Measuring Spillover and Convergence Effects in the Asia-Pacific Region: Is the US No Longer the Economy of First Resort?

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Abstract: This paper tests the hypothesis that the links and dependency relationships in the Asia-Pacific region have changed over the past 20 years with the industrialisation of China, and the emergence of Japan as a source of finance and sophisticated manufactures. Has this changed the size and direction of spillovers in the region, and has it curtailed or eliminated American economic leadership?

We use time-varying spectral methods to decompose the linkages between 6 advanced Asian economies and the US. We find: (a) the links with the US have been weakening, while those within a bloc based on China have strengthened; (b) that this is not new – it has been happening since the 1980s, but has now been partly reversed with the surge in trade; (c) that there are (may be) two Pacific blocs, one based on China and one on Japan; (d) that the links with the US are rather complex, with the US still able to shape the cycles elsewhere through her control of monetary conditions, and China/Japan influencing the size of those cycles; and (e) there appears to be no real evidence that pegged exchange rates per se encourage convergence, but the reverse may be true.

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1 Introduction.

This paper investigates a popular hypothesis, that the emergence and industrialisation of China as one of the world's largest trading economies, and the increasing sophistication of Japan as a financial and manufacturing centre, has changed the dependency relationship and therefore the spillovers between the economies of the Asia-Pacific area. The US was long regarded at the dominant economy if the region, and hence the locomotive or economy of first resort through its consumption of intermediate products, trade in sophisticated manufactures, supply of investment capital, and financial stability where there were fixed exchange rates.

But the rise of China as a major trader in cheaper manufactures and intermediates, and Japan as a provider of sophisticated manufactures and source of finance (particularly after the 1987 stockmarket crash and the Asia crisis) may have changed all that. These two economies may have become just as important as trading partners and locomotive economies for the other Asian economies; and may also have significant spillovers, by virtue of their size, on the US too. Moreover their rapidly expanding stocks of foreign assets, acquired through the large and continuing trade imbalances in the region, gives them a certain influence over monetary conditions and financial stability (even if exchange rates are becoming a little more flexible). In that case the pattern of spillovers may have changed, perhaps even to the point that they have become locomotives for the region, while the US is playing a supporting or beggar-thy-neighbour role.

Those are the changes we wish to test for in this paper. Enhanced trade and financial integration effects come in three parts: an increased convergence (coherence, correlation) between the economies, an increased impact (or spillovers) from events in one economy on another, and stronger lead/lag relationships between economies (a lead for those supplying materials or intermediate inputs, a lag for those consuming manufactures, services, investment goods or finance etc), as shown in Chaplyguin et al (2006). We examine all three in the Asian context, focusing on measures of coherence, gain and phase shifts respectively. We can then ask, to what extent are growth cycles becoming more correlated in the Asia-Pacific region? Is there evidence of cyclical convergence at the business cycle frequency (the focus for policy purposes), or at any other frequencies? Does that imply a common business cycle? Cyclical convergence is an essential condition for the continued success of fixed exchange rates and the implied dependence on foreign monetary conditions.

At present a selective reading of the literature could lead to almost any conclusion, and to find a way to measure the extent and characteristics of the linkages/dependencies between economies is not easy. In this paper we show how spectral analysis can be used to answer such questions, even where data samples are small and where structural breaks and changing structures are an important part of the story. We need a spectral approach to determine the degree of convergence at different frequencies and cycles. The inconclusive results obtained in the past, particularly in the Euro area, may have been the result of using a correlation analysis which averages the degree of convergence across all frequencies. That is problematic because two economies may share a trend or short term shocks, but show no coherence between their business cycles for example.

From a theoretical perspective, neoclassical growth models show that every economy approaches a steady-state income level determined by the discount rate, the elasticity of factor substitution, the depreciation rate, capital share, and population growth. Once at the steady-state, the economy grows at a constant rate. Thus, to the extent that the determinants of the steady-state are similar across economies, convergence is expected. But if these determinants are different, they will not converge. Thus, Mankiw et al. (1992), Dowrick and Nguyen (1989), Wolff (1991), Barro and Sala-I-Martin (1991; 1992), and Quah (1993) find evidence of convergence for a sample of OECD countries at similar levels of development over the years 1960-1985. But they reject that convergence hypothesis in a wider sample of 75 economies whose structures and vulnerability to uncertainty vary a good deal more. Similarly, Chauvet and Potter (2001) report that the US business cycle was in line with the G7 from the mid 70s, but then diverged thereafter. Likewise Stock and Watson (2002, 2005), Hughes Hallett and Richter (2006) find divergence caused by structural breaks, and argue that cyclical convergence is a global rather than regional phenomenon.

In contrast, Artis and Zhang (1997), Frankel and Rose (1998) and Prasad (1999) have all argued that if exchange rates are successfully pegged, and trade and financial links intensify, business cycles are likely to converge. On the other hand, Inklaar and de Haan (2000) do not find any evidence for a common business cycle in the Eurozone. Similarly Gerlach (1989), and Baxter and Kouparitsas (2005), find no evidence of greater convergence among the OECD economies as exchange rates have stabilised or trade increased. Doyle and Faust (2003); Kalemli-Ozcan et al. (2001); Peersman and Smets (2005) provide further

evidence in the same direction. All these results suggest a time-varying approach is going to be necessary if we are to analyse an emerging convergence among economies[1].

The studies cited above also make it clear that the results in this literature are sensitive to: a) the choice of coherence measure (correlation, concordance index); b) the choice of cyclical measure (classical, deviation or growth cycles); and c) the detrending measure used (linear, Hodrick-Prescott filter, band pass etc.). This sensitivity to the detrending technique is a difficulty highlighted in particular by Canova (1998). The advantages of using a time-frequency approach are therefore:

i)   It does not depend on any particular detrending technique, so we are free of the lack of robustness found in many recent studies.

ii)   Our methods also do not have an "end-point problem" – no future information is used, implied or required as in band-pass or trend projection methods.

iii)   There is no arbitrary selection of a smoothing parameter, such as in the HP algorithm and equivalent to an arbitrary band-pass selection (Artis et al., 2004).

iv)   We use a coherence measure which generalises the conventional correlation and concordance measures.

