Spectral Analysis of International Synchronization of Cycles

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Abstract

This paper analyzes the pattern of co-movement of growth rate cycles across countries and their lead-lag structure (phase shifts) using spectral methods. Using Economic Cycle Research Institute's growth rate of the coincident index of economic activity[2] for five countries and three regional groups for the period 1974 to 2010, we estimate partial coherences and report confidence intervals based on Gaussian approximations to the distribution of the sample coherence.

We find that average partial coherences are higher during the sub-period 1991-2010 over that in 1974-1990, and for most paired comparisons, have risen in the growth rate cycle frequency. Additionally, for some pairs, coherences rise for low frequency while for others, they increase in the higher frequency band. Average phase shifts indicate that the synchronization is faster in the latter period. We evaluate these against the reference chronology given by ECRI and find that the results conform directionally across the two methodologies.

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.

Since the intensification of the current phase of globalization in the early 1990s and the recent financial meltdown in the US economy spreading to other economies, there has been renewed interest in the international character of the business cycle. 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.

The question of international synchronization of cycles has been addressed with a variety of techniques. 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 transmission 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.
Inferences based on studies on international synchronization of cycles far elude consensus in cycle literature. While a majority concedes 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.

We study the 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 these vis-à-vis each other. Spectral techniques in the frequency domain study time series in terms of repetitive cycles. Since most cyclical phenomena 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. These techniques are powerful instruments to study correlation, and a lead-lag sequencing of the correlation between two series, converted from the time domain to the frequency domain.

Since the business cycle is a consensus of cycles in many activities it makes it imperative to look beyond the use of a single series like the GDP or the IIP to characterize business cycles. In this context, the Economic Indicator Analysis (specifically the coincident composite index of economic activity) merits attention.

While classical business cycles are less frequent in occurrence, growth cycles, measured in terms of deviations from trend, require a 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 Euro zone, North America, Asia Pacific, and pick 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.

Using the spectra and co-spectra of series we estimate coherences, which are the frequency domain counterparts of dynamic (time varying) correlations in the time domain. Frequency-wise coherences for bilateral country pairs are obtained for country group and country pairs. However, when we estimate relationships between two variables, each of which is associated with other variables, then the correlations or coherences may not reflect the 'pure' effect of one series on the other. It may be feedbacks of different variables playing on each other. To remove the 'gross' effect of other variables, we estimate partial cross spectra and partial coherences. These are obtained by estimating coherences between VAR residuals of series.
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). The sample distribution of the coherence follows a complex Wishart distribution.

Phase shifts, derived from the cross-spectra are used to infer the inherent leads or lags in the synchronization sequence between country/country group pairs over the two periods 1974-1990 and 1991-2010. Average phase shifts over growth rate cycle frequency indicate that it takes less time for the cycles to get transmitted 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 characterize the international synchronization of business cycles. 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

World economic history is replete with episodes where economic circumstances in one country have moved systematically in tandem with those in others, providing empirical support to the international character of business cycle fluctuations. 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 is a function of the organizational and institutional mechanisms that get together to define the economy.

International business cycles transmission and common movements in the cyclical components of country aggregate variables have received much attention in the time domain through the use of cointegration and vector autoregressions. Backus Kehoe and Kydland (1990), 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) infer the degree of synchronization by constructing a dynamic Pearson correlation coefficient between cyclical components of GDP of countries for 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 both countries in the comparison were in the same cycle phase (contraction or expansion) to infer synchronization. Artis et al. (1997) and Bodman and Crosby (2000) find evidence of synchronization of business cycles across the G7 countries. Diebold and Yilmaz (2009) spillover index uses VAR and VECMs. Allegret and Essaadi (2010) define a measure based on the time-varying coherence function, which detects endogenously structural changes in the co-movement process between outputs.

Engle and Kozicki (1993) proposed common serial correlation feature to detect 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. The two-step procedure consists of first estimating the unknown threshold in a VAR or a VECM (Tsay, 1998). Candelon and Hecq (2000) use simultaneously common trends and common cycles (proposed by Engle and Kozicki (1993) and Engle and Vahid (1993)), 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 expansion and the recession 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).
Newer 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. 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 non-parametric 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.

Economic Indicator Analysis

An alternative way of measuring economic activity and thus capturing international transmission in a broader sense is the Economic Indicator Analysis. 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[3] 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.

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

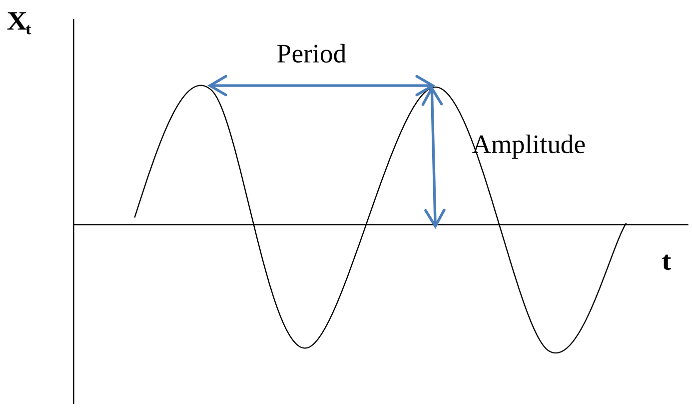
Amongst the plethora of tests for examining the stationarity status of a time series, like the augmented Dickey-Fuller (ADF), Phillips-Perron (1988) DF-GLS, KPSS (1992) etc., in this paper, we focus on the DF-GLS and the KPSS test proposed by Kwiatkowski et al. (1992).

[3] See Klein (2002) and Bry and Boschan (1971) for details.

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[4]. 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 $f = \omega/2\pi$

By the Spectral Representation Theorem, arbitrary functions can be represented as sums of sines and cosines terms. If a periodic function *f(x)* 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 (Janecek and Swift, 1993)

$$S(x) = \frac{1}{2}a_0 + \sum_{j=1}^{\infty} a_j \cos\left(\frac{j\pi x}{R}\right) + \sum_{j=1}^{\infty} b_j \sin\left(\frac{j\pi x}{R}\right)$$ is periodic with period (-R, R)[5].

If we define the function on (-π, π), then we have

$$S(x) = \frac{1}{2}a_0 + \sum_{j=1}^{\infty} a_j \cos(jx) + \sum_{j=1}^{\infty} b_j \sin(jx),$$

[4] This paper uses non-evolutionary spectral theory, which requires the series to be stationary.

[5] $a_j = \frac{1}{R}\int_{-R}^{R} f(x)\cos\frac{j\pi x}{R}dx$ $\quad b_j = \frac{1}{R}\int_{-R}^{R} f(x)\sin\left(\frac{j\pi x}{R}\right)dx$ $\quad a_0 = \frac{1}{R}\int_{-R}^{R} f(x)dx$

For a real valued weakly stationary discrete stochastic process $\{X_t; t = ..., -2, -1, 0, 1, 2, ...\}$ with zero mean and covariance function $R(s) = E[X_t X_{t-s}] = R(-s)$ the spectral density function 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[6]. Smoothing procedures are required by using windows.

