology. Spectral techniques in the frequency domain decompose a complex time series with cyclical components into underlying sinusoidal (sine and cosine) functions of particular wavelengths. The spectral representation of a time series is used to infer correlation, and a lead-lag sequencing of two series. We study these parameters across three frequency bands, growth rate cycle frequency (cycles between 12 months and 8years, corresponding to a frequency band $[\pi/48, \pi/6]$), low frequency (cycles of duration more than 8 years) and high frequency (cycles of less than 12 months duration). To remove any feedbacks of different variables playing on each other, we also report partial cross spectra and partial coherences, obtained by estimating coherences between VAR residuals of series.

Recognizing that the business cycle is a consensus of cycles in many activities, the use of a single series like the GDP or the IIP to characterize business cycles seems restrictive. We use the coincident composite index of economic activity.

While classical business cycles are less frequent in occurrence, growth cycles, measured in terms of deviations from trend, require prior specification of a detrending filter, which may extract different information from the parent raw series (Canova, 1998). We, therefore, use the concept of growth rate cycles that measure the slowdowns and pickups in economic activity. We use the smoothed growth rate of the coincident index of economic activity sourced from the Economic Cycle Research Institute (ECRI) for country groups, like the Europe, America, Asia Pacific, and select important countries from each of these groups for the study, including United States, United Kingdom, Germany, India and Japan on a monthly basis for the period 1974 to 2010 to characterize growth rate cycles. To further examine whether there has been a change in the pattern of co-movements of cycles, we divide the sample into two periods, 1974-1990 and 1991-2010.

We find that average coherences are higher during the period 1991-2010 over that in 1974-1990. During the period 1991-2010, for most bilateral comparisons, they have risen in the defined growth rate cycle frequency. Additionally, for some pairs, coherences rise in longer cycles (low frequency) while for others, they increase in the higher frequency band. We also report confidence intervals for the estimated parameters based on the Gaussian approximations to the distribution of sample coherence given by Enochson and Goodman (1965), which follows a complex Wishart distribution.

Average phase shifts over growth rate cycle frequency indicate that it takes less time for the cycles to get in phase vis-à-vis each other in the latter period. Finally, we compare the spectral results with the reference chronology of growth rate cycles in various countries and country groups, given by the Economic Cycle Research Institute (ECRI) based on the NBER methodology. We find that directionally, they are in line with the reference chronologies.

This paper is organized along the following lines. Section 2 discusses the international character of business cycles, and the various methodologies that have been used to measure and characterize the synchronization process. Section 3 deals with the econometric methodology used in the paper. Section 4 discusses definitional and measurement issues. This is followed by a presentation of the major empirical results and their analysis in section 5. Section 6 concludes.

2. International Business Cycles

The prime focus of international business cycle research has been on analyzing how economic connections among countries impact the transmission of aggregate fluctuations. How and to what extent the various channels get played out in an economy is a function of the organizational and institutional mechanisms that get together to define the particular socio-economic fabric.

The inter-war years and the Great Depression brought in an urgency to the issue of being able to capture the 'goings', and so focus shifted from whys and wherefores to the what the data spoke and sensed. This led to the birth of an empirical body of work which builds on a system of economic indicators to measuring current economic activity and to track future movements of key variables in the economy. One of the earliest methods to be used in the context was the Harvard ABC curves[3] (earlier referred to as barometers), devised shortly before World War I. Later work at the National Bureau of Economic Research (NBER), Mitchell and Burns (1938), Burns and Mitchell (1946), Moore (1950, 1958, 1961, and 1982), Klein (1983), Zarnowitz (1991), and others essentially builds on this framework.

From the perspective of international transmission of business cycles, economic indicator analysis defines the lead or lag in growth cycle peaks and troughs in one country vis-a-vis turns in the other countries. To determine the dating of peaks and troughs, turning point dates are selected from some coincident economic indicators which reflect economic processes such as output, income, employment, sales, and from a coincident composite index. A set of rules[4] guides the selection of the cyclical turning points of a single indicator.
Banerji and Hiris (2002) apply the classical indicator approach within a multidimensional framework and an international extension of this framework for comparison across major economies. Reference dates are then constructed for international business cycles and growth rate cycles on the basis of a uniform set of procedures based on the NBER approach. These reference chronologies serve as benchmarks for cross-country comparisons of cyclical patterns. Boehm (2004) compares states of business cycles across countries using economic indicator analysis. Dua and Banerji (2009) look at the diffusion index, measuring the severity of a recession.

International business cycles transmission and common movements in the cyclical components have received much attention in the time domain through the use of cointegration and vector autoregressions. Backus Kehoe and Kydland (1992), Zimmerman (1997) and Baxter (1995) also use model calibration techniques, and a comparison of artificially constructed economies and real economies. Den Haan (2000) uses the correlations of the VAR forecast errors at different horizons as a measure of business cycle synchronization, while Yetman (2011) and Otto et al. (2001) use a dynamic Pearson correlation coefficient between cyclical GDP of 17 OECD countries and find that cross-country correlations have declined between 1960–1979 and 1980–2000.1. Harding and Pagan (2006), Artis et al (1997) and Medhiuob (2009) use the concordance index defined as the fraction of time that two countries are in the same cycle phase (contraction or expansion) to infer synchronization. Allegret and Essaadi (2011) base their inferenes on a time-varying coherence function, with endogenously determined structural changes in the co-movement process. Artis et al. (1997) and Bodman and Crosby (2000) find

[3] The work was originally attributed to Warren Persons at the Harvard University, hence the name. While the A curve represented speculation, measured by stock prices, the B curve denoted business activity, measured by the volume of cheques drawn on bank deposits and the C curve represented the money market and was measured by the rate of interest on short-term commercial loans.
[4] See Klein (2002) and Bry and Boschan (1971) for details.

evidence of synchronization of business cycles across the G7 countries. Diebold and Yilmaz (2009) spillover index uses VAR and VECMs.

Engle and Kozicki's (1993) common serial correlation feature detects short-run co-movements among I(1) variables. Cubadda and Hecq (2001) extend this in multiple time series to define *polynomial serial correlation common features (PSCCF)*. Hecq (2009) has investigated the presence of common cyclical features at different data points separated by a threshold variable. Candelon and Hecq (2000) use simultaneously common trends and common cycles, while Breitung and Candelon (2001) use a frequency domain common cycle test to analyze synchronization at different business cycle frequencies.

Recent studies have emphasized nonlinear specifications which introduce a significant distinction between the expansionary and recessionary phases. Among these non-linear models are autoregressive threshold models (Tiao and Tsay 1993), SETAR models (Terasvirta and Anderson, 1992) and the regime switching models (Hamilton 1989, Filardo and Gordon, 1994) and dynamic factor analysis (Gregory et al., 1997).
It has also been shown that the degree of co-movement of country business cycles is asymmetric across phases of the business cycles, exhibiting more 'correlatedness' in the recessionary phases than otherwise. Hamilton (2005) argued that recessions are fundamentally different from "normal" times. Bordo and Hebling (2003), Hebling and Bouyami (2003) and Canova et al (2007) find that the importance of global shocks is high in a worldwide downturn.

Other nonparametric methods include frequency domain methods, involving the use of spectral and cross-spectral estimates. Business cycle synchronization studied in the frequency domain retains some desirable features of non-linear models. Spectral techniques are powerful instruments to study correlation, and a lead-lag sequencing of the correlation between two series translated into the frequency domain. Frequency domain analysis of business cycle transmission across countries has involved the use of spectral and cross-spectral estimates. In particular, cross-spectral coherence estimates give co-movements by frequency. Dynamic correlation in frequency domain was proposed by Forni, Reichlin and Croux (2001) to analyze synchronization between series. Jensen and Selover (1999) explain national business cycles synchronization over time using a mode-locking phenomenon. Pakko (2004) applies spectral analysis to the consumption correlation puzzle. Other important papers looking at the issue of synchronization using spectral techniques are Canova and Dellas (1993), Burnside (1998), Canova (1998) and Mendez and Kapetanios (2001). The latter conclude that synchronization itself is asymmetric across different phases of the cycle. Dellas (1986) found that the growth rates of countries were correlated both in the time and frequency domains.

We use frequency domain methods to infer international synchronization and comparatively place together results from the reference chronology given by ECRI based on the NBER methodology. The next section discusses the econometric methodology followed in the paper.

3. Econometric Methodology

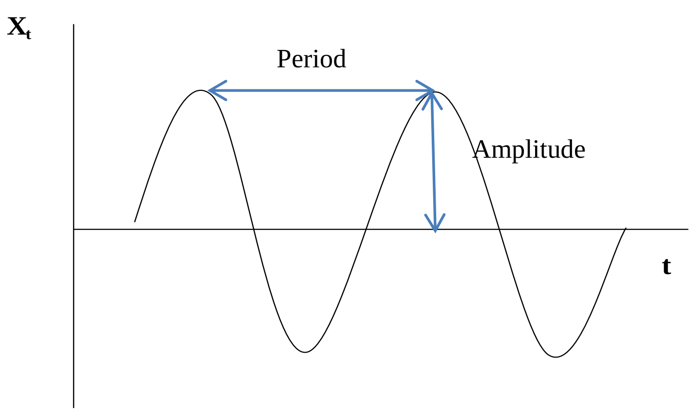
The following steps were followed for the estimation procedure.

3.1 Stationarity and Unit root Tests

In this paper, we focus on the DF-GLS (Elliot et al, 1996) and the KPSS test proposed by Kwiatkowski et al. (1992).

3.2 Spectral Analysis

Time series have been generally viewed in terms of models involving time functions or correlations, known as the *time domain* view. An alternative approach is to study time series in the frequency domain, that is, in terms of repetitive cycles[5]. Since most cyclical phenomena resemble and have wave-like characteristics, such processes can be studied in terms of a frequency-wise break up of its constituent parts contributing to the variance of the process.
Spectral analysis decomposes the variance of a stochastic process by frequency. This decomposition ascribes certain portions of the total variance to components of various frequencies (periods).



$$X_t = R\cos(\omega t + \theta) + Z_t$$

R: Amplitude, ω: Angular frequency (radians)
Period of a sinusoidal cycle, $T = \frac{1}{f} = 2\pi/\omega$, Frequency $f = \omega/2\pi$[6]

Spectral techniques in the frequency domain decompose a complex time series with cyclical components into underlying sinusoidal (sine and cosine) functions of particular wavelengths. If a periodic function X_t is defined on an interval [-R,R], then Fourier series *S(x)* is a representation of *f(x)* as a linear combination of cosine and sine functions, defined on (-π, π).