However, any spectral approach is tied to a model based on a weighted sum of sine and cosine functions. That is not restrictive. Any periodic function may be approximated arbitrarily well over its entire range, and not just around a particular point, by its Fourier expansion (a suitably weighted sum of sine and cosine terms) – and that includes non-differentiable functions, discontinuities and step functions. Hence, once we have time-varying weights, we can get almost any cyclical shape we want. For example, to get long expansions, but short recessions, we need only a regular business cycle plus a longer cycle whose weight increases above trend but decreases below trend (i.e. varies with the level of activity). This is important because many observers have commented on how the shape of economic cycles has changed over time in terms of amplitude, duration and slope (Harding and Pagan, 2001; Peersman and Smets, 2005; Stock and Watson, 2002). Once again, a time-varying spectral approach, which separates out changes at different cyclical frequencies in the economy, is

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[1] Also because structural characteristics and institutions change. It appears that cyclical correlations typically fall with the degree of industrial specialisation which increases, both in Europe and beyond, as trade and financial integration intensify (Kalemli-Ozcan et al 2001, 2003). But market reforms, liberalisation measures, and the extent to which policies are coordinated or made common to a group of economies may have the opposite effect.

going to be needed to provide the flexibility to capture these features. Similarly it will be needed if we are to be able to accommodate the structural breaks which must be expected with China emerging as one of the world's largest trading economies; and with the increasing sophistication of the Japanese economy, with increasing financial integration and investment flows, changes to the size and composition of trade imbalances, changes to the supply chain of components/inputs to China or Japan, and the strengthening of monetary institutions.

2 A Technical Introduction to Time Frequency Analysis

2.1 Time Varying Spectra

Spectral analysis decomposes the variance of a sample of data across different frequencies. The power spectrum itself shows the relative importance of the different cycles which helped create movements in that data, and hence describes the cyclical properties of a particular time series. It is assumed that the fluctuations of the underlying data are therefore produced by a large number of elementary cycles of different frequencies. Furthermore, it is usually assumed that the contribution of each cycle is constant throughout the sample.

However, as Chauvet and Potter (2001) show for the US, business cycles cannot be assumed to be constant over time. Hence their spectra may not be constant over time due to the changing weight of each of the elementary (component) cycles. A "traditional" frequency analysis cannot handle that case. But in recent years a time frequency approach has been developed which can do so. It depends on using a Wigner-Ville distribution for the weights (see for example: Matz and Hlawatsch, 2003). In this paper we use a special form of the Wigner-Ville distribution, namely the "short time Fourier transform" (STFT). The STFT catches structural changes (interpreted here as changes in the underlying lag structure of output, in accordance with Wells, 1996), but assumes local stationarity. We employ the STFT for two reasons: first, the time series we analyse are already in log-differenced form (see eq. (2.1) below) so stationarity may be assumed. Moreover, standard unit root tests performed on our data (specifically ADF and the Phillips-Perron tests, available on request) confirm that assumption. Finally, the available results in the literature on similar data (Campbell and Mankiw, 1987; Clark, 1987; Watson, 1986) also confirm that conclusion. Secondly, if the time series is stationary, then the STFT and the Wigner-Ville distribution actually coincide (Boashash, 2003). Employing the Wigner-Ville distribution directly would not have changed our results.

All the data collected are real GDP figures taken from the IMF's *International Financial Statistics*. We use seasonally adjusted quarterly data from 1987:4 to 2006:3.[2] For countries in the Asia-Pacific region, and for the US itself, GDP is expressed in US dollars over the entire sample. Growth rates are then defined, using GDP data, as follows:

$$y_t = \Delta\left(\log\left(Y_t\right)\right) = \log\left(\frac{Y_t}{Y_{t-1}}\right) \tag{2.1}$$

Next we employ a two step procedure. As Evans and Karras (1996) point out, if business cycles are to converge, they need to follow the same AR(p) process. We therefore estimate an AR(p) process for each variable individually. That is, we estimate the data generating process of each of the growth rates separately. Then we estimate the bilateral links between the cycles in those growth rates. In order to allow for the possible changes in the parameters, we employ a time-varying model by applying a Kalman filter to the chosen AR(p) model as follows:

$$y_t = \alpha_{0,t} + \sum_{i=1}^{9} \alpha_{i,t} y_{t-i} + \varepsilon_t \tag{2.2}$$

with $$\alpha_{i,t} = \alpha_{i,t-1} + \eta_{i,t}, \text{ for i=0...9} \tag{2.3}$$

and $\varepsilon_t, \eta_{i,t} \ \square \ \text{i.i.d.}\left(0, \sigma^2_{\varepsilon,\eta_i}\right)$, for i=0...9 .

In order to run the Kalman filter we need initial parameter values. The initial parameter values are obtained estimating them by OLS using the entire sample (see also Wells, 1996)[3]. Given these starting values, we can then estimate the parameter values using the Kalman filter. We then employed a general to specific approach, eliminating insignificant lags using the strategy specified below. The maximum number of lags was determined by the Akaike Criterion (AIC), and was found to be nine in each case. Each time we ran a new regression we used a new set of initial parameter values. Then, for each regression we applied

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[2] The sample starts earlier for Japan (1958), Korea (1974), and later for Malaysia (1990), but the analysis will be restricted to the period following the stockmarket/financial crash of 1987. The Taiwanese data is taken from the Taiwan national statistical service publications.

[3] Using the entire sample implies that we neglect possible structural breaks. The initial estimates may therefore be biased. The Kalman filter then corrects for this bias since, as Wells (1996) points out, the Kalman filter will converge to the true parameter values independently of the initial value. But choosing initial values which are "close" to the true values accelerates this convergence. Hence we employ an OLS estimate to start this process; and our start values have no effect on the parameter estimates by the time we get to 1990. Our results are robust.

a set of diagnostic tests shown in the tables in Appendix 1, to confirm the specification found. The final parameter values are then filtered estimates, independent of their start values.

Using the specification above implies that we get a set of parameter values for each point in time. Hence, a particular parameter could be significant for all points in time; or at some periods but not others; or it might never be significant. The parameter changes are at the heart of this paper as they imply a change of the lag structure and a change in the spectral results. We therefore employed the following testing strategy: if a particular lag was never significant then this lag was dropped from the equation and the model was estimated again. If the AIC criterion was less than before, then that lag was completely excluded. If a parameter was significant for some periods but not others, it was kept in the equation with a parameter value of zero for those periods in which it was insignificant. This strategy minimised the AIC criterion, and leads to a parsimonious specification. Finally, we tested the residuals in each regression for auto-correlation and heteroscedasticity.

The specification (2.2) – (2.3) was then *validated* using two different stability tests. Both tests check for the same null hypothesis (in our case a stable AR(9) specification) against differing temporal instabilities. The first is the fluctuations test of Ploberger et al. (1989), which detects *discrete* breaks at any point in time in the coefficients of a (possibly dynamic) regression. The second test is due to LaMotte and McWorther (1978), and is designed specifically to detect *random* parameter variation of a specific unit root form (our specification). We found that the random walk hypothesis for the parameters was justified for each country (results available on request). Finally, we chose the fluctuations test for detecting structural breaks because the Kalman filter allows structural breaks at any point and the fluctuations test is able to accommodate this.[4] Thus, and in contrast to other tests, the fluctuations test is not restricted to any pre-specified number of breaks.[5]

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[4] Note that all our tests of significance, and significant differences in parameters, are being conducted in the time domain, *before* transferring to the frequency domain. This is because no statistical tests exist for calculated spectra (the data transformations are nonlinear and involve complex arithmetic). Stability tests are important here because our spectra are sensitive to changes in the underlying parameters. But with the extensive stability and specification tests conducted, we know there is no reason to switch to another model that fails to pass those tests.