A consistent estimator of the spectrum 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. The spectral window corresponding to the covariance lag window requires knowledge of a truncation parameter M. When the true spectral density is known, the determination of the truncation point M can be related to the notion of spectral bandwidth. For cases where no prior information about the true spectral bandwidth exists, Priestley (1981) proposes using the sample autocovariance function and a window closing procedure. The spectral bandwidth is inversely proportional to the rate of decay of the autocovariance function. 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

The notion of coherence is applied to multiple series in frequency domain. For a bivariate case, with a stationary series $X_t = (X_{1t}, X_{2t})^T$ with a zero mean and covariance matrix $\gamma(k)$,

The coherency spectrum can be given by

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

$\hat{h}_{ii}(\omega)$ and $\hat{h}_{jj}(\omega)$ are the auto-spectra, while $\hat{c}^2{}_{ij}(\omega)$, $\hat{q}^2{}_{ij}(\omega)$ are the co-spectrum and the quadrature spectrum respectively. The modulus of the coherence measures the strength of relationships between corresponding frequency components of the two series in almost the same way as a correlation coefficient. The plot of $\hat{w}_{ij}(\omega)$ against ω over $0 \le \omega \le \pi$ is the coherence plot. The lead or lag of this relationship is measured by the slope of the phase.

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 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

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

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[7] for the sample coherence, it is useful to apply a Fischer's z-transformation to $\left|\hat{w}_{ij}(\omega)\right|$ such that

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

$$\mu_z = \frac{1}{2}\ln\frac{1+w_{ij}}{1-w_{ij}} + \frac{p-1}{2(n-p+1)} \qquad \sigma_z^2 = \frac{1}{2(n-p+k)}$$

The z-transform can then be used to find confidence intervals for the sample coherence.

Phase

A measure of the phase difference between the frequency components of the two processes is $\psi(\omega) = \tan^{-1}\left(\frac{q(\omega}{c(\omega)}\right)$ and the plot of $\psi(\omega)$ against ω over $0 \leq \omega \leq \pi$ is the phase diagram.

Confidence Intervals for Phase Estimates

Goodman (1957) also provides a frequency function for the estimated phase angle. If Γ^2 is the true coherence, $\delta = 1-\Gamma^2$, then the frequency function is given by

$$p(\phi) = \frac{\delta^k}{2\pi} - \frac{K\delta^k S}{2\pi(1-S^2)^{k+\frac{1}{2}}}\left[\frac{\Gamma(1/2)\Gamma(k+1/2)}{\Gamma(k+1)} \pm B_S\, 2(\frac{1}{2}, k+\frac{1}{2})\right]$$

Where *k=n/m*, $S = -\Gamma\cos(\phi-\phi_0)$, $E\left|\hat{\phi}(\omega)\right| = \phi_0$ and $B_x(p.q)$ represents the incomplete beta function. Based on Goodman's work, Granger and Hatanaka (1964) provide confidence bands for phase angle in degrees.

Partial Coherences

It is interesting to look into whether a high correlation between X and Y is due to an intrinsic association between them or whether it is because they are each highly correlated with another variable(s). Partial correlation coefficient measures the correlation between X and Y after the influence of Z on each of these variables has been removed.

To define 'partial coherency' between X_t and $Y_{1,t}$, allowing for $Y_{2,t}$, we remove the influence of $Y_{2,t}$ on X_t and $Y_{1,t}$ by considering the processes

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

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[7] $C(w|n,p,w) = \frac{\widehat{\Gamma(n)}}{\Gamma(p-1)\Gamma(n-p+1)}(1-w)^n\hat{w}^{(p-2)}(1-\hat{w})^{n-p}F(n,n;p-1;w,\hat{w})$

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 (q-1) where q is the number of other variables removed in evaluating the partial coherence (see Hannan, 1970)

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

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

5. Results

We conducted two unit root tests on the smoothed growth rates of the coincident index given by ECRI for each country series for determining the stationarity status of the series. These were the DF-GLS test and the KPSS test. Inferred from these, we found the smoothed growth rates of the coincident index to be stationary, I(0). Results for individual unit root tests are shown in Tables 1A, and 1B. Table 2 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 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 3.1.

Between regional groups, North America (NAM) and Euro area (EZ) show the highest coherence in the low frequency band, of the order of 0.77. NAM-Aspac and EZ-Aspac 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 NAM-EZ. 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 co-movements, we divided the sample into two parts.

Since the beginning of 1990s has historical significance as far as events in the international economy is 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 3.2 and 3.3. We find that over the period 1974-1990, across various frequency bands, for all regional group 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) estimate cross-country correlations of output, consumption, investment, employment and Solow residuals using a calibrated real business cycle model. For the sub-sample 1970.1-1990.2 they 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 quite close to our estimates at low frequency during the period 1974-1990 as shown in Table 3.2.

However, from 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 NAM-EZ and NAM-Aspac, long cycles are more tied in this period too, EZ-Aspac 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.

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. E.g. for the partial coherence between India and the US, we removed the effect due to Germany, Japan and the UK by running the four variable VAR and taking the residuals obtained there from. Similarly residuals for the US were estimated.

Partial coherences and phase estimates for the full sample are reported in Tables 4.1. 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 NAM-EZ, US-UK and Germany-Japan), the average coherences over the three frequency bands spike at growth rate cycle frequency. The results are consistent with those obtained by other studies. Yetman (2011) uses a time varying dynamic correlation coefficient in the time domain and finds that business cycles strongly commove 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 periods are reported in Tables 4.2 and 4.3. As a cursory reading, we learn that except the pair NAM-EZ, 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 5 gives the direction of movement of average partial coherences from the period 1974-1990 to 1991-2010 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 significant increase in the average coherence in the lower frequency band and a simultaneous fall in the same over higher frequency. This fits together with the evidence that 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 role of the monetary policy

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.

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 6), 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 magnitude-wise there are some discrepancies.