The spectrum may be interpreted as the contribution of a given frequency to the variance of the process at that frequency. The area under the spectrum is the total variance of the series. Thus, an examination of the spectrum enables us to infer the proportion of the variance explained by the cycle frequencies. For a real valued weakly stationary discrete stochastic process $\{X_t; t = ..., -2, -1, 0, 1, 2, ...\}$ with zero mean and covariance function

[5] This paper uses non-evolutionary spectral theory, which requires the series to be stationary.
[6] For example, for a function 2cos(3t+5), period of the cycle = $T = \frac{1}{f} = \frac{2\pi}{3} = 2.0944$ (Janecek and Swift, 1993)

$R(s) = E[X_t X_{t-s}] = R(-s)$ the spectral density function (or power spectrum) is the Fourier transform of the covariance function $\hat{h}(\omega) = \frac{1}{2\pi} \sum_{s=-(N-1)}^{(N-1)} \hat{R}(s) e^{-i\omega s}$

The so estimated spectral density function although unbiased, is an inconsistent estimate of the spectrum[7]. Smoothing procedures, using windows give a consistent estimator of the spectrum which is given by $\hat{h}(\omega) = \frac{1}{2\pi} \sum_{s=-(N-1)}^{(N-1)} \lambda_N(s) \hat{R}(s) e^{-i\omega s}$ where $\{\lambda_N(s)\}$is a sequence of decreasing weights, also known as a covariance lag window, defined with a truncation parameter M. With the true spectral density known, M can be related to the spectral bandwidth, but where no prior information about the true spectral bandwidth exists, Priestley (1981) proposes using the sample autocovariance function and a window closing procedure. We use the autocovariance function plotted as a function of s to determine M from its observed rate of decay.

3.2.1 Cross-Spectral Estimates

Coherence

Coherence measures the strength of relationships between corresponding frequency components of the two series in the same way as a correlation coefficient. Thus, it allows a comparison of how country cycles may have associations that are varying across frequencies. In particular, we can infer if country cycles are more tied at low frequencies (long cycles), growth rate cycle frequencies or high frequencies (short cycles).

For a bivariate case, with a stationary series $X_t = (X_{it}, X_{jt})^T$ coherency spectrum[8] can be given by

$$|\hat{w}_{ij}(\omega)| = \frac{|\hat{h}_{ij}(\omega)|}{\{\hat{h}_{ii}(\omega)\hat{h}_{jj}(\omega)\}^{1/2}} = \left\{ \frac{\hat{c}_{ij}^2(\omega) + \hat{q}_{ij}^2}{\hat{h}_{ii}(\omega)\hat{h}_{jj}(\omega)} \right\}^{1/2}$$

$\hat{h}_{ii}(\omega)$ and $\hat{h}_{jj}(\omega)$ are the auto-spectra of $\{X_{it}\}$ and $\{X_{jt}\}$respectively, and $\hat{h}_{ij}(\omega)$ is the cross-spectrum of $\{X_{it}\}$ and $\{X_{jt}\}$, while $\hat{c}^2{}_{ij}(\omega)$, $\hat{q}^2{}_{ij}(\omega)$ are the co-spectrum and the quadrature spectrum derived from the polar form of $\hat{h}_{ij}(\omega)$ [9]

$w_{ij}(\omega)$ can be interpreted as the correlation coefficient between the random coefficients of the components in X_{it} and X_{jt} at frequency ω. It follows that for all ω, $0 \le |w_{ij}(\omega)| \le 1$ for any two jointly stationary processes. Thus, a value close to zero would be indicative of low linear association between the two processes, while a value close to one would mean that the two processes are closely associated.

As in the case of the spectral density estimation, the coherence estimator is an inconsistent estimator. For consistency, as discussed above, the lag window and spectral window requires a

[7] See Granger and Hatanaka (1964) or Priestley (1981) for proof.

[8] Some authors refer to $|w_{ij}(\omega)|^2$ as the coherence.

[9] For the polar form $\hat{h}_{ij}(\omega) = \hat{c}_{ij}(\omega) - i\hat{q}_{ij}(\omega)$ the co-spectrum is the real part and quadrature spectrum the imaginary part.

truncation parameter M. In the univariate case of spectrum estimation, it suffices to use the rate of decay of the sample autocovariance function. For the estimation of coherence, we note that there are three elements in its definition, and there is no guarantee that the rates of decay of the sample autocovariance functions would be the same. An alternative could be to use a cross-covariance function. Nettheim (1966) proposes that two values of M could be used, an upper bound and a lower bound.

Confidence Intervals for Coherence

Goodman (1957) in studying multivariate spectral estimates introduced the complex Wishart distribution, and used it as an approximation for the distribution of the estimated spectral matrix. He suggested that for $\omega \neq 0, \pi$ the distribution of $(2m+1)\hat{h}(\omega)$ may be approximated by the complex Wishart distribution with parameters *(2m+1)*, $h(\omega)$. Enochson and Goodman (1965) show that given the probability density function for the sample coherence, Fischer's z-transformation[10] can be applied such that the z-transform can then be used to find confidence intervals for the sample coherence.

Phase

The phase difference[11] between two series measures the leads or lags between frequency components vis-à-vis each other. At frequency ω a phase lead of θ radians is equivalent to θ / ω periods, which is the number of periods by which a cycle in one country occurs ahead of a similar cycle in another.
With regard to the confidence intervals for phase estimates, Goodman (1957) provides a frequency function for the estimated phase angle. Based on Goodman's work, Granger and Hatanaka (1964) provide confidence bands for phase angle in degrees.

Partial Coherences

Partial correlation coefficient measures the correlation between X and Y after the influence of Z on each of these variables has been removed. For X_t and $Y_{1,t}$, allowing for $Y_{2,t}$, the influence of $Y_{2,t}$ on X_t and $Y_{1,t}$ is removed by considering the processes

$$\eta_{1,t} = X_t - \sum_{u=-\infty}^{\infty} b_1(u) Y_{2,t-u} \qquad \eta_{2,t} = Y_{1,t} - \sum_{u=-\infty}^{\infty} b_2(u) Y_{2,t-u}$$

Where $\{b_1(u)\}, \{b_2(u)\}$ are determined by minimizing $E[\eta_{1,t}^2]$ and $E[\eta_{2,t}^2]$

The partial (complex) coherency is defined as the (complex) coherency of $\eta_{1,t}$ and $\eta_{2,t}$ after removing the influence of the third variable. Confidence intervals for partial coherences can be obtained by using the fact that the distribution of the sample partial coherence is the same as that of the sample coherence provided that the equivalent number of degrees of freedom of the spectral estimates is reduced by *(r-1)* where *r* is the number of other variables removed in evaluating the partial coherence.

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[10] $\hat{z}_{ij}(\omega) = \tanh^{-1}\left(\left|\hat{w}_{ij}(\omega)\right|\right) = \frac{1}{2}\ln\frac{1+\hat{w}_{ij}}{1-\hat{w}_{ij}}$

[11] $\phi_{ij}(\omega) = \tan^{-1}\left(-\frac{q_{ij}(\omega}{c_{ij}(\omega)}\right)$

3.2 Reference procedure: Economic Indicator Analysis

Boehm (2004) proposed that Economic indicator analysis can be used to acknowledge the extent to which growth cycle peaks and troughs in one country lag corresponding turns in the other country. This can be achieved by an identification of corresponding business cycle chronologies for individual countries to study the apparent economic linkages between countries. Thus, the international economic indicators allow international comparisons of the state of business cycles in different countries or group of countries. This is important in recognition of the international character of business cycles.

The Economic Cycle Research Institute uses the NBER methodology of dating turning points of the indexes of economic activity (coincident, leading and lagging indicators). The turning points are then used to compare the leads or lags between country pairs or country group pairs.

4. Data

For monitoring fluctuations in business activity a broad measure of 'aggregate economic activity' is ideal in that it recognizes the fact that the business cycle is a consensus of cycles in many activities, which have a tendency to peak and trough around the same time. The coincident index comprises indicators that measure current economic performance such as measures of output, income, employment and sales, which help to date peaks and troughs of business cycles (Dua and Banerji, 2004). It is used to represent the level of current economic activity.

The study uses the coincident index of economic activity and growth rate cycle data, obtained from ECRI, which provides data on indices for 19 major countries, and for the world economy. We use the following regional groups for the study

1. America – US, Canada, Mexico and Brazil.
2. Europe – UK, France, Spain, Sweden, Germany, Austria, Switzerland, Italy
3. Asia Pacific – India, China, Japan, Korea, Taiwan, Australia, New Zealand

Among individual countries, we study US, UK, Germany, Japan and India.

5. Results

Basic Statistics

We begin by reporting some descriptive statistics over the cycle. The ECRI reference chronology based on the NBER methodology peak and trough dates for the five countries considered as given in graphs 1A to 1E. The spikes in blue define peaks while those in red give troughs.

Based on these dates we calculated the peak and trough amplitudes, durations of slowdowns, pickups and of the overall cycle as done in Harding and Pagan (2002). Amplitude is taken to be the value of the growth rate of the coincident index at a defined peak or a trough. A slowdown duration is reported as the number of months the growth rate cycle moves from a peak to a trough. Averages are calculated over all the peak to trough movements during a given period. Similarly, averages for pickup durations are calculated from a trough to a peak.

Statistics are reported in Table 1. To examine if the growth rate cycles are characteristically different across the two time periods considered, we report average statistics over both periods. We find that the (average) peak amplitudes during the period 1971-1990 are higher than those in the period 1991-2010 for all countries except in India. For the period 1971-1990, the average duration of slowdowns is longer than pickups duration for US and India. For Japan, Germany and UK, pickups are longer. For the period 1991-2010, US still observes slowdowns that are longer than pickups, along with Japan and Germany. However, for India and the UK, slowdowns are shorter.

Synchronization: Cross-Spectral Estimates

We conducted two unit root tests on the growth rates of the coincident index given by ECRI for each country series for determining the stationarity status of the series, the DF-GLS test and the KPSS test. Inferred from these, we found the growth rates of the coincident index to be stationary, I(0). Results for individual unit root tests are shown in Tables 2A, and 2B. Table 3 puts together the results for both the tests.

While the notion of business cycle duration and related frequency band is generally agreed upon (complying with the Burns and Mitchell definition of 1.5 years to 8 years), we inferred growth rate cycle frequency from available data on ECRI growth rate cycle dates. For each country across all regions, we calculated durations from peak to peak and trough to trough of all cycles. Then we calculated the overall growth rate cycle duration by averaging over the peaks and troughs. We then located the minimum and maximum over all countries to obtain a band. This worked out to be between 12 months to 96 months, and $[\pi/48, \pi/6]$ when converted into corresponding frequency bands. Low frequency band has been defined to be less than $\pi/6$ and high frequency refers to frequencies greater than $\pi/48$.

Spectral methods were run on the smoothed growth rates of the coincident index. Following are some important results obtained from the exercise.

Co-movements: Coherences

As a first step, average coherences over all three frequency bands were calculated for the entire sample. We report the coherence and phase shift parameters for ECRI smoothed growth rates of the coincident index in Table 4.1.

Between regional groups, America and Europe show the highest coherence in the low frequency band, of the order of 0.77. America-Asia Pacific and Europe-Asia Pacific are at a low of 0.22 and 0.39 respectively. Looking at the pattern across frequency bands, we find that the coherence deceases as frequency increases for America-Europe. However, for the other two pairs, coherence spikes at growth rate cycle frequency.

Regarding country pairs, the average coherence is the highest between US and UK, standing at 0.82. US-India and UK-India stand close at 0.53 and 0.54 respectively. To have a deeper insight into the changes in the pattern of comovements, we divided the sample into two parts.