[5] The fluctuations test works as follows: one parameter value is taken as the reference value, e.g. the last value of the sample. All other observations are now tested whether they significantly differ from that value. In order to do so, Ploberger et al. (1989) have provided critical values which we have used in the figures (horizontal line). If the test value is above the critical value then we have a structural break, i.e. the parameter value differs significantly from the reference value and vice versa.

Once this regression is done, it gives us a time-varying AR(p) model. From this AR(p) we can *calculate* the short–time Fourier transform, as originally proposed by Gabor (1946), in order to calculate the time-varying spectrum. We briefly introduce the STFT here: for details, the reader is referred to Boashash (2003). The basic idea is to find the spectrum of a signal x(t), at time t, by analysing a small portion of the signal around that time.

a) Spectra: Consider a signal $s(\tau)$ and a real, even window $w(\tau)$, whose Fourier transforms are S(f) and W(f) respectively. To obtain a localised spectrum $s(\tau)$ at time $\tau = t$, we multiply the signal by the window $w(\tau)$ centred at time $\tau = t$. We obtain

$$s_w\left(t,\tau\right) = s\left(\tau\right)w\left(\tau-t\right) \tag{2.4}$$

We then calculate the Fourier transform w.r.t. τ which yields

$$F_s^w\left(t,f\right) = \underset{\tau\to f}{\mathcal{F}}\left\{s\left(\tau\right)w\left(\tau-t\right)\right\} \tag{2.5}$$

$F_s^w\left(t,f\right)$ is the STFT. It transforms the signal into the frequency domain across time. It is therefore a function of both. Using a bilinear kernel and a Gabor transform (the time series is stationary, but may contain parameter changes), Boashash and Reilly (1992) show that the STFT can always be expressed as a time-varying discrete fast-Fourier transform calculated for each point in time. That has the convenient property that the "traditional" formulae for the coherence or the gain are still valid, but have to be recalculated at each point in time. The time-varying spectrum of the growth rate series can therefore be calculated as (Lin, 1997):

$$P_t\left(\omega\right) = \frac{\sigma^2}{\left|1 + \sum_{i=1}^{9}\alpha_{i,t}\exp\left(-j\omega i\right)\right|_t^2} \tag{2.6}$$

where ω is angular frequency and j is a complex number. The main advantage of this method is that, at any point in time, a power spectrum can be calculated instantaneously from the updated parameters of the model (see again Lin, 1997). Similarly, the power spectrum for any particular time interval can be calculated by averaging the filter parameters over that interval. This would then result in the "traditional" spectra.

b) Cross-spectra: Returning to the second step of our analysis, we can now estimate the one to one relationship between two economies. We restrict ourselves to bilateral relationships in order to avoid multicollinearity between a series of potentially interrelated cycles.

By transferring the time domain results into the frequency domain, we can show how the relationship between two economies has changed in terms of individual frequencies. That is, we are able to investigate whether any convergence took place over time; and, if so, at which frequencies. As a measure of that relationship, we use the coherence. We then decompose the coherence in order to see whether a change in the coherence is caused by a change in the relationship between the two variables (i.e. in the ADL model below); or by a change in the data generating process itself (i.e. in the AR(p) model itself). With a time-invariant method that cannot be done. The next section outlines those ideas.

2.2 Time Varying Cross-Spectra

Suppose we are interested in the relationship between two variables, $\{y_t\}$ and $\{x_t\}$, where $\{y_t\}$ is the US growth rate and $\{x_t\}$ is a Asian growth rate for example. We assume that they are related in the following way:

$$V(L)_t\, y_t = A(L)_t\, x_t + u_t,\; u_t \sim \text{i.i.d.}\left(0,\sigma^2\right) \tag{2.7}$$

where A(L) and V(L) are filters, and L is the lag operator such that $Ly_t = y_{t-1}$. Notice that the lag structure, A(L), is time-varying. That means we need to use a state space model (we use the Kalman filter again) to estimate the implied lag structure. That is

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\begin{aligned}
v_{i,t} &= v_{i,t-1} + \varepsilon_{i,t},\; \text{for } i = 1, ..., p \text{ and } \varepsilon_{i,t} \sim \left(0,\sigma^2_{\varepsilon_i}\right) \\
a_{i,t} &= a_{i,t-1} + \eta_{i,t},\; \text{for } i = 0, ..., q \text{ and } \eta_{i,t} \sim \left(0,\sigma^2_{\eta_i}\right)
\end{aligned}
\tag{2.8}
$$

As before, we tested for the random walk property using the LaMotte-McWother test. And for structural breaks, we employ the fluctuations test (Ploberger et al., 1989). Finally, we use our general to specific approach to estimate (2.8); starting off with lag lengths of nine and p=q, and dropping those lags which were never significant (as we did before).[6]

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[6] The symmetry in the lag structure, and general to specific testing, allows the data to determine the direction of causality in these regressions. We do not report ant results where reverse causalities were not accepted.

Having estimated the coefficients in (2.8), we can calculate the gain, coherence and cross spectra based on the time-varying spectra just obtained. That allows us to overcome a major difficulty in this kind of analysis: namely that a very large number of observations would usually be necessary to carry out the necessary frequency analysis by direct estimation. This may be a particular problem in the case of structural breaks, since the sub-samples would typically be too small to allow the associated spectra to be estimated directly.

In Hughes Hallett and Richter (2002; 2004; 2006) we use the fact that the time-varying cross spectrum, $f_{YX}(\omega)_t$, using the STFT is given by

$$f_{YX}(\omega)_t = |A(\omega)|_t \, f_{XX}(\omega)_t \tag{2.9}$$

where $A(\omega)$ is the gain which can be calculated using the short time Fourier transform of the weights $\{a_j\}_{j=-\infty}^{\infty}$. As noted above, the traditional formulae can be used to do this at each point in time. The last term in (2.9), $f_{XX}(\omega)_t$, is the spectrum of the predetermined variable. Hence this spectrum may be time varying as well. As a result, we calculate the time varying gain as:

$$|A(\omega)|_t = \left| \sqrt{ \left(\frac{ \sum_{b=1}^{q} a_{b,t} \exp(-j\omega b) }{ 1 - \sum_{i=1}^{p} v_{i,t} \exp(-j\omega i) } \right)^2 } \right|_t , \text{ for b=1...q and i=1...p} \tag{2.10}$$

However, we are principally interested in the coherence between x_t and y_t here, and in the decomposition of the changes to that coherence over time. So we need to establish a link between the coherence and the gain. The spectrum of any dependent variable is defined as (Jenkins and Watts, 1968; Nerlove et al., 1995; Wolters, 1980):

$$f_{YY}(\omega)_t = |A(\omega)|_t \, f_{XX}(\omega)_t + f_{VV}(\omega)_t \tag{2.11}$$

where $f_{VV}(\omega)_t$ is the time-varying residual spectrum and $f_{YY}(\omega)_t$ is the time varying spectrum of the endogenous variable.