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 North 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 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, it takes less time for transmission. 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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Unit root test results

Table 1A. 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
Eurozone	-4.18	-4.01	No
NAM	-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 1B. 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
Eurozone	0.087	0.101	No
NAM	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 2. Unit Root Tests: Summary
Smoothed Growth Rates of the Coincident Index

Test variable	**DFGLS**	**KPSS**	**Inference**
AsPac	I(0)	I(1)	No unit root
Eurozone	I(0)	I(0)	No unit root
NAM	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 3.1 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 (radians)**	**Coherence**	**Phase (radians)**	**Coherence**	**Phase radians**
NAM-EZ	**0.77**	0.05	0.63	-0.20	0.35	-0.09
NAM-AsPac	0.22	0.01	0.47	-0.02	0.30	-0.16
EZ-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 3.2 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 (radians)**	**Coherence**	**Phase (radians)**	**Coherence**	**Phase radians**
NAM-EZ	**0.778**	0.013	0.660	0.065	0.350	-0.153
NAM-AsPac	0.792	0.008	0.618	0.130	0.248	-0.282
EZ-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 3.3 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 (radians)**	**Coherence**	**Phase (radians)**	**Coherence**	**Phase radians**
NAM-EZ	**0.714**	0.023	0.590	-0.050	0.320	-0.129
NAM-AsPac	0.071	-0.370	0.440	-0.115	0.296	-0.088
EZ-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 4.1 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 (radians)**	**Coherence**	**Phase (radians)**	**Coherence**	**Phase radians**
NAM-EZ	**0.761**	0.061	0.539	-0.050	0.318	-0.048
NAM-AsPac	0.282	0.865	0.413	0.207	0.262	-0.040
EZ-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 4.2 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 (radians)**	**Coherence**	**Phase (radians)**	**Coherence**	**Phase radians**
NAM-EZ	**0.858**	-0.011	0.603	0.025	0.372	-0.059
NAM-AsPac	0.240	0.247	0.601	0.291	0.327	0.069
EZ-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 4.3 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 (radians)**	**Coherence**	**Phase (radians)**	**Coherence**	**Phase radians**
NAM-EZ	**0.584**	0.013	0.494	-0.020	0.364	-0.099
NAM-AsPac	0.294	-0.497	0.368	0.122	0.286	-0.042
EZ-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 5. Direction of Movement of Average Partial Coherences across the period 1974-1990 and 1991-2010.

	Low frequency	Growth cycle frequency	High frequency
NAM-EZ	↓	↓	↓
NAM-AsPac	↑	↓	↓
EZ-AsPac	↓	↓	↑
US-UK	↑	↑	↓
US-Germany	↓	↓	↑
US-Japan	↑	↑	↑
US-India	↑	↓	↓
Japan-India	↑	↑	↓
UK-India	↓	↑	↑
Germany-India	↓	↑	↑
UK-Japan	↓	↑	↑
Germany-Japan	↓	↑	↑

Table 6 Comparative Results: Spectral Phase shifts Vs EIA Reference Chronology

Country Pairs	Spectral Estimates		EIA Reference Chronology	
	1974-1990	**1991-2010**	**1974-1990**	**1991-2010**
NAM-EZ	-3.51	-2.70	-4.60	-1.00
NAM-AsPac	-7.02	-6.21	-3.70	-2.25
EZ-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 7.1 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 7.2 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 7.3 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 7.4 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 7.5 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 7.6 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 7.7 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 7.8 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 7.9 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 7.10 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

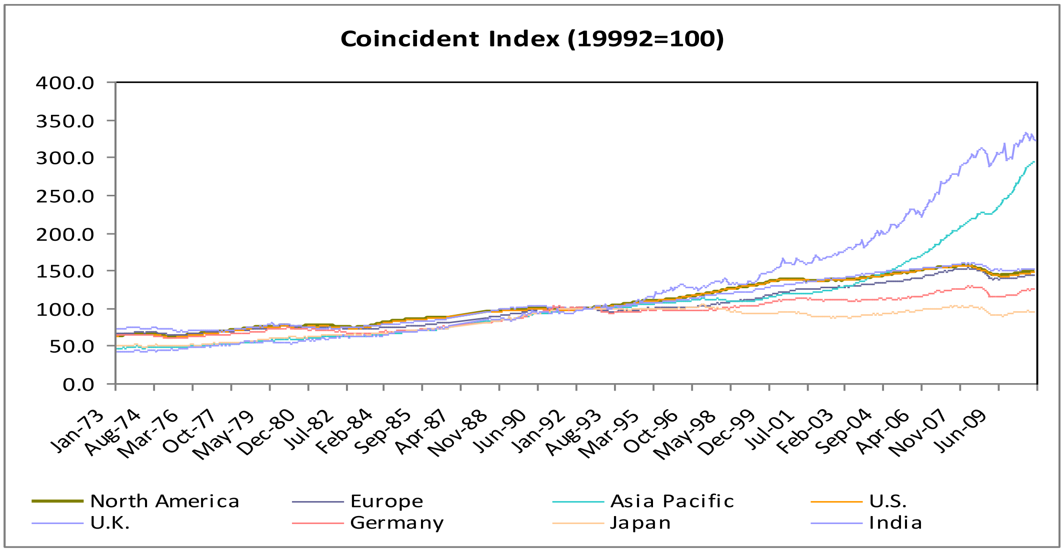
Table 7.11 Leads/Lags of country growth rate cycles vis-a`-vis each other

Growth rate cycle turning points: North America (NAM)		Asia Pacific		Lead (-)/Lag (+) in months of NAM over 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 7.12 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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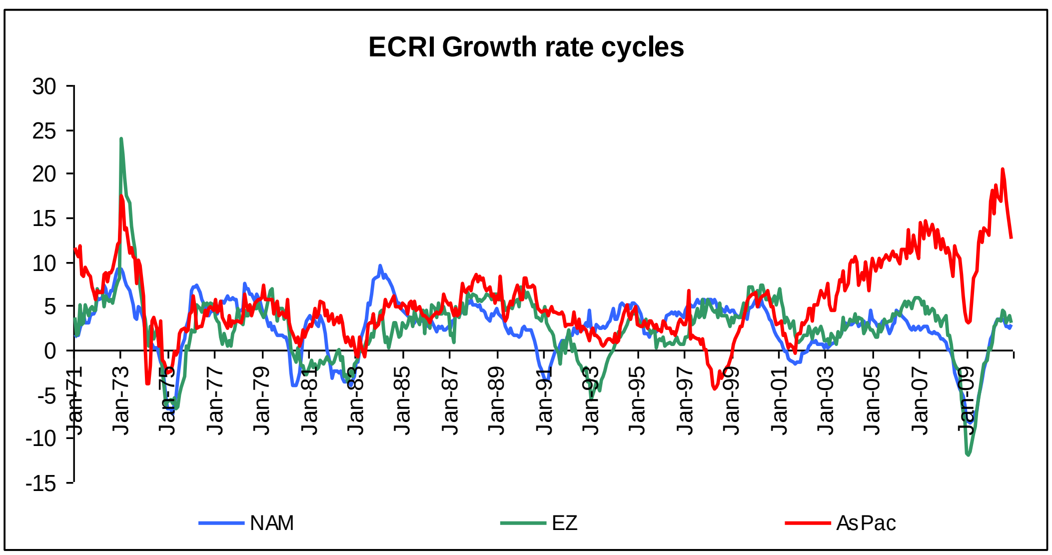
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan-73
Aug-74
Mar-76
Oct-77
May-79
Dec-80
Jul-82
Feb-84
Sep-85
Apr-87
Nov-88
Jun-90
Jan-92
Aug-93
Mar-95
Oct-96
May-98
Dec-99
Jul-01
Feb-03
Sep-04
Apr-06
Nov-07
Jun-09
North America
Europe
Asia Pacific
U.S.
U.K.
Germany
Japan
India