Since the beginning of 1990s has historical significance as far as events in the international economy are concerned, this was used as a divide year for the sample. The sample was divided into two periods, 1974-1990 and 1991-2010 to examine if there was any significant difference across the two periods. Results for the sub-period analysis are reported in Tables 4.2 and 4.3. We find that over the period 1974-1990, across various frequency bands, for all regional groups and country pairs except US-India, coherence is highest at the low frequency band, falls in the growth rate cycle frequency band and falls further in the high frequency band. This seems to imply a more long run tying of cycles for this period. Baxter, Kehoe and Kydland (1992) in estimating cross-country correlations for 1970.1-1990.2 find that output correlations for the pair US-Germany stands at 0.69 (0.697 from our spectral results at low frequency), for US-Japan at 0.60 (0.70) and for US-UK at 0.55 (0.76). These are close to our estimates at low frequency during the period 1974-1990 as shown in Table 4.2.

However, a glance at the average coherences over these bands during the period 1991-2010 suggests that there has been a change in the pattern of frequency-band wise coherence during this period. While for the regional groups America-Europe and America-Asia Pacific, long cycles are more tied in this period too, Europe-Asia Pacific cycles are more correlated at the growth rate cycle frequency. The country pairs (with the exception of US-UK, US-India and UK-India) also show a spike in the coherence parameter at growth rate cycle frequency, with the coherence being lower at both high and low frequency.

Partial Coherences

In trying to estimate coherences between two variables, it should be recognized that each of them may be associated with other variables. Then the coherences may not reflect the ‘pure’ effect of one series on the other. There may exist feedback effects among variables, to remove which we estimated partial cross spectra and partial coherences. We ran a four variable vector auto-regression and obtained the VAR residuals for each of the variables in each possible pairs of countries.

Partial coherences and phase estimates for the full sample are reported in Tables 5.1. The partial coherences for all pairs lie below the total coherences calculated over different frequency bands. This indicates that feedback and repercussion effects of varying degrees are present between country cycles.

We observe that for all the country and regional pairs (except America-Europe, US-UK and Germany-Japan), the average coherences over the three frequency bands spike at growth rate cycle frequency. Yetman (2011) using a time varying dynamic correlation coefficient in the time domain finds that business cycles strongly comove during periods of recession but are largely independent during non-recessionary periods for countries of the G7, OECD and Asia Pacific.

For the remaining three pairs, coherence is higher at low frequency, falls a little at growth rate cycle frequency and further at higher frequency. This means that the long cycles for these pairs show more co-movement than shorter cycles.

Frequency-wise average coherences over the two sub-periods 1974-1990 and 1991-2010 are reported in Tables 5.2 and 5.3. As a cursory reading, we learn that except the pair America-Eurpe, for all other pairs the average coherence shows a rise across one or more frequency bands during 1991-2010 compared to the preceding period 1974-1990. Table 6 gives the direction of movement of average partial coherences across the two periods using arrows.

Starting with coherences in the growth rate cycle frequency, which is of primary interest to us, we find that except the two pairs US-Germany and US-India, all other country pairs show higher degree of co-movement in this frequency band during the period 1991-2010 than in 1974-1990. Artis (2003) in a panel study using clustering techniques for growth rate cycles using real GDP (1970-2001) finds that Japan is as strongly associated with the core European countries as are many other European countries, as is often the US.

For US-India, there is substantial increase in the average coherence in the lower frequency band and a simultaneous fall in the same over higher frequency. The Indian economy has lived a far more regulated policy framework than most other countries in the sample. Mohan (2011) suggests that it is the conservatism towards full liberalization (of particularly the capital account) that allowed relative autonomy in the conduct of the monetary policy in not pushing the economy to operate at 'the corners of the Impossible Trinity'. The 'prohibitive' and 'corrective' roles of the monetary policy have probably been responsible for a low coherence observed at cycle frequency.

Across high frequency band, except three pairs, i.e. US-UK, US-India and Japan-India, all other pairs show an increase in the partial coherence. This result might be put together with the fact that the 90s have been associated with financial innovations, and development of financial derivatives. The Indian economy has followed a very cautious and gradualist path in opening up to the world. The move to capital account convertibility has been slow with multiple restrictions on the movement of capital across borders.

- Average (total) coherences over the period 1974-1990 indicate that except for the pair US-India, all pairs show long cycles (low frequency) to be more tied than shorter ones (high frequency). This might in some way be reflective of spillover of productivity processes or similarity of production and/or industrial structures.
- Average (total) coherences during the period 1991-2010 over growth rate cycle frequency are higher than those observed at either higher or lower frequencies for most country pairs, except US-UK among others. All other country pairs have a spike at growth rate cycle frequency.
- A move away from long cycles being more tied during the period 1974-1990 to they being more tied at growth rate cycle frequency during the period 1991-2010 may in some way be reflective of tying of policies than of productive capacities.
- Partial coherences over the two periods for all pairs lie consistently below overall coherences, indicating the existence of feedback and repercussion effects of varying orders.
- With sub-sampling of data a comparison of average partial coherences across the period 1974-1990 and 1991-2010 reveals that these have increased over at least one frequency band. For country pairs, except US-Germany and US-India, every other pair has a higher coherence at growth rate cycle frequency apart from other frequencies as well. This shows that while correlations between country cycles have increased, the nature of the increased coherences for different pairs is different.

Some important graphs showing coherences and phase shifts are presented after the Tables section. 95% confidence intervals are reported.

As already discussed in section 2, there does not seem to emerge a consensus view on whether cycles are converging or decoupling. Faia (2007) has shown using a DSGE model that financial globalization weakens business cycle synchronization. Heathcote and Perri (2004) find empirical support to the proposition that a rise in financial globalization reduces business cycle synchronization. Herrero and Ruiz (2007) find that bilateral financial links are inversely related to comovements of output, implying that financial integration in allowing for easier transfer of resources enables their decoupling. Kose et al (2003), Morgan et al (2004) and Imbs (2004) find to the contrary. Similarly, while Frankel and Rose (1998) propose that greater trade ties imply more comovement, Krugman (2001) argues that the trade ties could be responsible for more decoupling between country cycles, since the degree of specialization due to trade may cause the cycles to be out of phase vis-à-vis each other.

Spectral Phase shifts and ECRI/NBER Reference Chronology: A Comparison

In defining bilateral pairs, the spectral techniques infer leads/lags from the phase shift estimate. While coherences are analogous to correlations, phase shifts have to be read more carefully. A positive value of the phase shift means the second in the pair is that fraction of a cycle ahead of the first country. The ordering in a pair is important. The months equivalent of the radian fractions are reported in the tables reporting coherences and also in Table 6 in comparison with ECRI leads/lags. The convention in reference chronology uses a negative value for a lead and positive for a lag.

Over both periods, within regional groups, North America leads both Europe and Asia Pacific. For country comparisons, we find that vis-à-vis India, all other countries, US, Japan, UK and Germany lead India. Japan and UK cycles lead those in the US.

We observe that the time it takes for cycle transmission is lower during the period 1991-2010 as compared to that in 1974-1990. This is irrespective of whether coherences for that pair increased in the low frequency band or in the high frequency ones.

Finally, we place together our spectral results with those of ECRI reference chronology. We see that the same direction of leads and lags is obtained across the two methodologies though magnitudes for some country pairs vary (Table 7), except one pair, US-Germany. For this pair, the ECRI reference chronology suggests a lead by the US over Germany, while the spectral phase shift indicates that Germany leads US.

- Phase shifts across the two periods 1974-1990 and 1991-2010 show that the synchronization process in general is faster.
- However, when we look at the corresponding coherence movements, we find that this is uncorrelated with what band the coherences have risen in. This may be kept in the perspective of advances in information technology and development of financial derivatives and instruments that may have been a proximate cause.
- A comparative evaluation of the spectral and EIA results indicates that they are broadly in agreement with each other directionally but magnitudes differ.

6. Conclusions

In this paper, we looked at the issue of international synchronization of growth rate cycles to analyze the pattern of co-movement of growth rate cycles across countries. We employed spectral methods on the ECRI's growth rate of the coincident index of economic activity for the period 1974 to 2010 for country groups America, Europe and Asia Pacific, and select countries from these groups, US, UK, Germany, Japan and India. We found evidence of co-movements in the cyclical components, and these in general seem to be higher within the defined growth rate cycle frequency than outside it.

Next, we divided the sample into sub-parts, 1974 to 1990 and from 1991 to 2010. We find that in the latter period coherences have increased across one or more frequency bands. The increases in general (except two country pairs) have been in the growth rate cycle frequency bands. Simultaneously, other frequency bands also show an increase in coherence, in the low frequency band for some while in the high one for the others.

Phase shifts have become lower, indicating that country cycles are not only more tied post 1990s, the leads and lags of cycles vis-à-vis each other have become smaller. The phase shifts were then used to compare with the reference chronology of growth rate cycles in various countries and country groups, given by the Economic Cycle Research Institute (ECRI). We find broad comparability direction-wise in the results obtained by both methods.

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Table 1. Growth rate cycle characteristics

		US	Japan	India	Germany	UK
Average Durations (months)						
1971-1990	PT(Contractions)	34.00	16.29	17.43	22.00	17.33
	TP(Expansions)	14.40	17.57	12.71	28.80	23.00
1991-2010	PT(Contractions)	17.67	15.88	13.57	17.43	20.00
	TP(Expansions)	15.71	14.00	16.38	16.14	21.67
Average Amplitudes at turning points						
1971-1990	P	7.058	8.437	12.772	8.006	7.795
	T	-3.345	0.904	-1.064	-2.689	-2.546
1991-2010	P	3.980	5.043	15.079	6.875	4.185
	T	-0.645	-3.081	-2.354	-4.649	-0.846

Unit root test results

Table 2A. DF-GLS Unit root test results: Smoothed Growth Rates of the Coincident Index

Variable	Intercept and Trend	Intercept	Inference (Unit root present)
AsPac	-3.23	-1.39	No
Europe (EU)	-4.18	-4.01	No
America(AM)	-5.26	-5.25	No
Germany	-4.19	-3.72	No
India	-6.56	-3.50	No
Japan	-3.13***	-2.64	No
UK	-2.61*	-1.67*	No
US	-4.72	-4.65	No
Critical Values			
*10%	-2.57	-1.62	
**5%	-2.89	-1.94	
***1%	-3.48	-2.57	

Table 2B. KPSS Unit Root Results (after lag truncation convergence): Smoothed Growth Rates of the Coincident Index

Null hypothesis: No unit root

Variable	Intercept and Trend	Intercept	Inference (Unit root present)
AsPac	0.131	0.041	No
Europe (EU)	0.087	0.101	No
America (AM)	0.099	0.159	No
Germany	0.068	0.068	No
India	0.038	0.474	No
Japan	0.124**	0.605	No
UK	0.178***	0.206	No
US	0.111	0.166	No
Critical Values			
*10%	0.119	0.347	
**5%	0.146	0.463	
***1%	0.216	0.739	

Table 3. Unit Root Tests: Summary
Smoothed Growth Rates of the Coincident Index

Test variable	DFGLS	KPSS	Inference
AsPac	I(0)	I(1)	No unit root
EuroPe	I(0)	I(0)	No unit root
America	I(0)	I(0)	No unit root
Germany	I(0)	I(0)	No unit root
India	I(0)	I(0)	No unit root
Japan	I(0)	I(0)	No unit root
UK	I(0)	I(0)	No unit root
US	I(0)	I(0)	No unit root