Given knowledge of $f_{YY}(\omega)_t$, $|A(\omega)|^2$, and $f_{XX}(\omega)_t$, we can now calculate the coherence as

$$K^2_{YX,t} = \frac{1}{\left\{ 1 + f_{VV}(\omega)_t \Big/ \left(\left| A(\omega) \right|_t f_{XX}(\omega)_t \right) \right\}} \tag{2.12}$$

The coherence is equivalent to the R^2 of the time domain. The coherence measures, for each frequency, the degree of fit between X and Y: or the R^2 between each of the corresponding cyclical components in X and Y. Hence, the coherence measures the link between two variables at time t. For example, if the coherence has a value of 0.6 at frequency 1.2, then this means that country X's business cycle at a frequency of 1.2 determines country Y's business cycle *at this point in time* by 60%. The coherence does not take into account a shift in the business cycle, e.g. the European business cycle leads the German one by 1 quarter. In this paper, we are concerned only with the coherence, not the gain or phase shift elements.

The next question is, in which cyclical components do structural breaks or changes in behaviour appear? We define structural changes as changes that occur in the underlying relationship between two variables. To identify such changes, we reformulate the coherence. Solving (2.11) for $f_{VV}(\omega)$, and substituting the result into (2.12), yields:

$$\begin{aligned} K^2_{XY,t} &= \frac{1}{\left\{ 1 + \left(f_{YY}(\omega)_t - \left| A(\omega) \right|_t f_{XX}(\omega)_t \right) \Big/ \left(\left| A(\omega) \right|_t f_{XX}(\omega)_t \right) \right\}} \\ &= \left| A(\omega) \right|_t \frac{f_{XX}(\omega)_t}{f_{YY}(\omega)_t} \end{aligned} \tag{2.13}$$

Finally, defining
$$\frac{f_{XX}(\omega)_t}{f_{YY}(\omega)_t} = f_{DD}(\omega)_t, \tag{2.14}$$

we get
$$K^2_{YX,t} \equiv \left| A(\omega) \right|_t f_{DD}(\omega)_t \tag{2.15}$$

This last equation, (2.15), allows us to analyse structural changes in the coherence between X and Y. We can now write the changes in the coherence as:

$$\Delta K^2_{XY,t} = \Delta \left| A(\omega) \right|_t \Delta f_{DD}(\omega)_t \tag{2.16}$$

As shown in Hughes Hallett and Richter (2002; 2004), (2.16) may be obtained from (2.10), (2.12), and the single variable spectra of section 3 needed to generate (2.14).

Last, but not least, a note on the figures shown in the following two sections. We first present the time-varying spectra and then the coherences and gains. One can see from these figures that the spectra change. However, one cannot infer directly from those figures that the changes in the spectra are also statistically significant. The figures for the time-varying spectra/cross-spectra have to be accompanied by the fluctuation test results. Once a structural break has been identified by the fluctuations test, the results will show up as a significant change in the associated spectrum or coherence or gain.

3   Single Spectra

In this section and the next, we study the spectra and cross-spectra of output growth in selected Asian economies compared to the US, or compared to China or Japan, over the past 20 years. We take the US, China and Japan to be the potential leading economies ("economies of first resort") in the Asia-Pacific area, and analyse the changing relations between themselves; and between them and the other emerging economies of the region (Korea, Taiwan, Malaysia and Singapore) since the Asian financial crisis in 1996-7. Similar results for the US and the UK, and for the US vs. the Eurozone, will be found in Hughes Hallett and Richter (2006) and can be used as a benchmark for these comparisons. We use quarterly, seasonally adjusted data for real GDP in all seven economies, as published in the IMF's *International Financial Statistics*, and then log difference them once to obtain growth rates. The resulting series were then fitted to an AR(p) model as described above, and tested for stationarity, statistical significance, and a battery of other diagnostic and specification checks. Our sample starts in 1987Q4 or earlier, and finishes in 2006Q3 in each case.

a) The Core Economies: the US, China and Japan. One striking feature of the individual country spectra is that, in all three core economies, the trend growth rate does not play an important role in terms of spectral mass. Indeed, taking into account the vertical scale in each diagram, there is very little volatility in output growth of any kind in either China or Japan after 1987; except at the business cycle frequency in the Asian crisis period (1998-2002) in Japan, and until the period of especially rapid trade growth (and trade surpluses) in China from 2004 onwards. This is in stark contrast to the US spectrum which shows the declining power of trend growth after 1987, and very mildly increasing volatilities at short or short-to-medium cycle lengths, but a clear persistence in her trend growth rates nonetheless.

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In making these points, we are drawing a clear distinction between persistent trends, meaning events whose effects on performance last a long time before dying away or being overtaken by subsequent events/changes; and constant growth trends whose effects are persistent and always the same in terms of economic performance. Obviously the former implies some variance in the outcomes, if only slowly changing, and hence some long cycle power in the associated spectrum. But the latter implies no effective variance in the outcomes, and hence no power in the corresponding spectrum at low frequencies (or anywhere else).

So there may have been change in these economies; but it is not a change that has altered the pattern of growth in the US in any significant way, or the growth in Japan and China for that matter (except perhaps in the period 2003-5). That is not to say that the relationships between these economies have not changed. But if they have, it must have been a change involving others outside the region; or, more likely, a change that involved a reallocation of roles between the economies of the Asia-Pacific area rather than a change in behaviour/dependency as such. The latter appears more likely because the pattern of structural (regime) breaks shows little in common taking each economy separately. Had they been settling into a new regime, there would have been something in common in the structural breaks as each economy entered that regime. As it is, the US is only showing structural breaks in 1996 and 2001 (the Clinton-Greenspan boom); while Japan shows breaks in 1977-80, 1983-92 and in 1994-2002 (boom, then deflation), and China a series of small breaks in 1993, 1995, 1999-2000 and 2002 and then a very large one in 2004-5 (expansion of trade, curtailing of imports) . With a pattern like that, these breaks are far more likely to reflect changes in the domestic economies.

b) The Smaller Asian Economies. The spectra in the smaller Asian economies are quite different, and they have little in common. Korea and Singapore show some volatility in growth, both at long cycles and at short cycles. But neither shows any marked tendency for the strength of those cycles to increase or decrease. In Korea's case, there is some additional short cycle volatility after the 1987 stockmarket crash, and some more generally in the Asian crisis after 1997. But it did not persist. Singapore has seen some increase in both long and short cycle volatility since 2002, but it is not large and does not change the pattern of growth.