ECRI Growth rate cycles
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25
20
15
10
5
0
-5
-10
-15
Jan-71
Jan-73
Jan-75
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Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
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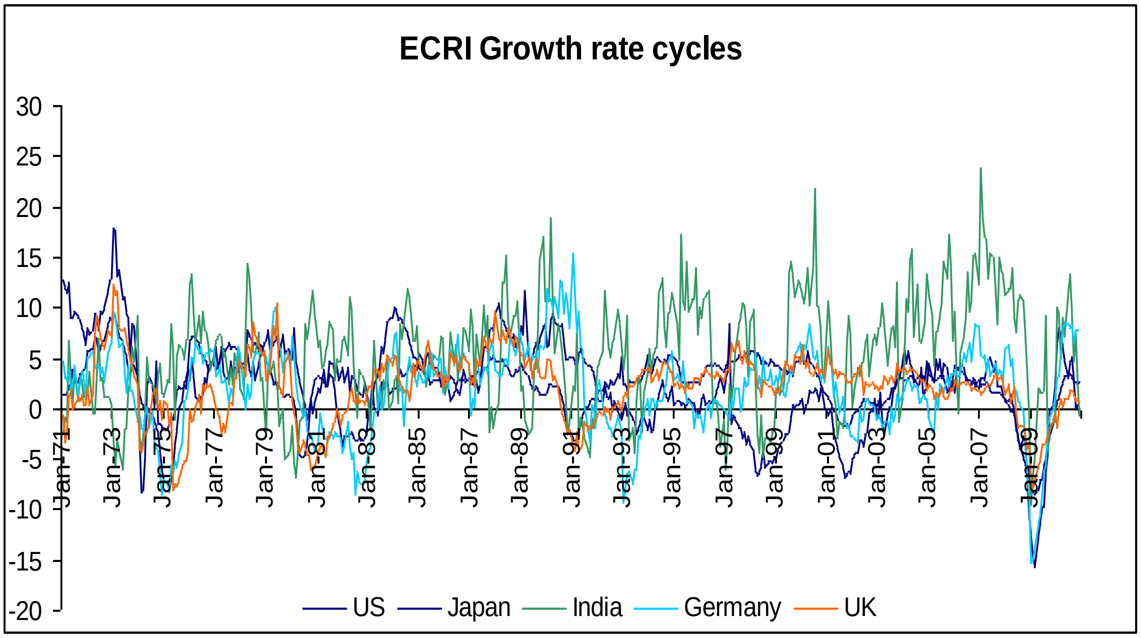
Jan-03
Jan-05
Jan-07
Jan-09
NAM
EZ
AsPac



ECRI Growth rate cycles
30
25
20
15
10
5
0
-5
-10
-15
-20
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
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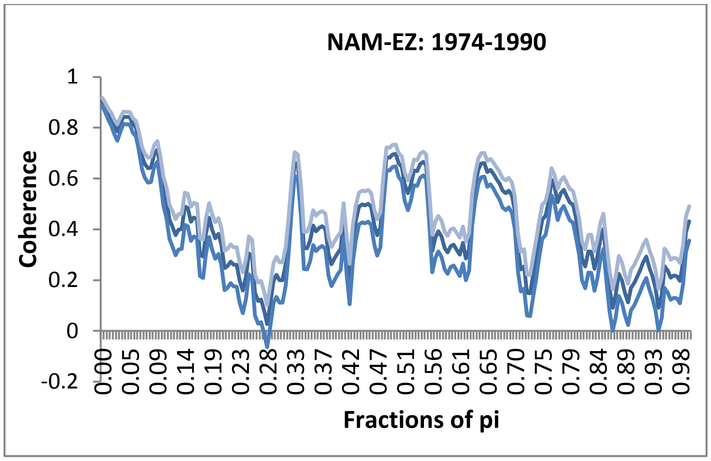
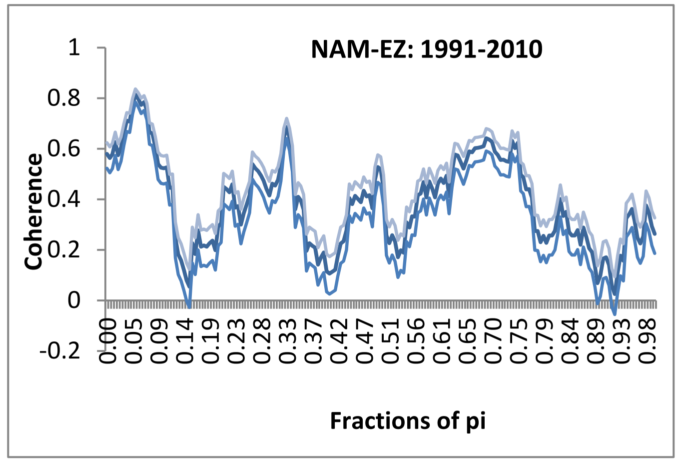
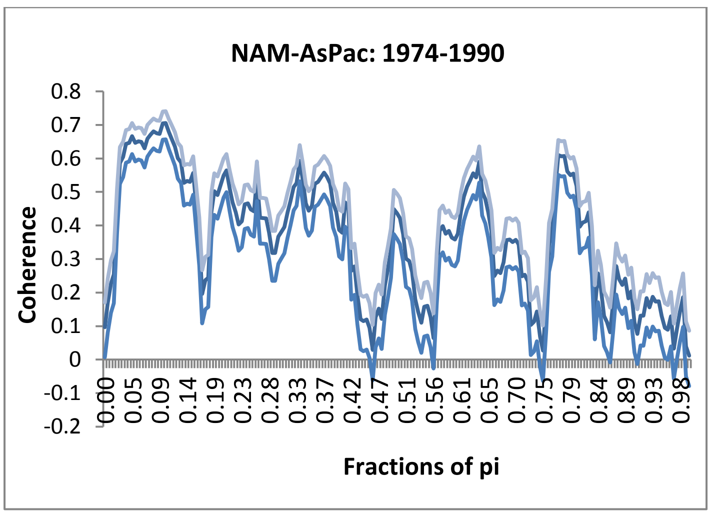
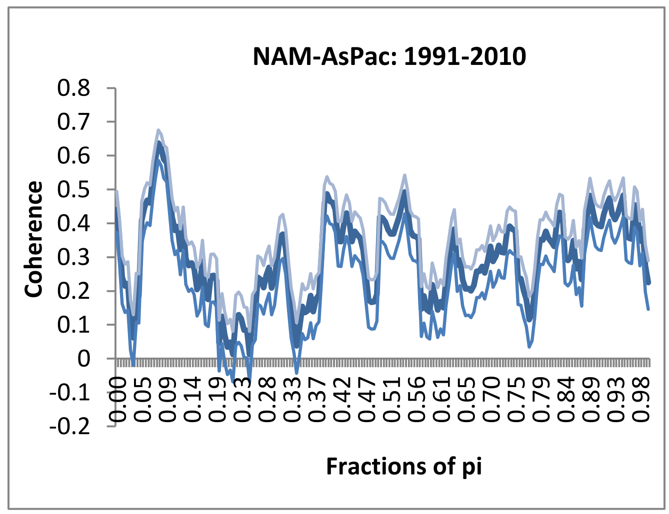
Jan-05
Jan-07
Jan-09
US
Japan
India
Germany
UK