Spectral Results

Table 4.1 Average Coherences and Phase Estimates of Smoothed Growth Rates of the Coincident Index

	Low frequency@		Growth rate cycle frequency*		High frequencies#	
Country pairs	**Coherence**	**Phase**	**Coherence**	**Phase**	**Coherence**	**Phase**
AM-EU	**0.77**	0.05	0.63	-0.20	0.35	-0.09
AM-AsPac	0.22	0.01	0.47	-0.02	0.30	-0.16
EU-AsPac	0.39	-0.01	0.59	0.00	0.26	-0.13
US-UK	**0.82**	0.03	0.46	0.16	0.30	0.02
US-Germany	**0.60**	0.09	0.52	0.03	0.33	-0.13
US-Japan	0.44	0.03	0.47	0.08	0.21	-0.17
US-India	**0.53**	0.01	0.43	-0.23	0.29	-0.02
Japan-India	0.33	-0.01	0.34	0.06	0.27	-0.10
UK-India	**0.54**	-0.01	0.31	-0.19	0.25	-0.04
Germany-India	0.45	-0.03	0.32	-0.13	0.23	-0.20
UK-Japan	0.36	0.04	0.39	-0.07	0.24	0.01
Germany-Japan	0.65	-0.01	0.57	0.08	0.23	-0.11

**Average growth rate cycle duration has been calculated to be between 1 year and 8 years, which corresponds to a frequency band of (π/48, π/6).*
 # refers to all frequencies> π/48.
@ refers to all frequencies< π/6.
(-) Phase shift is to be read as that fraction of a cycle the first country in the pair leads the other.

Table 4.2 Average Coherences and Phase Estimates of Smoothed Growth Rates of the Coincident Index: 1974-1990

	Low frequency@		**Growth rate cycle frequency***		**High frequencies#**	
Country pairs	**Coherence**	**Phase**	**Coherence**	**Phase**	**Coherence**	**Phase**
AM-EU	**0.778**	0.013	0.660	0.065	0.350	-0.153
AM-AsPac	0.792	0.008	0.618	0.130	0.248	-0.282
EU-AsPac	0.858	-0.002	0.712	0.050	0.287	-0.020
US-UK	**0.760**	0.011	0.497	0.323	0.354	-0.067
US-Germany	**0.697**	0.017	0.555	0.174	0.270	-0.012
US-Japan	0.702	0.010	0.504	0.230	0.224	-0.341
US-India	**0.667**	-0.003	0.390	-0.271	0.394	-0.144
Japan-India	0.786	-0.002	0.396	-0.436	0.316	-0.141
UK-India	**0.462**	-0.031	0.307	-0.384	0.275	0.102
Germany-India	0.500	-0.011	0.390	-0.487	0.334	-0.096
UK-Japan	0.735	0.009	0.362	-0.017	0.258	-0.001
Germany-Japan	0.801	-0.013	0.592	0.019	0.246	0.022

**Average growth rate cycle duration has been calculated to be between 1 year and 8 years, which corresponds to a frequency band of (π/48, π/6).*
 # refers to all frequencies> π/48.
@ refers to all frequencies< π/6.

Table 4.3 Average Coherences and Phase Estimates of Smoothed Growth Rates of the Coincident Index: 1991-2010

	Low frequency@		Growth rate cycle frequency*****		High frequencies#	
Country pairs	**Coherence**	**Phase**	**Coherence**	**Phase**	**Coherence**	**Phase**
AM-EU	**0.714**	0.023	0.590	-0.050	0.320	-0.129
AM-AsPac	0.071	-0.370	0.440	-0.115	0.296	-0.088
EU-AsPac	0.140	-0.075	0.575	-0.035	0.329	-0.118
US-UK	**0.837**	0.014	0.702	-0.025	0.324	0.094
US-Germany	**0.467**	0.035	0.534	0.099	0.486	-0.349
US-Japan	0.247	0.010	0.501	0.076	0.296	0.076
US-India	**0.456**	0.029	0.436	-0.079	0.320	-0.046
Japan-India	0.285	-0.007	0.358	-0.036	0.256	-0.157
UK-India	**0.572**	-0.003	0.408	0.037	0.351	-0.117
Germany-India	0.455	0.044	0.474	-0.021	0.264	-0.315
UK-Japan	0.059	-0.130	0.359	-0.029	0.277	-0.200
Germany-Japan	0.359	0.037	0.598	0.072	0.287	-0.059

**Average growth rate cycle duration has been calculated to be between 1 year and 8 years, which corresponds to a frequency band of (π/48, π/6).*
 # refers to all frequencies> π/48.
@ refers to all frequencies< π/6.

Table 5.1 Average Partial Coherences and Phase Estimates of Smoothed Growth Rates of the Coincident Index: Full sample (VAR Residuals)

	Low frequency@		Growth rate cycle frequency*****		High frequencies#	
Country pairs	**Coherence**	**Phase**	**Coherence**	**Phase**	**Coherence**	**Phase**
AM-EU	**0.761**	0.061	0.539	-0.050	0.318	-0.048
AM-AsPac	0.282	0.865	0.413	0.207	0.262	-0.040
EU-AsPac	0.468	-0.048	0.535	-0.005	0.240	-0.166
US-UK	**0.699**	0.051	0.396	0.242	0.308	0.049
US-Germany	**0.277**	0.132	0.440	0.065	0.314	-0.107
US-Japan	0.279	-0.075	0.418	0.154	0.219	0.019
US-India	**0.191**	0.802	0.437	-0.036	0.278	0.120
Japan-India	0.072	0.244	0.272	0.205	0.257	-0.059
UK-India	**0.192**	-0.258	0.288	-0.197	0.247	-0.028
Germany-India	0.157	0.094	0.251	-0.022	0.230	-0.179
UK-Japan	0.210	0.087	0.257	-0.167	0.255	-0.192
Germany-Japan	0.495	-0.023	0.466	0.103	0.258	-0.164

**Average growth rate cycle duration has been calculated to be between 1 year and 8 years, which corresponds to a frequency band of (π/48, π/6).*
 # refers to all frequencies> π/48.
@ refers to all frequencies< π/6.

Table 5.2 Average Partial Coherences and Phase Estimates of Smoothed Growth Rates of the Coincident Index (VAR Residuals)
1974-1990

	Low frequency@		Growth rate cycle frequency*****		High frequencies#	
Country pairs	**Coherence**	**Phase**	**Coherence**	**Phase**	**Coherence**	**Phase**
AM-EU	**0.858**	-0.011	0.603	0.025	0.372	-0.059
AM-AsPac	0.240	0.247	0.601	0.291	0.327	0.069
EU-AsPac	0.677	-0.019	0.579	0.129	0.251	0.058
US-UK	**0.478**	0.009	0.379	0.373	0.366	0.027
US-Germany	**0.457**	-0.000	0.519	0.014	0.283	-0.052
US-Japan	0.406	0.923	0.419	0.388	0.251	0.009
US-India	**0.462**	0.060	0.459	-0.004	0.403	-0.018
Japan-India	0.338	-0.016	0.242	0.017	0.293	-0.109
UK-India	**0.327**	-0.261	0.272	-0.450	0.279	0.126
Germany-India	0.373	-0.078	0.287	-0.422	0.303	-0.112
UK-Japan	0.534	-0.006	0.292	-0.230	0.250	-0.113
Germany-Japan	0.386	-0.071	0.413	0.067	0.264	0.073

**Average growth rate cycle duration has been calculated to be between 1 year and 8 years, which corresponds to a frequency band of (π/48, π/6).*
 # refers to all frequencies> π/48.
@ refers to all frequencies< π/6.

Table 5.3 Average Partial Coherences and Phase Estimates of Smoothed Growth Rates of the Coincident Index (VAR Residuals) 1991-2010

	Low frequency@		Growth rate cycle frequency*		High frequencies#	
Country pairs	**Coherence**	**Phase**	**Coherence**	**Phase**	**Coherence**	**Phase**
AM-EU	**0.584**	0.013	0.494	-0.020	0.364	-0.099
AM-AsPac	0.294	-0.497	0.368	0.122	0.286	-0.042
EU-AsPac	0.635	-0.033	0.551	-0.048	0.306	-0.269
US-UK	**0.499**	0.090	0.509	-0.008	0.295	0.147
US-Germany	**0.060**	0.271	0.386	-0.014	0.375	-0.107
US-Japan	0.642	-0.005	0.567	0.178	0.271	0.125
US-India	**0.621**	0.942	0.303	-0.176	0.297	0.028
Japan-India	0.801	-0.026	0.288	0.041	0.248	0.027
UK-India	**0.108**	-0.105	0.330	0.071	0.316	-0.044
Germany-India	0.201	0.215	0.319	-0.007	0.331	-0.279
UK-Japan	0.236	-0.189	0.450	-0.221	0.309	-0.153
Germany-Japan	0.342	0.088	0.448	0.167	0.273	-0.092

**Average growth rate cycle duration has been calculated to be between 1 year and 8 years, which corresponds to a frequency band of (π/48, π/6).*
 # refers to all frequencies> π/48.
@ refers to all frequencies< π/6.

Table 6. Direction of Movement of Average Partial Coherences across the period 1974-1990 and 1991-2010.

	Low frequency	**Growth cycle frequency**	**High frequency**
AM-EU	↓	↓	↓
AM-AsPac	↑	↓	↓
EU-AsPac	↓	↓	↑
US-UK	↑	↑	↓
US-Germany	↓	↓	↑
US-Japan	↑	↑	↑
US-India	↑	↓	↓
Japan-India	↑	↑	↓
UK-India	↓	↑	↑
Germany-India	↓	↑	↑
UK-Japan	↓	↑	↑
Germany-Japan	↓	↑	↑

Table 7 Comparative Results: Spectral Phase shifts Vs EIA Reference Chronology

Country Pairs	Spectral Estimates		EIA Reference Chronology	
	1974-1990	**1991-2010**	**1974-1990**	**1991-2010**
AM-EU	-3.51	-2.70	-4.60	-1.00
AM-AsPac	-7.02	-6.21	-3.70	-2.25
EU-AsPac	2.70	-1.89	1.20	-0.35
US-UK	17.44	-1.35	0.00	-3.17
US-Germany	9.40	5.35	-0.84	-1.93
US-Japan	12.42	4.11	1.38	2.17
US-India	-14.63	-4.27	-6.67	-4.30
Japan-India	-2.35	-1.95	-0.10	-1.00
UK-India	-20.74	2.00	-6.17	1.00
Germany-India	-26.30	-1.14	-4.38	-1.79
UK-Japan	-0.92	-1.57	-2.42	-1.92
Germany-Japan	1.03	3.89	2.17	0.94