Malaysia is different in that she shows power (volatility) at the business cycle and short cycle frequencies. But again, this has not changed since 1996. And there is very little power at long cycles or trend growth. Taiwan, likewise, has no power at long cycles or trend growth; and very limited power at the business cycle frequencies (with the exception of the spike at that

frequency in 2004-5, and in the previous two years). In that regard, the Taiwanese economy is remarkably similar to the Chinese but with less power at the business and trend growth cycles.

c) Commentary: The tentative conclusion at this stage is that there is no great change in the growth patterns of these economies in the past two decades; with the exception of the increase in volatility at business cycle frequencies in Japan and Korea at the time of the Asian crisis, and from 2003/4 in China, Taiwan and (possibly) Singapore. This makes it hard to see if there is an emerging group of Asia-Pacific economies with common cyclical behaviour. One suspects not; although it is possible that a group centred on China is starting to emerge, and another consisting of Japan and Korea. But to show that, we need to see if the within group coherences and gains have increased; and if those out-of-group, particularly with the US, have decreased at the same time. If that were true, it would be consistent with Demertzis et al. (1998) who found that the "core" and "periphery" economies in Europe had more in common with each other than any of them did with those out-of-group. Even so, the low spectral power in these Asia-Pacific economies implies they are all influenced by stable growth rates. That much they do have in common, and in contrast to the US. But it is not a new phenomenon.

4 Increasing Coherence between Asian Economic Cycles?

We turn now to the coherence, or correlations, between the economic cycles of our Asian economies at different frequencies – and whether those coherences have been increasing or decreasing. These results supply a test of the hypothesis that the Asian economies form a coherent economic group, more similar in their performance than with those outside the group, and that their dependence on the US economy has decreased as the strength of the linkages between them has increased. More specifically, we can test the proposition that, if exchange rates are pegged, then business cycles will converge as trade and financial links intensify. This is an important matter. Artis and Zhang (1997), Prassad (1999) and Frankel and Rose (1998, 2002) all argue that this will happen as trade and financial links strengthen[7]. On the other hand, Kalemli-Ozcan et al (2001, 2003), Hughes Hallett and Piscitelli (2002), Baxter and Kouparitsas (2005), Peersman and Smets (2005) show that it has seldom happened in practice and may not happen in this case. The advantage of our approach is that we have

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[7] The rapid increase in trade and financial flows make the Pacific region the right test bed for that hypothesis.

two control groups: the China group with (mostly) fixed exchange rates within and without, and the Japan-Korea-US group with flexible rates. We can examine this hypothesis directly therefore, and attribute the results to the exchange rate arrangements rather than to increased trade and financial flows. Indeed, the fact that we have two emerging groups, and not one as often supposed, may be due to that distinction.

This section provides empirical evidence on these two hypotheses, with the addition that we can show the frequencies at which increased spillovers occur. This is important because spillovers may occur at certain frequencies and not others, implying that average correlations can appear to increase when the vital linkages at the business cycle frequency have decreased (or vice versa). We are primarily interested in coherence at business cycle frequencies because of what it implies will be demanded from policy makers and market responsiveness; and of price and wage flexibility in particular. But short and long cycle coherences are important too, for their ability to transmit persistent or short term shocks.

a) Coherence among the big three: the US, China and Japan.

We first examine the coherence and gains, cyclical association (or dependence) and spillover effects between the larger economies in the Asia-Pacific region. Taking the China-US relationship first ("US affects China")[8], we can see that the coherence has been gradually declining from 1987 to 2001; but has remained at a fairly high level of 0.4 to 0.5 throughout. However it increased again rather abruptly from 2001, to imply a stronger if somewhat uncertain (there are several interruptions to this increased coherence) influence of US growth on China at the long, short, and (most of all) at the business cycle frequencies from 2004 to 2006. The gains however show that the impact of US growth on the Chinese economy to be quite small, with multipliers of below 0.08 per unit change in the US, and declining, until 2002. But then there is a sudden increase in the US influence at short, long and business cycle frequencies in 2003-4; such that, by 2005, the spillovers onto China had settled back to the

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[8] Note that each coherence/gains relationship implies a direction of causality, and hence different degrees of association or spillover effects, depending on whether we are looking at how much US growth affects growth in China or how much Chinese growth affects the US performance. We therefore get different results, and different implications, depending on whether the underlying regressions (2.7) specify Chinese growth as a function of US growth rates; or US growth as a function of Chinese growth. Coherences can therefore imply one growth pattern is more closely associated or dependent on another, than will hold in reverse (the dependence/association of the second on the first).Coherence therefore measures the generalized closeness of fit between two variables x and y, rather than the simple correlation coefficient which is symmetric. Gains likewise measure the impact effects of growth in one economy on another, and therefore vary with the direction in which the linkage is supposed to run.

levels reached in 1990-91. So there is partial support for our first hypothesis, but not quite as expected. US dominance and economy of first resort effects have indeed been declining with respect to China, but slowly and only up until 2002. The recent surge in trade with the US, based as it is expanding exports and the (domestic) substitution of imports, has restored much of the US influence on China although that influence is still rather small.

In the light of those results, it is important to see if the counterpart is true: if China's impact on the US economy has also been increasing. We might expect to see the China to US gains and coherence increasing with the expansion of trade and financial flows between the two, in the same way as the US to China coherence and gains increased. And to some extent we do. The US-China coherence is rather low, but falls steadily (from 0.1 to 0.05) up until 2001 just as the China-US coherence did. It then jumps back up to 0.1 (and temporarily to 0.3 at the business cycle frequency) and remains, rather uncertainly, at that level. In the same way, the US-China gain (the impact of Chinese growth on the US) is high but falls steadily until 2001, and then recovers sharply thereafter to values similar to those of the early 1990s – again similarly to the China-US case[9]. Those results might therefore suggest a continuing linkage between China and the US, based on the assumed leadership of the US economy in the 1980s and 1990s. However that would probably be wrong because of the asymmetry in the linkage: the US to China linkage has a high coherence but a low gain, while the China to US linkage has low coherence but a high gain. Such asymmetries give us the pattern of dependency or leadership. In this case, it appears the US has the power to *shape* the cycle in China through her dominance of monetary (interest rates, supply of capital, exchange rates) and financial conditions; while China has the power to influence spillover effects onto the US (and hence the *size* of the cycle) through the "outsourcing" of manufactures and cheap intermediate inputs for the US economy. This gives a more complex view of the relationship between the US and Chinese economies, where they dominate and where they are vulnerable, than is generally assumed. It is consistent with the idea that China has gained greater influence through trade; at the cost of a dependence on foreign monetary conditions (risking inflation, excess liquidity, asset bubbles). However, the key point is that this relationship is not new. It has been in this form since the 1980s; but has become stronger, if more uncertain, since 2000.