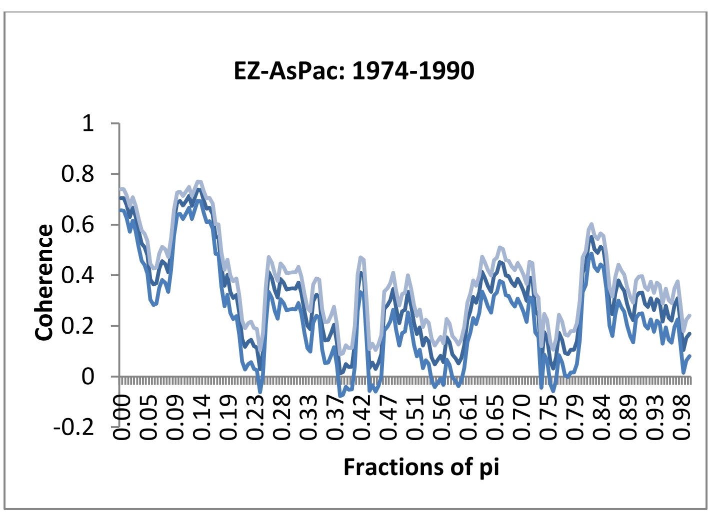
Cross-Spectral Estimates: Coherences and 95% Confidence Bands

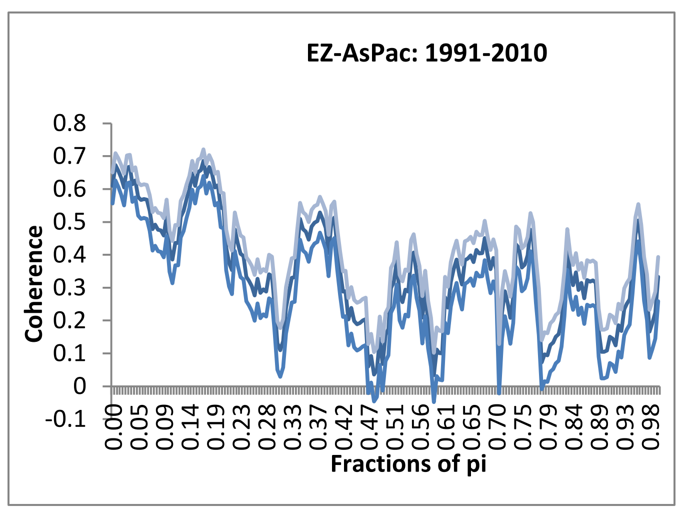


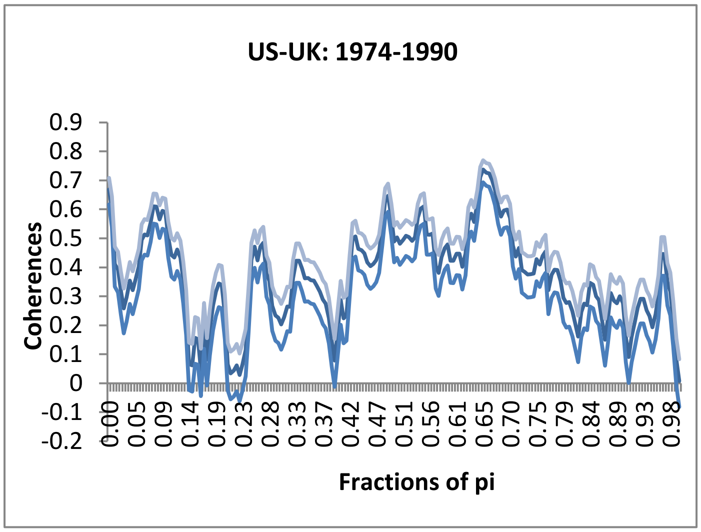








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Coherences
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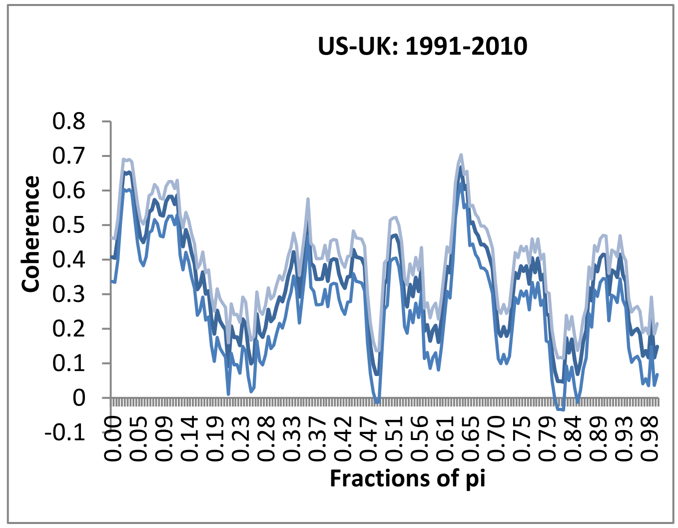
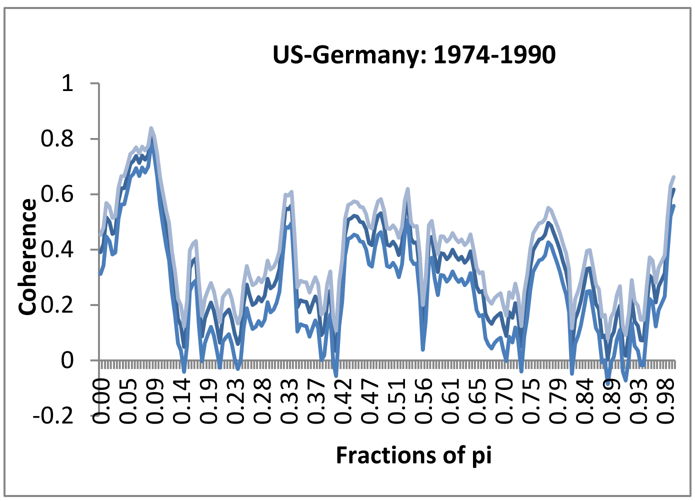
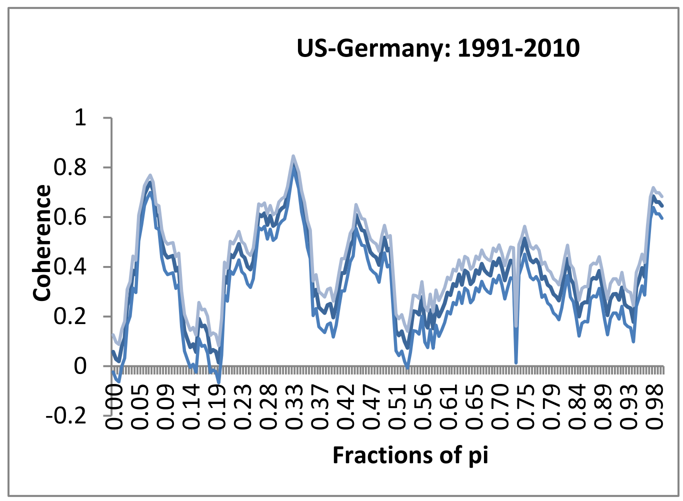
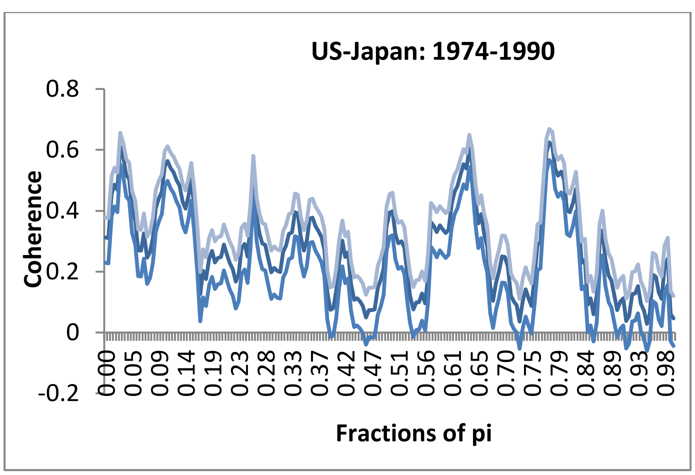
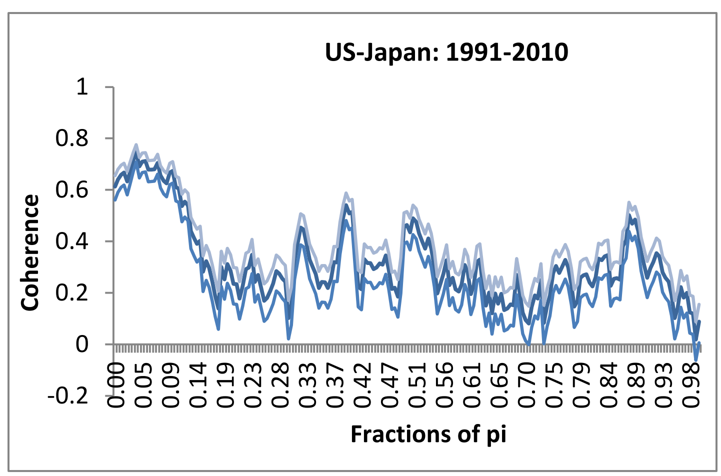
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0.00 0.05 0.09 0.14 0.19 0.23 0.28 0.33 0.37 0.42 0.47 0.51 0.56 0.61 0.65 0.70 0.75 0.79 0.84 0.89 0.93 0.98
Fractions of pi