Table 8.1 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				Lead (-)/Lag (+) in months of US over India		
United States		**India**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
		2/74				
3/75						
	2/76		2/76		0	
		9/77				
			5/78			
		12/79				
			10/80			
6/80						
	1/81					
7/82		2/83		-7		
	1/84		8/84		-7	
		9/85				
			10/86			
1/87		12/87		-11		
	12/87		6/88		-6	
		5/89				
			3/90			
2/91		9/91		-7		
			4/92			
		4/93				
	5/94		4/95		-11	
1/96		11/96		-10		
			9/97			
		10/98				
	1/98					
9/99						
	4/00		3/00		+1	
11/01		7/01		+4		
	7/02					
2/03						
	3/04		4/04		-1	
		10/04				
			10/05			
8/05		3/06		-7		
	1/06		1/07		-12	
3/09		1/09		+2		
	5/10		7/10		-2	
				Troughs	Peaks	Overall
		1974-1990	Average	-9	-4.33	-6.67
		1991-2010	Average	-3.6	-5	-4.3

Table 8.2 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				**Lead (-)/Lag (+) in months by US over UK**		
United States		**United Kingdom**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
3/75		5/75		-2		
	2/76		7/76		-5	
		4/77				
			6/79			
6/80		5/80		+1		
	1/81					
7/82						
	1/84		10/83	+3	+3	
		8/84				
			5/85			
		12/85				
1/87						
	12/87					
			1/88			
2/91		4/91		-2		
	5/94		7/94		-2	
1/96		8/95		+5		
			7/97			
	1/98					
9/99		2/99		+7		
	4/00		1/00		+3	
11/01						
	7/02					
2/03		2/03		0		
	3/04		3/04		0	
8/05		5/05		+3		
	1/06		9/07		-20	
3/09		2/09		+1		
	5/10		6/10		-1	
				Troughs	Peaks	Overall
		1974-1990	Average	+1	-1	0.00
		1991-2010	Average	-2.33	-4	-3.17

Table 8.3 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				**Lead (-)/Lag (+) in months of US over Germany**		
United States		**Germany**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
3/75		12/74		+4		
	2/76		4/76		-2	
		7/77				
			5/79			
6/80						
	1/81					
7/82		10/82		-3		
	1/84					
			4/86			
1/87		1/87		0		
	12/87					
2/91						
			1/91			
		1/93				
	5/94		12/94		-7	
1/96		3/96		-2		
	1/98		3/98		-2	
9/99		4/99		+5		
	4/00		5/00		-1	
11/01		3/02		-4		
	7/02		9/02		-2	
2/03		8/03		-6		
	3/04		4/04		-1	
8/05		2/05		+6		
	1/06		11/06		-10	
3/09		2/09		+1		
	5/10		8/10		-3	
				Troughs	Peaks	Overall
		1974-1990	Average	0.33	-2	-0.84
		1991-2010	Average	0	-3.86	-1.93

Table 8.4 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				Lead (-)/Lag (+) in months of US over Japan		
United States		Japan				
Troughs	Peaks	Troughs	Peaks	Troughs	Peaks	
3/75		2/74		+13		
	2/76		12/76		-10	
		7/77				
			2/79			
6/80		11/80		-5		
	1/81		7/81		-6	
7/82						
		5/83				
	1/84					
			1/85			
1/87		7/86		+6		
	12/87		2/88		-2	
2/91		5/89		+21		
			3/90			
		12/93				
	5/94		12/94		-7	
1/96		1/96		0		
			3/97			
	1/98					
9/99		4/98		+17		
	4/00		8/00		-4	
11/01		12/01		-1		
	7/02					
2/03						
	3/04		1/04		+2	
8/05		11/04		+9		
			4/05			
		10/05				
	1/06		4/06		-3	
		9/06				
			8/07			
3/09		3/09		0		
	5/10		2/10		+3	
				Troughs	Peaks	Overall
		1974-1990	Average	+8.75	-6	+1.38
		1991-2010	Average	+5	-0.67	+2.17

Table 8.5 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				Lead (-)/Lag (+) in months of Japan over India		
Japan		India				
Troughs	Peaks	Troughs	Peaks	Troughs	Peaks	
2/74		2/74		0		
	12/76		2/76		+10	
7/77		9/77		-2		
			5/78			
	2/79					
		12/79				
11/80			10/80			
	7/81					
5/83		2/83		+3		
			8/84			
	1/85					
		9/85				
			10/86			
7/86		12/87		-17		
	2/88		6/88		-4	
5/89		5/89		0		
	3/90		3/90		0	
		9/91				
			4/92			
12/93		4/93		+8		
	12/94		4/95		-4	
1/96		11/96		-10		
	3/97		9/97		-6	
4/98						
		10/98				
	8/00		3/00		+5	
12/01		7/01		+5		
	1/04		4/04		-3	
11/04		10/04		+1		
	4/05		10/05		-6	
10/05		3/06		-5		
	4/06		1/07		-9	
9/06						
	8/07					
3/09		1/09		+2		
	2/10		7/10		-5	
				Troughs	Peaks	Overall
		1974-1990	Average	-3.2	+3.0	-0.1
		1991-2010	Average	+2	-4.0	-1.0

Table 8.6 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				Lead (-)/Lag (+) in months of UK over India		
United Kingdom		India				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
		2/74				
5/75						
	7/76		2/76		+5	
4/77		9/77		-5		
			5/78			
	6/79					
		12/79				
5/80						
			10/80			
		2/83				
	10/83		8/84		-10	
8/84		9/85		-13		
	5/85					
12/85						
			10/86			
		12/87				
	1/88		6/88		-5	
		5/89				
			3/90			
4/91		9/91		-5		
			4/92			
		4/93				
	7/94		4/95		+3	
8/95						
		11/96				
	7/97		9/97		-2	
		10/98				
2/99						
	1/00		3/00		-2	
		7/01				
2/03						
	3/04		4/04		-1	
5/05		10/04		+7		
			10/05			
		3/06				
	9/07		1/07		+8	
2/09		1/09		+1		
	6/10		7/10		-1	
				Troughs	Peaks	Overall
		1974-1990	Average	-9.0	-3.33	-6.17
		1991-2010	Average	+1.0	+1.0	+1.0

Table 8.7 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				Lead (-)/Lag (+) in months of Germany over India		
Germany		India				
Troughs	Peaks	Troughs	Peaks	Troughs	Peaks	
12/74		2/74		+10		
	4/76		2/76		+2	
7/77		9/77		-2		
			5/78			
		12/79				
	5/79		10/80		-17	
10/82		2/83		-4		
			8/84			
		9/85				
	4/86		10/86		-6	
1/87		12/87		-11		
			6/88			
		5/89				
			3/90			
	1/91					
		9/91				
			4/92			
1/93		4/93		-3		
	12/94		4/95		-4	
3/96		11/96		-8		
			9/97			
		10/98				
	3/98					
4/99						
	5/00		3/00		+2	
		7/01				
3/02						
	9/02					
8/03						
	4/04		4/04		0	
		10/04				
2/05			10/05			
		3/06				
			1/07			
	11/06					
2/09		1/09		+1		
	8/10		7/10		+1	
				Troughs	Peaks	Overall
		1974-1990	Average	-1.75	-7.0	-4.38
		1991-2010	Average	-3.33	-0.25	-1.79

Table 8.8 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				Lead (-)/Lag (+) in months of Germany over Japan		
Germany		**Japan**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
12/74		2/74		+10		
	4/76		12/76		-8	
7/77		7/77		0		
	5/79		2/79		+3	
		11/80				
			7/81			
10/82		5/83		-7		
	4/86		1/85		+15	
		7/86				
1/87						
			2/88			
		5/89				
	1/91		3/90		+9	
1/93		12/93		-11		
	12/94		12/94		0	
3/96		1/96		+2		
	3/98		3/97		+12	
		4/98				
4/99						
	5/00		8/00		-3	
3/02		12/01		+3		
	9/02					
8/03						
	4/04		1/04		+3	
		11/04				
			4/05			
2/05		10/05		-8		
	11/06		4/06		+7	
		9/06				
			8/07			
2/09		3/09		-1		
	8/10		2/10		+6	
				Troughs	Peaks	Overall
		1974-1990	Average	+1	+3.33	+2.17
		1991-2010	Average	-3.0	+4.89	+0.94

Table 8.9 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points				**Lead (-)/Lag (+) in months of UK over Japan**		
United Kingdom		**Japan**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
		2/74				
5/75						
	7/76		12/76		-5	
4/77		7/77		-3		
	6/79		2/79		+4	
5/80		11/80		-6		
			7/81			
		5/83				
	10/83					
8/84						
	5/85		1/85		+4	
12/85		7/86		-7		
	1/88		2/88		-1	
		5/89				
			3/90			
4/91						
		12/93				
	7/94		12/94		-5	
8/95		1/96		-5		
	7/97		3/97		+4	
		4/98				
2/99						
	1/00		8/00		-7	
		12/01				
2/03						
	3/04		1/04		+2	
		11/04				
			4/05			
5/05		10/05		-5		
			4/06			
		9/06				
	9/07		8/07		+1	
2/09		3/09		-1		
	6/10		2/10		+4	
				Troughs	Peaks	Overall
		1974-1990	Average	-5.33	+0.5	-2.42
		1991-2010	Average	-3.66	-0.166	-1.92

Table 8.10 Leads/Lags of country growth rate cycles vis-a`-vis each other

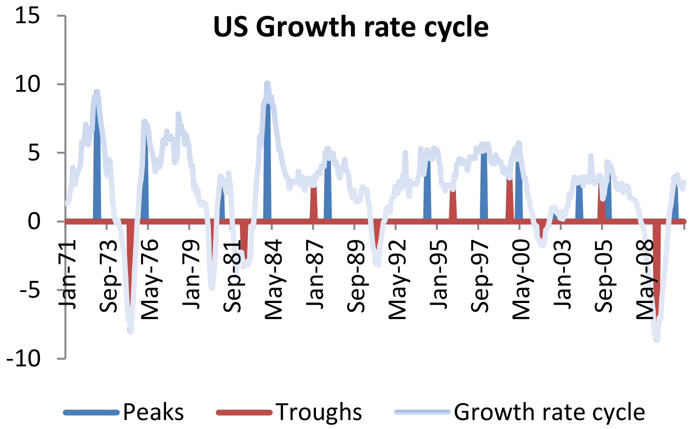
Growth rate cycle turning points				Lead (-)/Lag (+) in months of North America over EZ		
North America		Euro area (EZ)				
Troughs	Peaks	Troughs	Peaks	Troughs	Peaks	
3/75		5/75		-2		
	4/76		9/76		-5	
10/76		9/77		-11		
	4/78					
			6/79			
6/80		12/80		-6		
	7/81					
			4/82			
10/82		9/82		+1		
	1/84					
6/86			7/86		-1	
		3/87				
	12/87		8/88		-8	
		5/89				
3/91			1/90			
		1/93				
	10/94		12/94		-2	
7/95		3/96		-8		
	10/97		1/98		-3	
9/99		12/98		+9		
	4/00		11/99		+5	
9/01		11/01		-2		
			10/02			
		3/03				
			4/04			
		3/05				
	1/06		11/06		-10	
3/09		2/09		+1		
	7/10		7/10		0	
				Troughs	Peaks	Overall
		1974-1990	Average	-4.5	-4.7	-4.6
		1991-2010	Average	0	-2	-1.0