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[9] Although more in the long and short cycles than at business cycles. That suggests a change in the phase relationship. If there is such a change, then the strength of the coherence or gain must increase at some frequency (and decrease at another) while the change itself takes place. Since we are not interested in the size of the leads/ lags, only their changes, we limit our tests for changing phase shifts (and associated product mix) to such events.

The Japan-US relationship presents a much simpler picture. The coherence shows a steady but surprisingly strong linkage between Japanese growth and US performance. That association may be stronger at long cycles, and may have weakened in the past 5 years, but those effects are very small. The gain, the impact of US income movements on Japanese growth, shows larger changes; those spillovers fall from around 0.3 in the 1970s and 1980s, especially in the persistence of long cycles and short term volatility, to about 0.15 now. But that is still twice the corresponding impact of the US on China. And there are business cycle spillovers at twice that strength after 2001. These results also support our hypothesis; but only weakly so because the linkage between business cycles is increasing (if anything) at the end of the sample, and because the constant coherence means there will be correspondingly few changes in the Japan to US relationship.

b) Coherence between the Smaller Asian Economies and the US.

Compared to the China-US and Japan-US coherences, that between Korea and the US is very weak: 0.02 at the end of the sample, in place of 0.5 to 0.9. Moreover, the profile appears to be similar to the China-US case but the timing is different. The coherence gradually diminishes, almost to zero, until 1998; and then jumps to its highest sustained level in the sample period, with more coherence at the long and trend cycle end of the spectrum. But even then, the coherence remains low compared to the Japanese-US case. So if there is an emerging Japan-Korea(-US) bloc as the earlier single spectra and Japan-US results (and those for Korea-Japan which follow) suggest, then the Korea component is only just now starting to emerge in the wake of the Asia crisis. The corresponding gain figures tell the same story. The impact, on Korean growth, of events in the US economy is very small and several times lower than the impacts on China or Japan. But after falling to near zero in the early 90s, the gains increase to imply a multiplier of 0.015 after 1999. Again that is small, but consistent with an emerging Japan-Korea(-US) bloc, with Korea's US link going through Japan, given the stronger Korea-Japan figures to come.

Like China, two of the other economies (Taiwan, Singapore) had experienced a weakening of their linkage to the US since the 1980s. They show low coherences and falling gains from US activity, but coherences and gains that pick up in 2000-01. Korea showed the same pattern of course, but at a coherence and gain level several times smaller than Taiwan and Singapore which distinguishes it from that group. Malaysia also shows the same pattern, but only at the business cycle frequency and only faintly which makes her a marginal member of this group.

The interesting point to note from these results is that both Singapore and Taiwan (and Korea briefly in 1998) have periods between 1991 and 2002 where their gains appear to go to zero. This is an artefact of the fact that cross-spectra are defined as real numbers. Consequently the gains are represented by the absolute value of the (complex) Fourier transform given at (2.10), of the coefficients of the underlying time domain ADL relationship (2.7). Hence the gains will go to zero if the coefficients in A(L) all go to zero; i.e. meaning, in this case, the US economy has no further influence on the growth cycles of the economy under investigation. And our general to specific specification and testing procedure automatically sets those coefficients at zero if they are not statistically significant in a particular period. So a zero gain means that Singapore and Taiwan became dissociated from the US economy in those periods; or to be more accurate, that the US economy had no *significant* impact on their growth or cycles. And once $|A(\omega)|$ goes to zero, then so does the corresponding coherence (by (2.12)). Since this happens to the China bloc (China-Singapore-Taiwan), but not the Japan bloc, this is further evidence of the emergence of two separate blocs in the Asia-Pacific area.

c) Between the Smaller Asian Economies and Japan.

The coherence between Korea and Japan is reasonably strong, at 0.25 in the 90s, rising to 0.4 after 1999, but very volatile. However, it has a similar profile to the China-US coherence with a gradually diminishing coherence in the 90s, and a sharp increase in the long cycles and the business cycle frequencies with the increase in Asian trade after 1999. The gains show the same pattern, with the increase happening at a slightly earlier date and focussed more on the long and short cycles. An increase in Japanese growth now implies a multiplier effect of between 0.5 and 1 on Korea, compared to just 0.25 before the Asia crisis. Thus if there is an emerging Japan-Korea bloc, it is only just now evolving with a link to the US through Japan. That it is detaching itself from the rest of East and South East Asia can be seen from the very low levels of coherence and gains for Japan-China and Korea-China, and the fact that (unlike what happens within the China bloc) those gains fall significantly after 2003.

Turning to Malaysia, the coherence with Japan is steady if fluctuating with different cycle lengths. At an average of 0.4, it is quite strong but shows a lot of additional uncertainty around the Asia crisis period (1995-2001). It also appears that the strength of that coherence has been building at the business cycles, and possibly weakening among the long cycles since 1999, consistent with Malaysia's position of a supplier of components and materials to Japan.. But these changes are small, and not comparable to the strengthening coherence in the China-

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US or Korea-Japan relationships. The gain figure confirms that observation: changes in Japanese growth has produced a more than proportionate impact on both the short and long cycles in Malaysian growth. But after 1999, this effect falls away to proportionality or a bit less. Similarly, the business cycle gain increases to an impact greater than 1 from 1996 to 2001, but then falls away again thereafter. That is consistent with a continuing similarity, but weakening linkage with Japan – as would happen if blocs start to separate.

Singapore and Taiwan show a rather clearer picture of the same thing. Like Malaysia, their coherences with Japan show slight decline from 1990, and a stronger one in the late 1980s, to reach a similar value of around 0.4 now. The lows and uncertainties of the Asia crisis are also clear to see. Then from 2003 things stabilise, with a small build up again at the long, short and business cycle frequencies (business cycle only in Taiwan). But, again like Malaysia, this is a restoration on the status quo ante and nothing like the increase in coherence seen in the China-US or Korea-Japan cases. The gain figures are broadly similar too. The impact of changes in growth in Japan on either economy had been around 1 for 1, or a bit less, in the 1980s and concentrated fairly evenly on the long, short and business cycles. But these spillover effects reduced substantially during the 90s before recovering to between 0.6 and 0.8 to 1 from 2003 onwards. The similarity of these results, and their similarity to the Malay-Japan and China-US results, gives a clearer picture of an evolving China based group separating itself from the Japan-Korea bloc which remains more closely allied to the US. But to establish that firmly we need to check that the counterpart changes have also occurred in the coherences with China.

d) Between the Asian Economies and China.