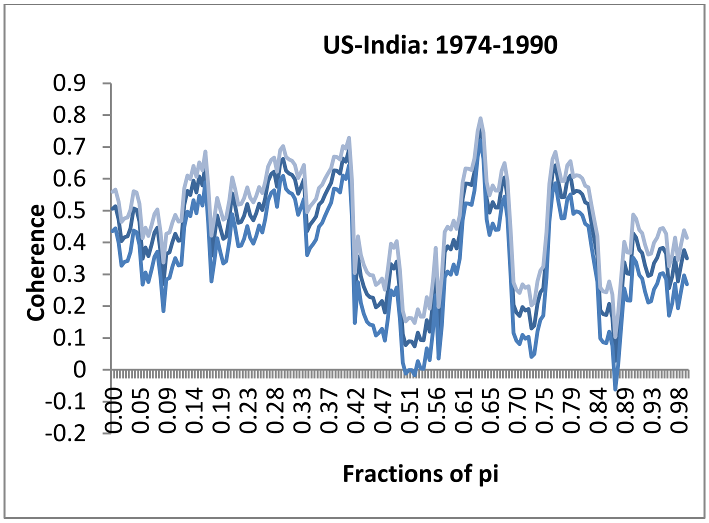

US-UK: 1991-2010
Coherence
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0.00 0.05 0.09 0.14 0.19 0.23 0.28 0.33 0.37 0.42 0.47 0.51 0.56 0.61 0.65 0.70 0.75 0.79 0.84 0.89 0.93 0.98
Fractions of pi


US-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


US-Germany: 1991-2010
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


US-Japan: 1974-1990
Coherence
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


US-Japan: 1991-2010
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


US-India: 1974-1990
Coherence
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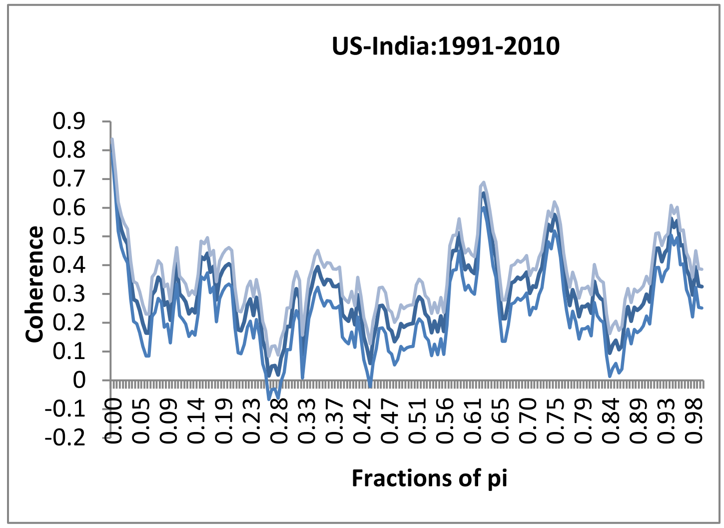
Fractions of pi


US-India:1991-2010
Coherence
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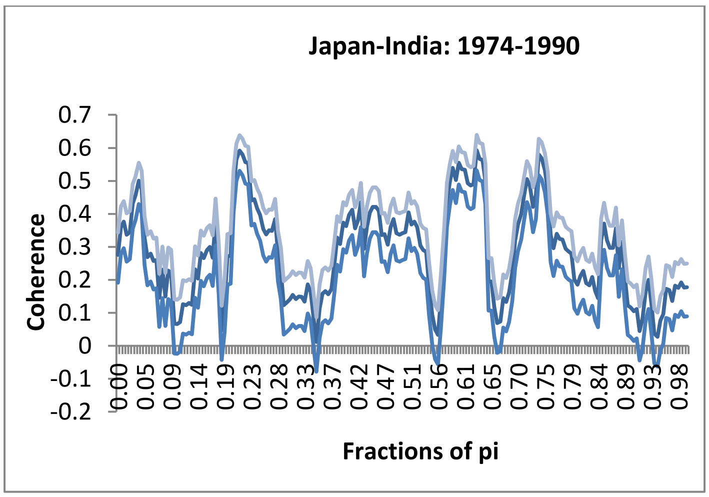
Fractions of pi