Table 8.11 Leads/Lags of country growth rate cycles vis-a`-vis each other

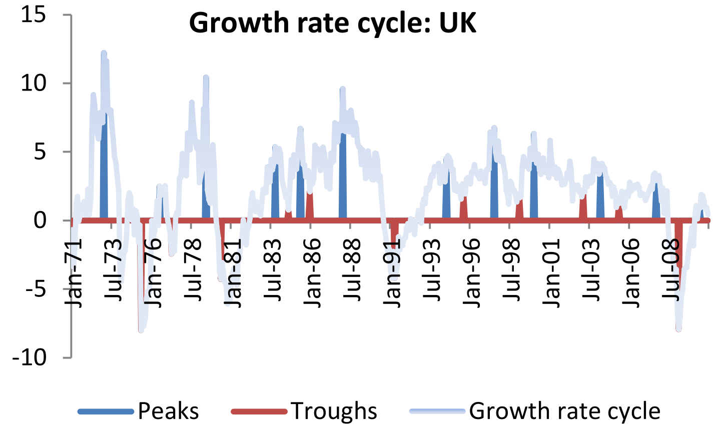
Growth rate cycle turning points				Lead (-)/Lag (+) in months of NAM over Asia Pacific		
North America (NAM)		**Asia Pacific**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
			6/74			
3/75		1/75		+2		
	4/76		1/77		-8	
10/76		7/77		-9		
	4/78		2/79		-10	
6/80		8/80		-2		
	7/81		7/81		0	
10/82		2/83		-4		
	1/84		8/84		-7	
6/86		3/86		+3		
	12/87		2/88		-2	
		5/89				
			4/90			
3/91						
		7/93				
	10/94		7/94		+3	
7/95		8/96		-13		
	10/97		3/97		+7	
		4/98				
9/99						
	4/00		7/00		-3	
9/01		9/01		0		
	1/06					
			4/07			
3/09		2/09		+1		
	7/10		7/10		0	
				Troughs	Peaks	Overall
		1974-1990	Average	-2	-5.4	-3.7
		1991-2010	Average	-4	+1.75	-2.25

Table 8.12 Leads/Lags of country growth rate cycles vis-a`-vis each other

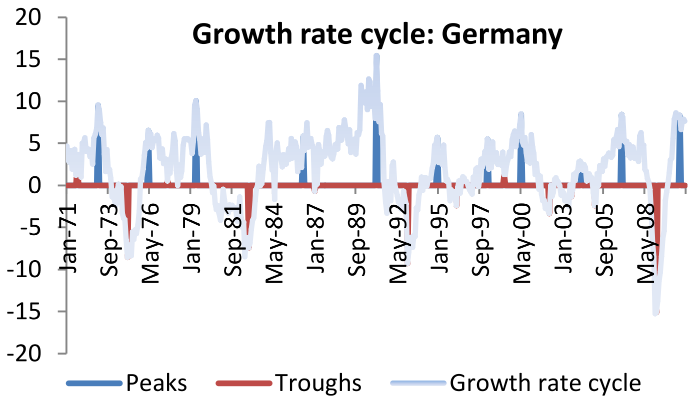
Growth rate cycle turning points				Lead (-)/Lag (+) in months of EZ over Asia Pacific		
Euro zone (EZ)		**Asia Pacific**				
Troughs	**Peaks**	**Troughs**	**Peaks**	**Troughs**	**Peaks**	
			6/74			
5/75		1/75		+4		
	9/76		1/77		-4	
9/77		7/77		+2		
	6/79		2/79		+4	
12/80		8/80		+4		
	4/82		7/81		+9	
9/82		2/83		-5		
			8/84			
		3/86				
	7/86					
3/87						
	8/88		2/88		+6	
5/89		5/89		0		
	1/90		4/90		-3	
1/93		7/93		-6		
	12/94		7/94		+5	
3/96		8/96		-5		
			3/97			
	1/98					
12/98		4/98		+8		
	11/99		7/00		-8	
11/01		9/01		+2		
	10/02					
3/03						
	4/04					
3/05						
	11/06		4/07		-5	
2/09		2/09		0		
	7/10		7/10		0	
				Troughs	Peaks	Overall
		1974-1990	Average	+1	+1.4	+1.2
		1991-2010	Average	-0.2	-0.5	-0.35



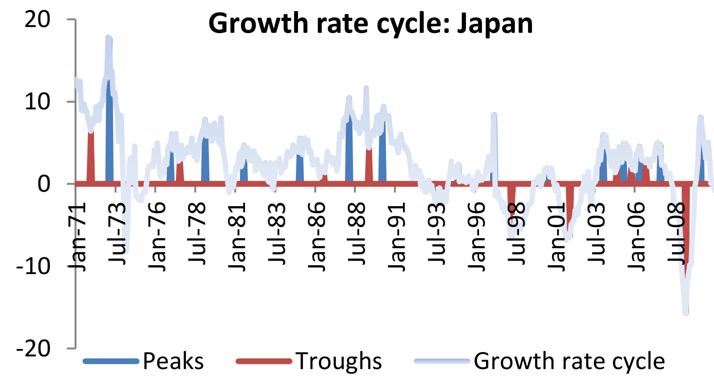
Graph 1A



Graph 1B



Graph 1C



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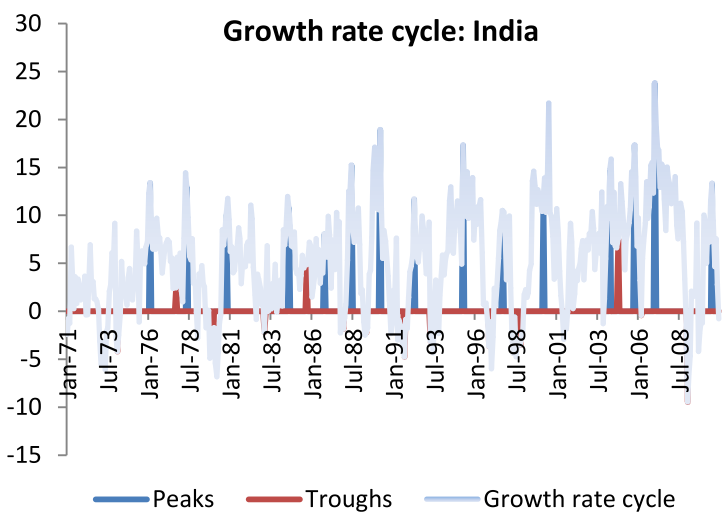
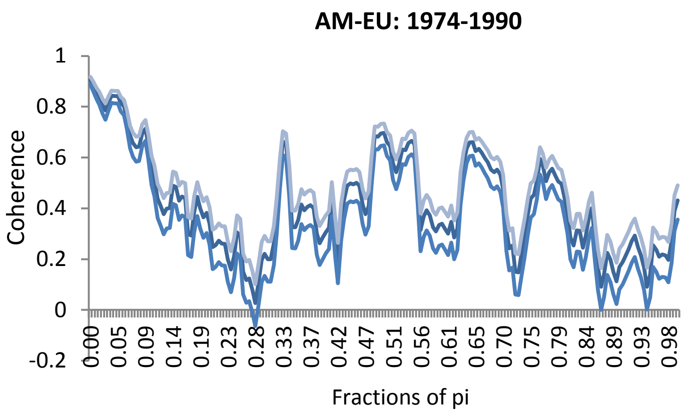
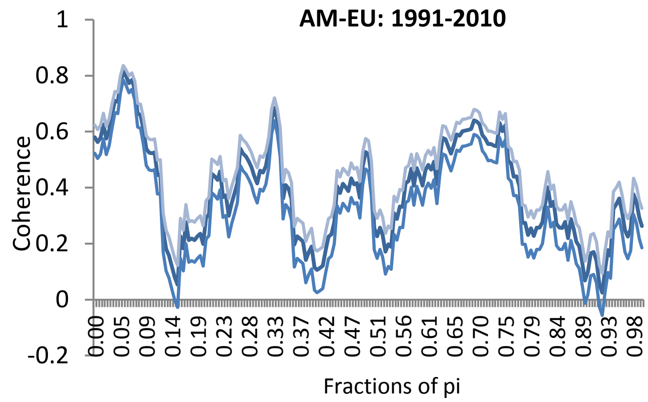
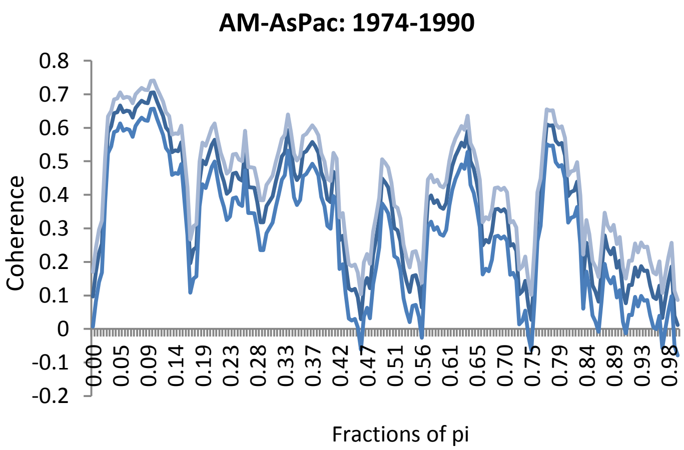


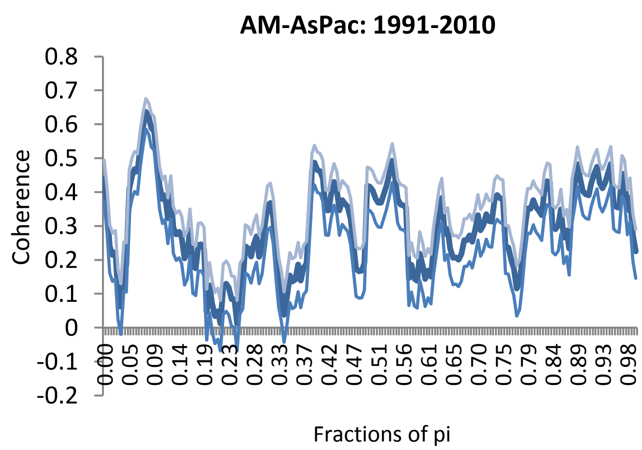
Graph 1E

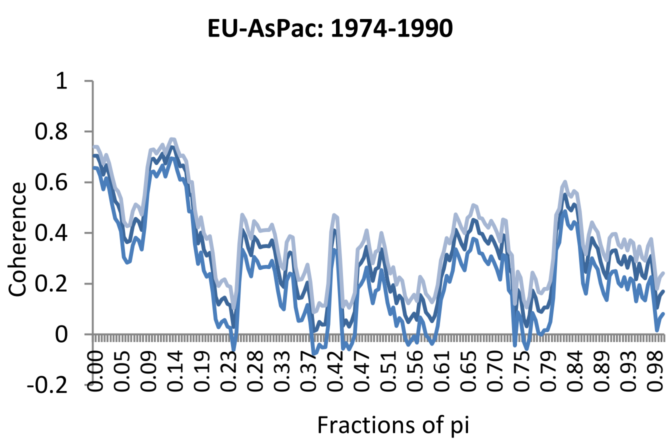
Cross-Spectral Estimates: Coherences and 95% Confidence Bands