We review the coherences between Japan and China, and Korea and China, separately from the coherences of the smaller economies (Malaysia, Taiwan and Singapore) with China, to allow for the fact that there may be two blocs in the Asia-Pacific region: one based on Japan (possibly involving the US) and one based on China.

The Japan-China (China influences Japan) coherence is very low throughout our sample, at 0.1 or less, but shows distinct increases in 1997 and in 2003 where the relationship starts to show a significant increase in volatility. At that point the transmissions from China are to the short, long, but mainly business cycle frequencies in Japan. However, the coherence remains small: no more than for China influencing the US, and far smaller (by factors of 5 to 6) than the US's coherence with China or Japan. The gains (China influencing Japan) are yet smaller

at 0.02-0.03, although they too show a clear increase in 1997 at the short and long frequencies before tailing off again after 2003. This is consistent with a Japan bloc developing separately from a China bloc, even though one might have expected more linkage between the two as Chinese components are increasingly used, and manufactures consumed, in Japan; and as more Japanese equipment or investment goes to China. The fact that the same thing is also happening in the US means that Japan and the US continue to behave in the same way despite their, and China's, changing roles in the Asian economy.

The Korea-China coherence and gains (China influences Korea) are essentially the same as in the Japan-China case, although there is a more even distribution across cycles. The Korea-China coherence is less than that for Japan-China, and lower than for Korea-Japan by a factor of 10 (and only a little stronger than between Korea and the US). There is a similar jump in 2000 which fades, but that too is small (unlike in the Korea-Japan case).The Korea-China gains are similarly small: roughly the same as for Korea-US, and a fraction of those for Japan's effect on Korea. The Korea-China gains also fade fast after 2004. In short, there is no evidence of a Japan or Korea link to China here; but some of a Korea-Japan bloc, and of an "association as usual" with the US, principally via Japan's association with the US.

Lastly, to the group based on China. The Malaysia-China coherence is relatively low; and has been falling across the board from 2002 onwards, to reach a level of 0.1 or less by 2005. It also shows a significant amount of volatility in the 1990s and during the Asian crisis. This coherence is therefore 4 or 5 times smaller than Malaysia's coherence with Japan, if larger than her coherence with the US. And it is volatile and declining, unlike the coherence with Japan. Thus, while some earlier results may have suggested the opposite, it is hard to argue that Malaysia really is part of an emerging bloc based on China. Given the falling coherence, the most that can be said is that she is a marginal, part-time member who flirted with that bloc but is now drifting away from it. The gains, the impact of China on the pattern of growth in Malaysia, also support that interpretation. These gains are very low and again falling, many times smaller than the effect of Japanese growth and no stronger than the impact of the US. Malaysia's role as supplier of components and materials to Japan therefore dominates. Moreover the gains and coherence with China remain focused at the short, long and business cycle frequencies; no evidence of shifts in phase or in product structure there.

The Singapore-China coherence and gains, while similar in some respects, offers rather a different picture.[10] The main feature here is a steady increase in the coherence from the late 80s through to 2001, then a crash in 2003, and a sharp recovery (almost to the previous peak) in 2004-6. Moreover, this is across the board rather than concentrated on three frequencies. The result is a coherence of 0.2-0.3 after 2000 (2003 excepted) which, while less than Singapore's coherence of 0.4 with Japan, is comparable with other potential members (Taiwan to come, Korea-Japan, Japan-US), much larger than the between bloc coherences with the US, Korea or Malaysia, and consistent with increasing investment and financial links in China since it appears at all frequencies. This looks to be an economy which is building up its links with China without having (yet) reduced those to Japan. The gains show a similar picture: increasing across the board, albeit at a considerably lower level of 0.1, which is less than the spillovers from Japan but more than those from the US. Again, the even spread across frequencies suggest no shifts in phase or product structures.

Finally Taiwan shows the closest relationship to and most influence from China. Our Taiwan-China coherence is substantially higher, at 0.4 to 0.5 in 2004, than the other China coherences (including with the US) or the Korea-Japan coherence. Moreover there has been a precipitous rise since 2002 (possibly since 1999), with the power concentrating at the long and business cycle frequencies (and away from the short/intermediate frequencies). That suggests a shift in phase and product structure has taken place with an increase in consumer goods traded either way, or intermediate inputs from China at business cycle frequencies; and increased financing from Taiwan to provide the long cycle connection. The gains show the same thing for the influence of China on Taiwan, although those gains remain fairly small[11] even after the shifts of 2002. Interestingly, they are also less than the now declining influence of Japan on Taiwan.

5 Conclusions

The contribution of this paper has been to examine the hypothesis that the economic links and leadership-dependency relationships in the Asia-Pacific area have changed over the past 20 years. Has this changed the size or direction of the spillovers between economies, and reduced US hegemony in the region by strengthening the links between Asian economies? How much does Asia influence the US economy, and can one speak a common Asian bloc?

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[10]The similarity with the other Asian economies is the tailing off and volatility in the coherence/gain after 2004.
[11] Although considerably larger than for the other members of this putative China bloc.

We have used time-varying spectral methods to decompose the growth rates, and the linkages between them, of 6 advanced Asian economies and the US; and study the coherence, spillover effects and any changes in leads, lags or product composition, at each cycle length. We find:

a) That the links with the US have indeed weakened, and those within a bloc centred on China have been strengthening;

b) But this is not a new phenomenon. It has been happening steadily since the mid-1980s, and it has now been largely (but not completely) reversed by the recent unbalanced expansion of trade.

c) There are, or may be, two Asian blocs emerging; one based on Japan whose relationship with the US remains unchanged, and one based on China where there have been substantial changes. The links between those two blocs are weak and uncertain; the primary difference between them resting on the flexibility of their exchange rates and the consequent control of domestic monetary and financial conditions.

d) There is little evidence of changing lead/lag relationships which might signal shifts in the industrial or product structures that create the links, except in the China-Singapore-Taiwan group which may be showing increased trade in intermediates and internal financing.

e) Of the countries examined, Japan-Korea(-US) form one group; and China-Singapore-Taiwan the other, with Malaysia as a part-time member of each group. The strongest changes are found in the China bloc, where there seems to have been some reallocation of activities.

f) The linkage with the US is more complex than usually supposed. It appears that the US still influences the shape and existence of cycles elsewhere through her control of monetary conditions where exchange rates are pegged; but the Asians have some control of the size of the cycles at home and elsewhere through their trade in consumption and intermediate goods.

g) There is no evidence that fixed exchange rates encourage convergence despite increasing trade and financial links. In fact the opposite is true here; most likely because of the capacity of misaligned (undervalued) exchange rates to generate excess liquidity, easy credit, and domestic asset bubbles (as Japan found in the early 1990s).