Japan-India: 1974-1990
Coherence
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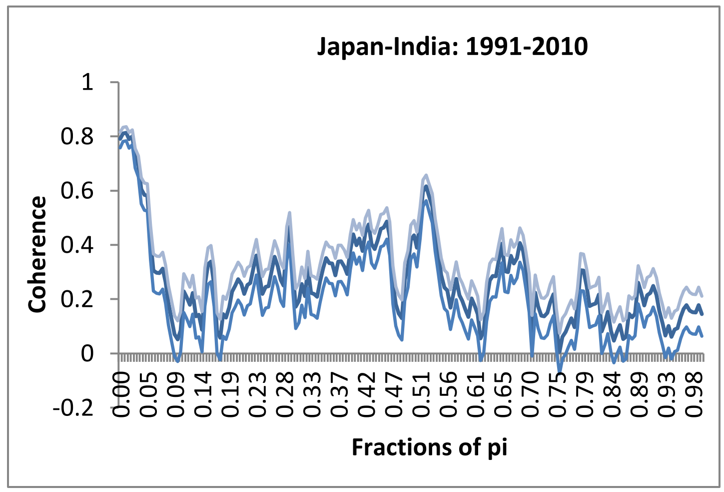
Fractions of pi


Japan-India: 1991-2010
Coherence
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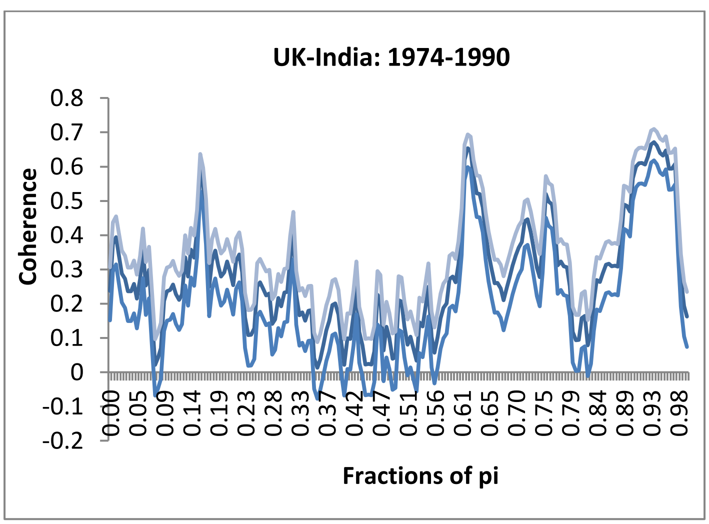
Fractions of pi


UK-India: 1974-1990
Coherence
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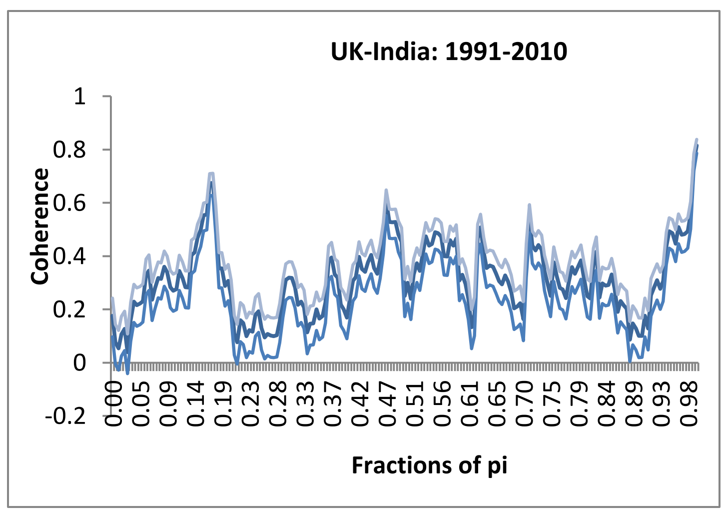
Fractions of pi


UK-India: 1991-2010
Coherence
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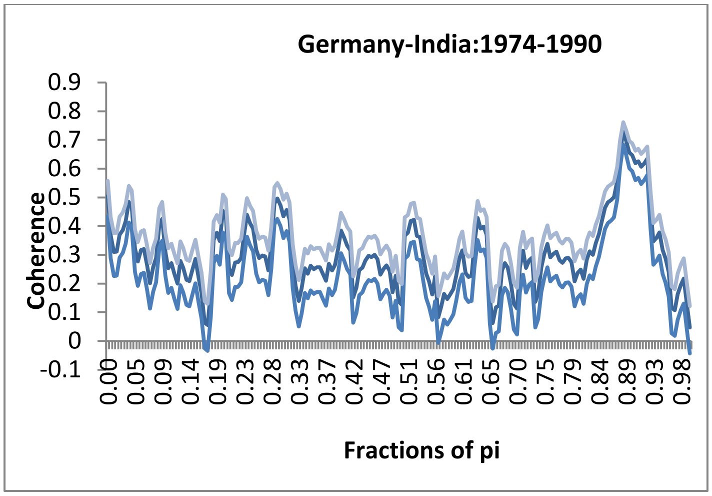
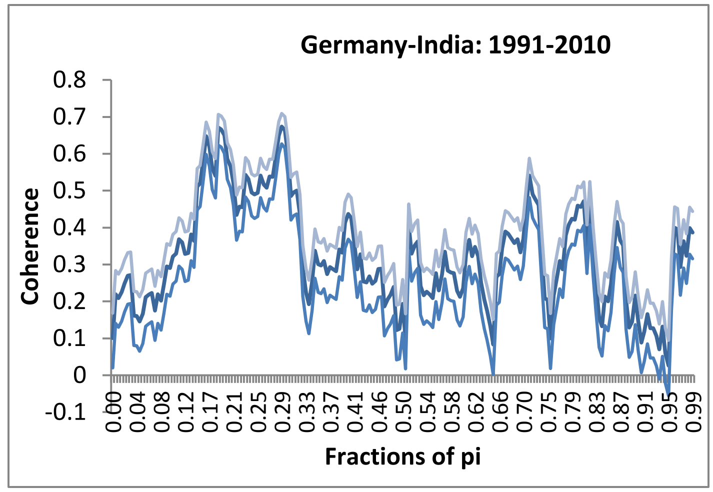
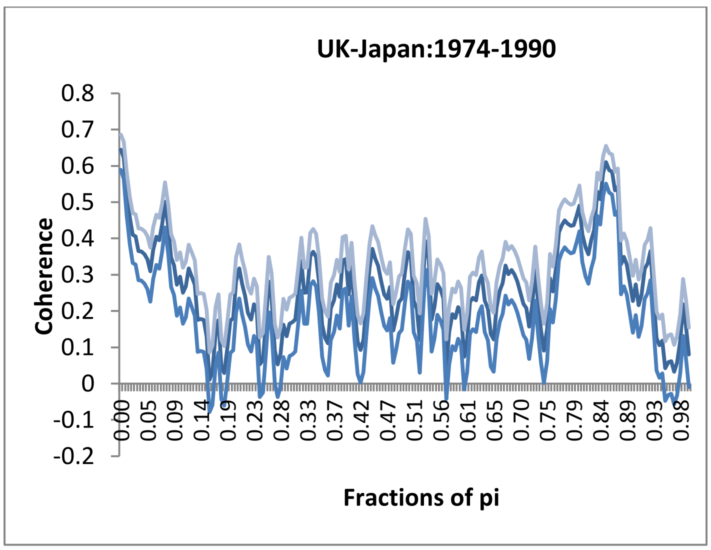
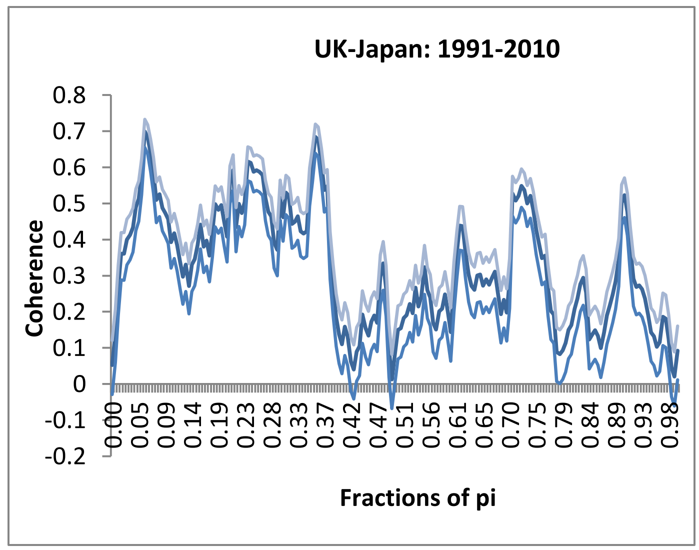
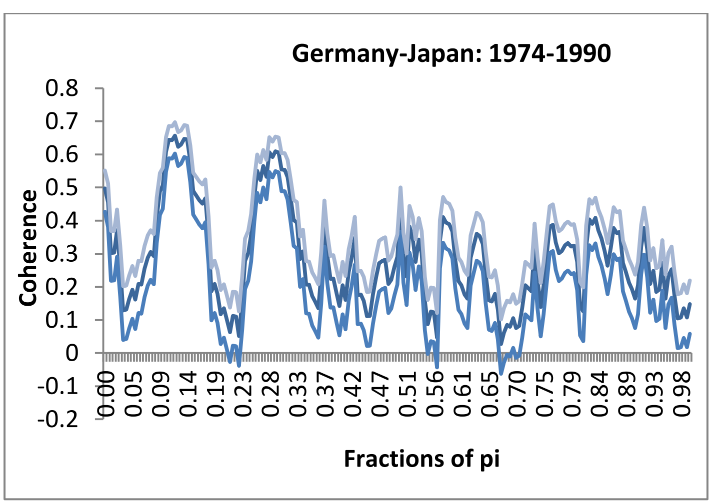
Fractions of pi