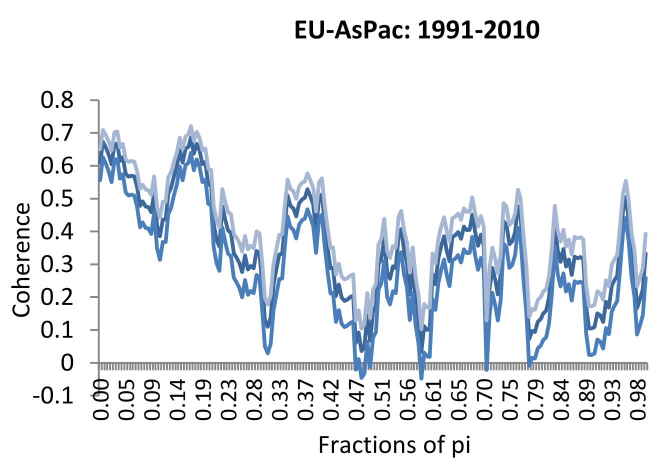


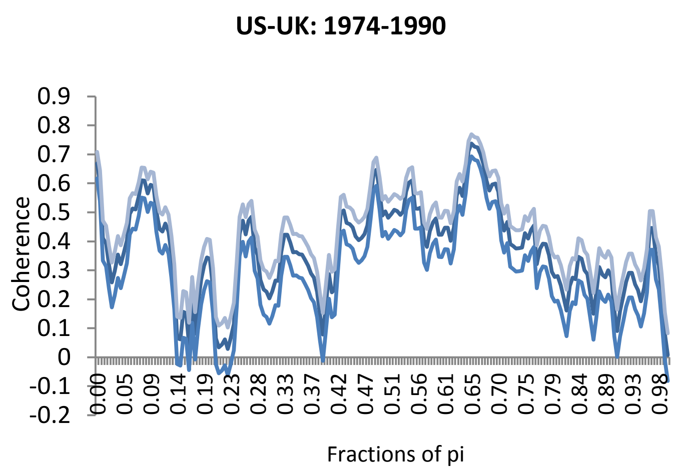


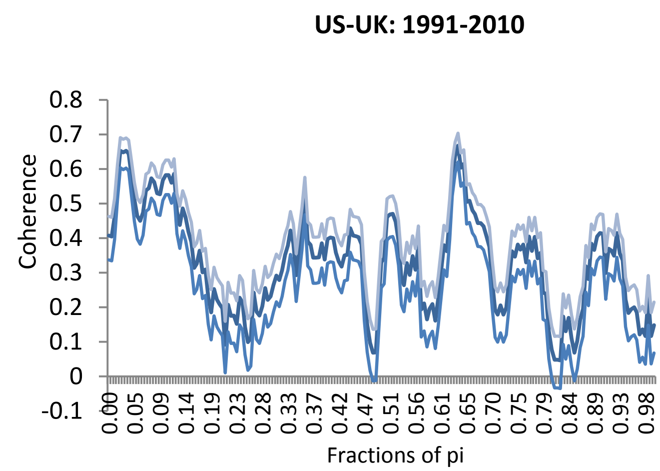


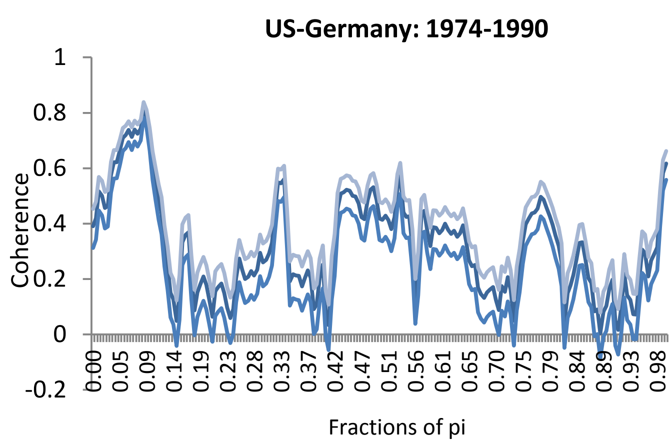


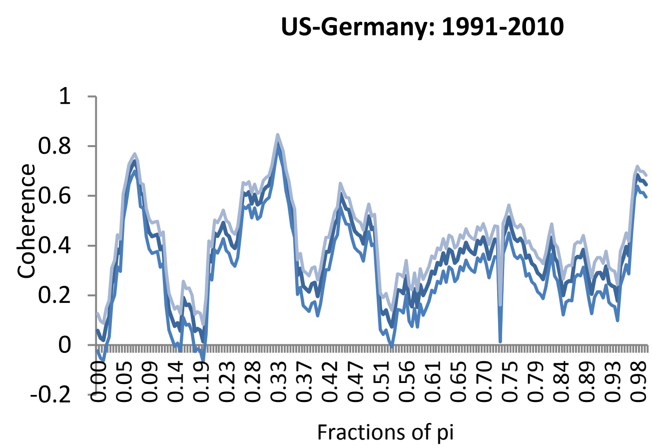


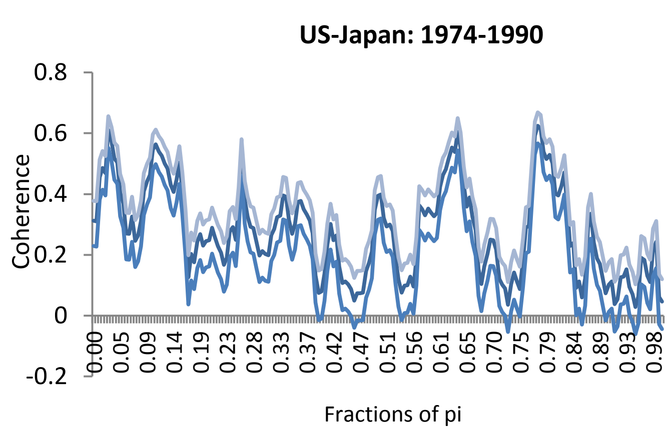


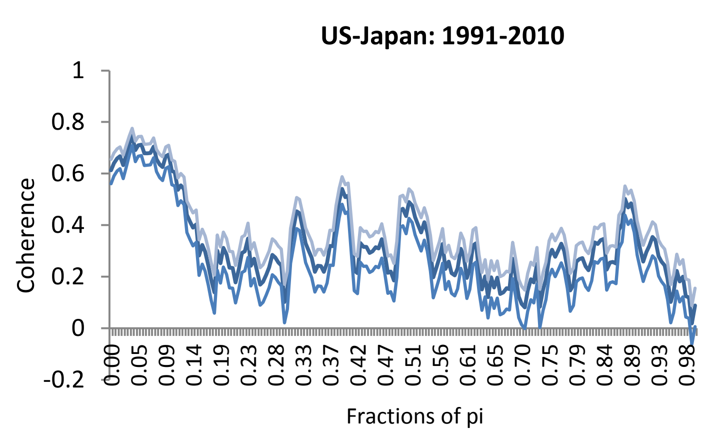

US-UK: 1974-1990
Coherence
Fractions of pi


US-UK: 1991-2010
Coherence
Fractions of pi

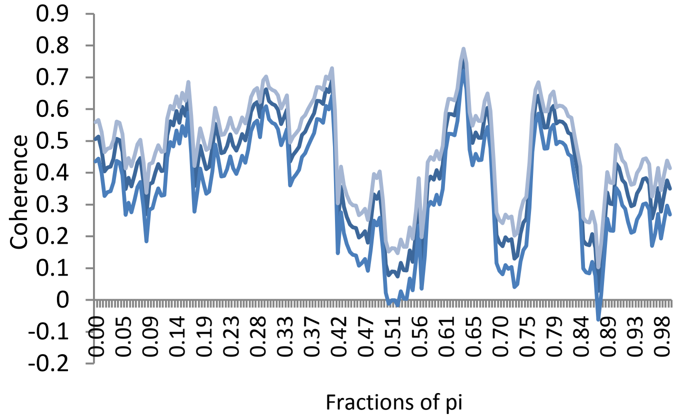

US-Germany: 1974-1990
Coherence
Fractions of pi


US-Germany: 1991-2010
Coherence
Fractions of pi

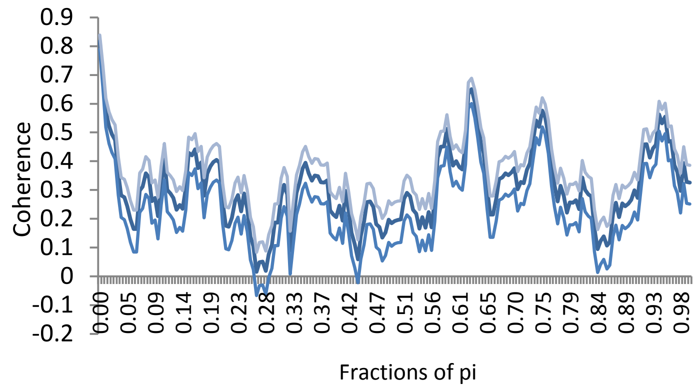

US-Japan: 1974-1990
Coherence
Fractions of pi


US-Japan: 1991-2010
Coherence
Fractions of pi

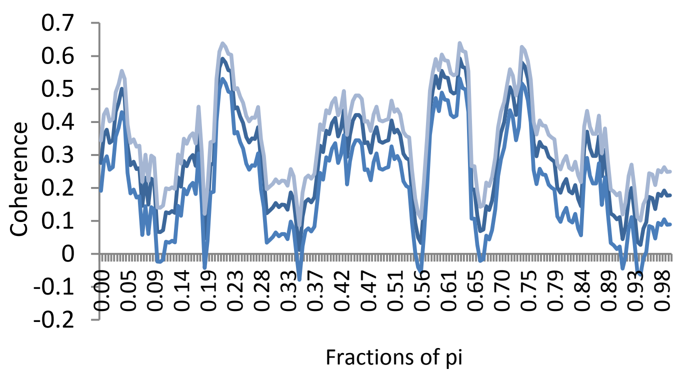
US-India: 1974-1990



US-India:1991-2010



Japan-India: 1974-1990



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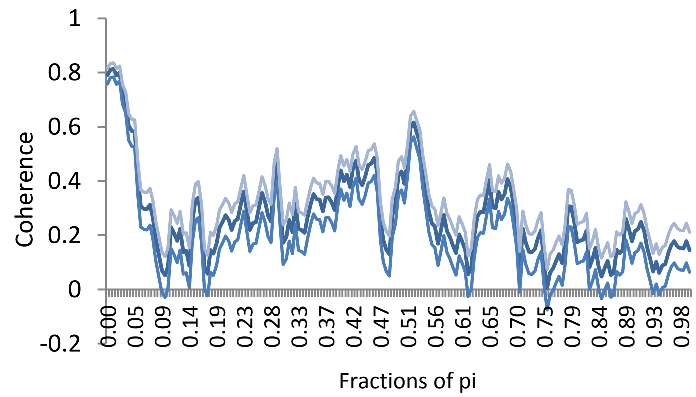
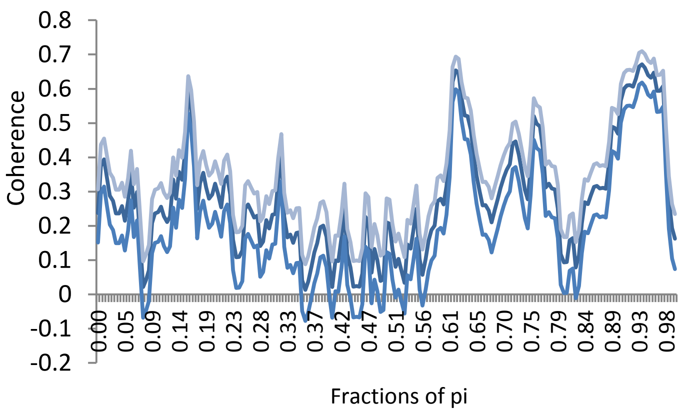