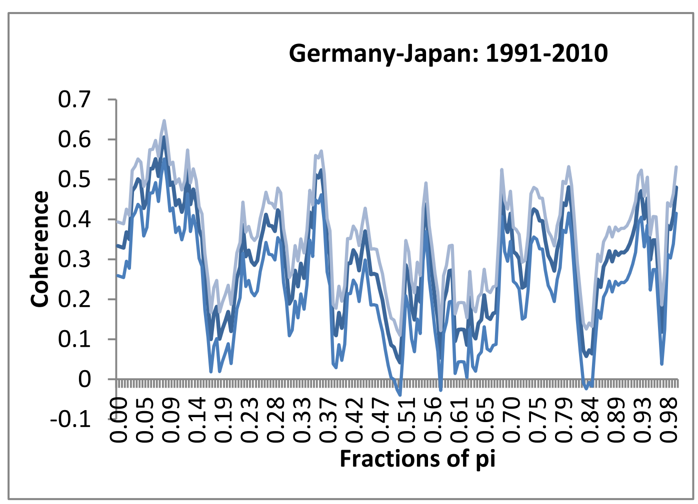

Germany-India:1974-1990
Coherence
Fractions of pi

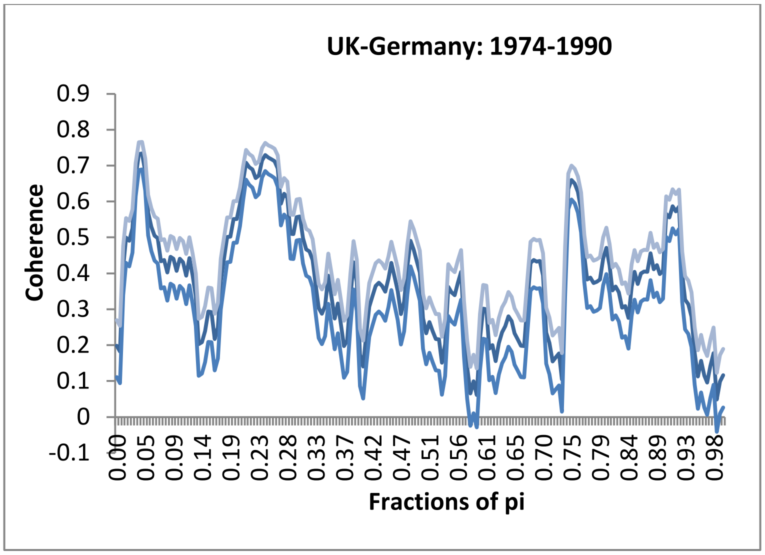

Germany-India: 1991-2010
Coherence
Fractions of pi


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
Fractions of pi
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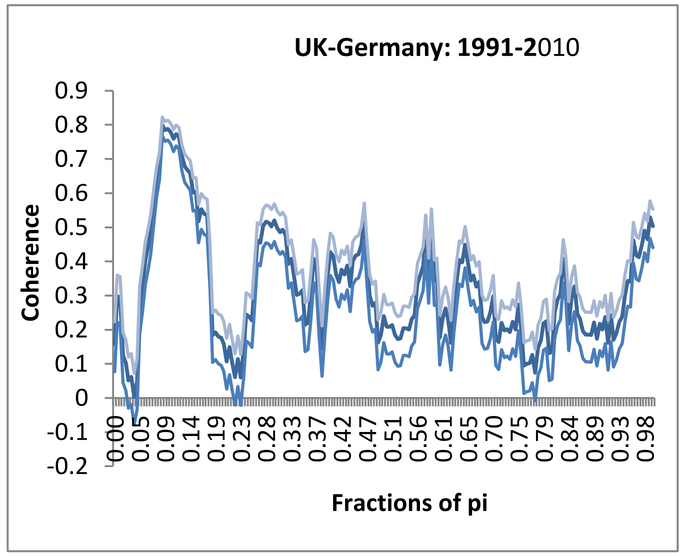
UK-Germany: 1991-2010
Coherence
Fractions of pi
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