UK-India: 1974-1990



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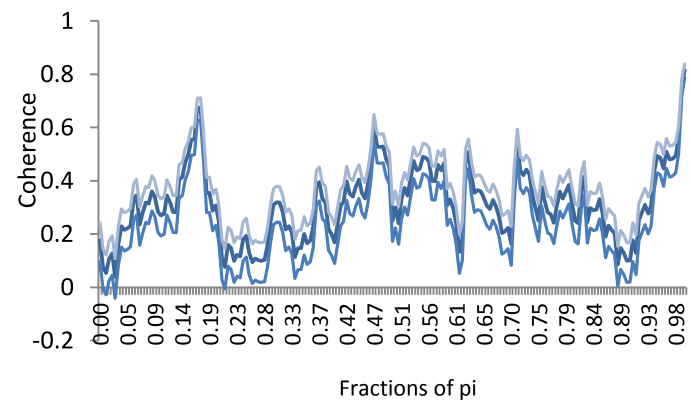
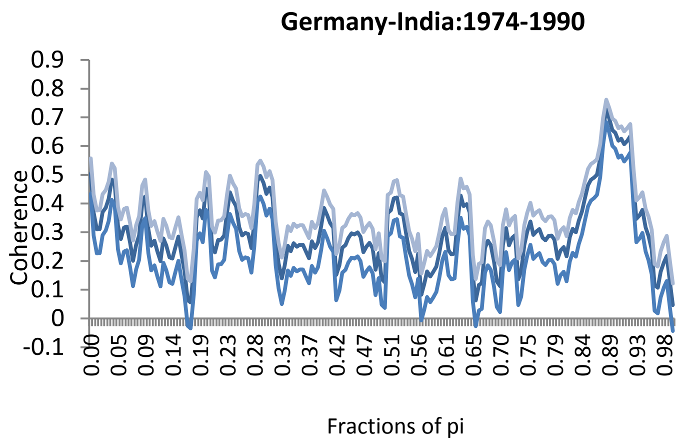
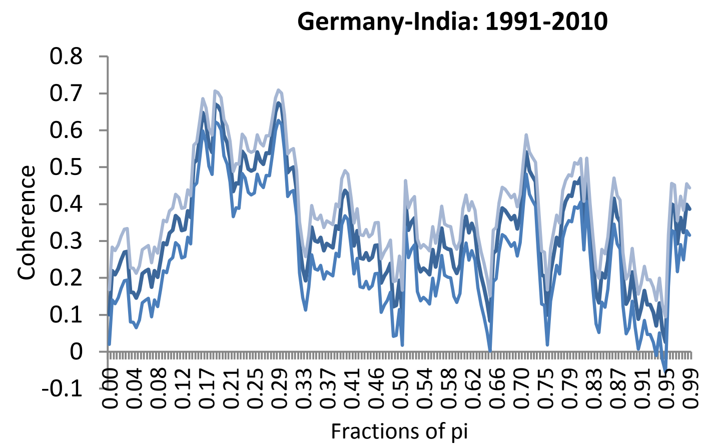
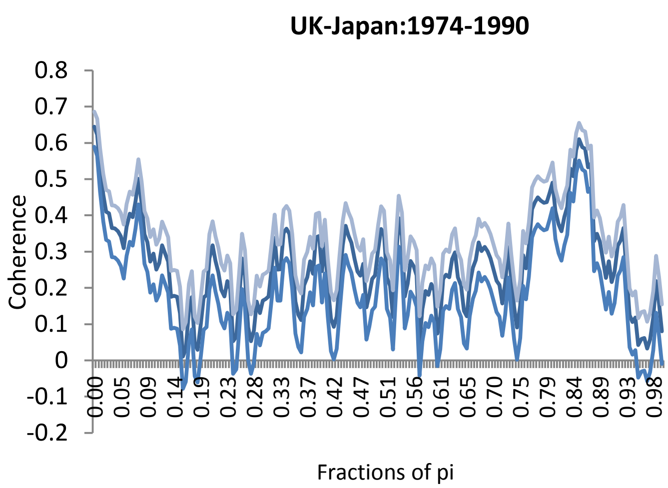
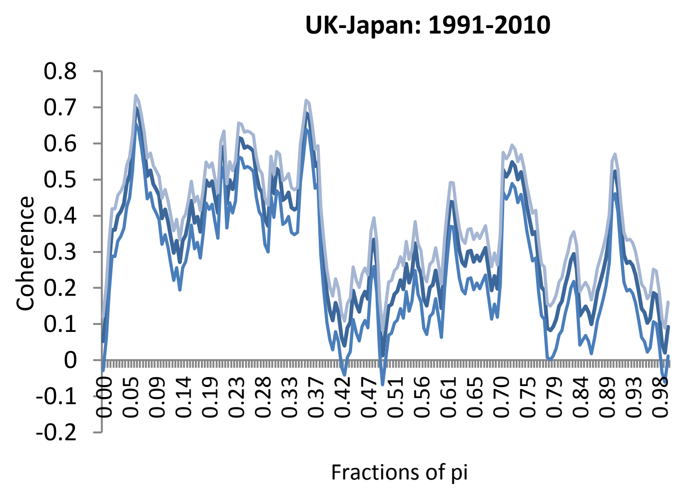
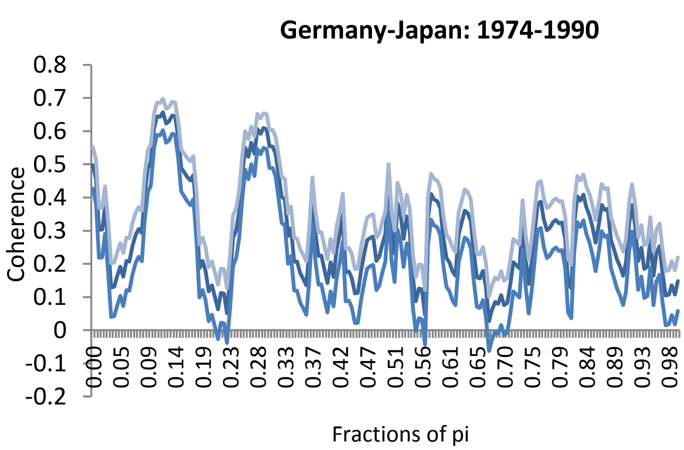


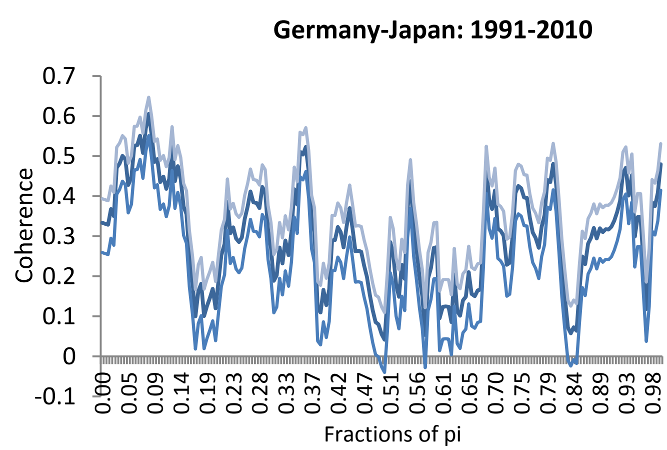

Germany-India:1974-1990
Coherence
Fractions of pi

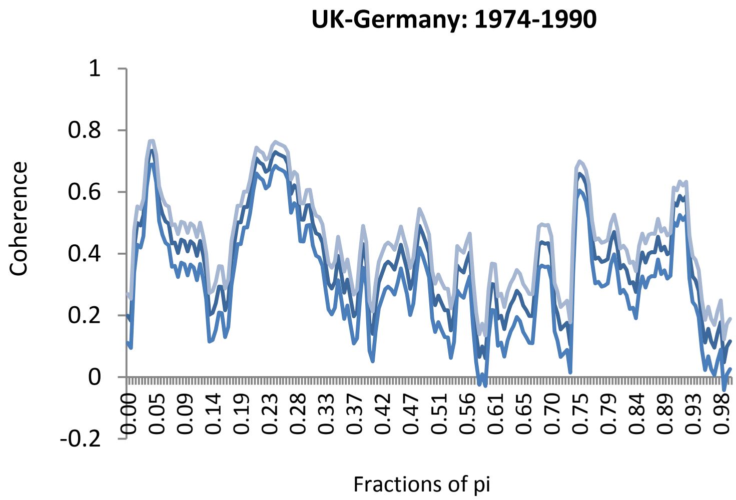

Germany-India: 1991-2010
Coherence
Fractions of pi

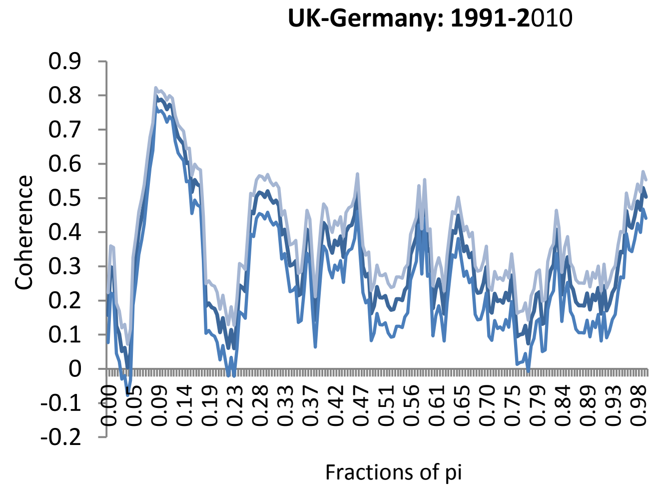

UK-Japan:1974-1990
Coherence
Fractions of pi


UK-Japan: 1991-2010
Coherence
Fractions of pi


Germany-Japan: 1974-1990
Coherence
Fractions of pi


Germany-Japan: 1991-2010
Coherence
Fractions of pi


UK-Germany: 1974-1990
Coherence
1
0.8
0.6
0.4
0.2
0
-0.2
0.00
0.05
0.09
0.14
0.19
0.23
0.28
0.33
0.37
0.42
0.47
0.51
0.56
0.61
0.65
0.70
0.75
0.79
0.84
0.89
0.93
0.98
Fractions of pi


UK-Germany: 1991-2010
Coherence
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0.00
0.05
0.09
0.14
0.19
0.23
0.28
0.33
0.37
0.42
0.47
0.51
0.56
0.61
0.65
0.70
0.75
0.79
0.84
0.89
0.93
0.98
Fractions of pi