References

Artis, M., Marcellino, M., and Priorietti, T. (2004): Dating the Euro Area Business Cycle. In L. Reichlin (Ed.): *The Euro Area Business Cycle: Stylised Facts and Measurement Issues*, Centre for Economic Policy Research, London.

Artis, M., and Zhang, W. (1997): International Business Cycles and the ERM: Is there a European Business Cycle? *International Journal of Finance and Economics* **2**, 1-16.

Barro, R. J., and Sala-I-Martin, X. (1991): Convergence across States and Regions. *Brookings Papers on Economic Activity* **1**.

Barro, R. J., and Sala-I-Martin, X. (1992): Convergence. *Journal of Political Economy* **100**, 223-251.

Baxter, M., and Kouparitsas, M. A. (2005): Determinants of Business Cycle Comovement: a Robust Analysis. *Journal of Monetary Economics* **52**, 113-158.

Boashash, B. (2003): Time Frequency Signal Analysis and Processing, Elsevier, Oxford.

Boashash, B., and Reilly, A. (1992): Algorithms for time-frequency signal analysis, pp. 163-181. In B. Boashash (Ed.): *Time-Frequency Signal Analysis - Methods and Applications*, Longman-Cheshire, Melbourne.

Campbell, J. Y., and Mankiw, N. G. (1987): Permanent and Transitory Components in Macroeconomic Fluctuations. *American Economic Review* **77**, 111-117.

Canova, F. (1998): Detrending and Business Cycle Facts. *Journal of Monetary Economics* **41**, 475-512.

Chaplyguin, V., A Hughes Hallett and C.R. Richter (2006), "Monetary Re-integration in the ex-Soviet Union: A Union of Four?" *Economics of Transition,* 14, 47-68.

Chauvet, M., and Potter, S. (2001): Recent Changes in the US Business Cycle: *mimeo*, University of California.

Clark, P. K. (1987): The Cyclical Component of the U.S. Economic Activity. *Quarterly Journal of Economics* **102**, 797-814.

Dowrick, S., and Nguyen, D.-T. (1989): OECD comparative economic growth 1950-85. *American Economic Review* **79**, 1010-1030.

Doyle, B., and Faust, J. (2003): Breaks in the Variability and Comovement of G7 Economic Growth. *International Finance Discussion Paper, no 786, Board of Governors, Federal Reserve System, Washington, DC.*

Evans, P., and Karras, G. (1996): Convergence revisited. *Journal of Monetary Economics* **37**, 249-265.

Frankel, J., and Rose, A. (1998): The Endogeneity of the Optimal Currency Area Criteria. *Economic Journal* **108**, 1009-25.

Frankel. J and Rose A (2002): An Estimate of the Effect of a Common Currency on Trade and Income. *Quarterly Journal of Economics,*117, 437-66.

Gabor, D. (1946): Theory of communication. *Journal of the Institute of Electrical Engineering* **93**, 429 - 457.

Gerlach, S. (1989): Information, Persistence, and real Business Cycles. *Journal of Economic Dynamics and Control* **13**, 187-199.

Harding, D., and Pagan, A. (2001): Extracting, Analysing and Using Cyclical Information: *mimeo*, Australian National University.

Hughes Hallett, A. and L. Piscitelli (2002) "Does Trade Cause Convergence?" *Economics Letters,* 75, 165-70.

Hughes Hallett, A., and Richter, C. (2002): Are Capital Markets Efficient? Evidence from the Term Structure of Interest Rates in Europe. *Economic and Social Review* **33**, 333 - 356.

Hughes Hallett, A., and Richter, C. (2004): Spectral Analysis as a Tool for Financial Policy: An Analysis of the Short End of the British Term Structure. *Computational Economics* **23**, 271-288.

Hughes Hallett, A and Richter, C (2006), Is the Convergence of Business Cycles a Global or a Regional Issue? The UK, US and Euroland, *International Journal of Finance and Economics,* 11, 177-94.

Inklaar, R., and de Haan, J. (2000): Is there really a European Business Cycle? *CESifo Working Paper* **No 268,** Munich.

Jenkins, G. M., and Watts, D. G. (1968): *Spectral Analysis and its Applications*. Holden-Day. San Francisco.

Kalemli-Ozcan, S., Sorenson, B., and Yosha, O. (2001): Economic Integration, Industrial Specialisation, and the Asymmetry of Macroeconomic Fluctuations. *Journal of International Economics* **55**, 107-137.

Kalemli-Ozcan, S., Sorenson, B., and Yosha, O., (2003): Risk Sharing and Industrial Specialisation: Regional and International Evidence. *American Economic Review,* 93, 903-18.

LaMotte, L. R., and McWorther, A. J. (1978): An exact test for the presence of random walk coefficients in a linear regression. *Journal of the American Statistical Association* **73**, 816-820.

Lin, Z. (1997): An Introduction to Time-Frequency Signal Analysis. *Sensor Review* **17**, 46-53.

Mankiw, N. G., Romer, D., and Weil, D. (1992): A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics* **107**, 407-437.

Matz, G., and Hlawatsch (2003): Time-Varying Power Spectra of Nonstationary Random Processes. In B. Boashash (Ed.): *Time Frequency Signal Analysis and Processing*, Elsevier, Amsterdam.

Nerlove, M., Grether, D. M., and Carvalho, J. L. (1995): *Analysis of Economic Time Series*. Academic Press. New York.

Peersman, G., and Smets, F. (2005): Industry Effects of Monetary Policy in the Euro Area. *Economic Journal* **115**, 319-342.

Ploberger, W., Krämer, W., and Kontrus, K. (1989): A New Test For Structural Stability in the Linear Regression Model. *Journal of Econometrics* **40**, 307-318.

Prassad, E. S., (1999) "International Trade and the Business Cycle", *Economic Journal*, 109, 588-606.

Quah, D. T. (1993): Galton's Fallacy and Tests of the Convergence Hypothesis. *Scandinavian Journal of Economics* **95**, 427-443.

Stock, J. H., and Watson, M. W. (2002): Has the Business Cycle Changed and Why? *NBER Working paper* **No 9127**.

Stock, J. H., and Watson, M. W. (2005): Understanding Changes in the International Business Cycles. *Journal of the European Economic Association,* **3,**966-1006.

Watson, M. W. (1986): Univariate Detrending Methods with Stochastic Trends. *Journal of Monetary Economics* **18**, 49-75.

Wells, C. (1996): *The Kalman Filter in Finance*. Kluwer Academic Publishers. Dordrecht.

Wolff, E. N. (1991): Capital formation and productivity convergence over the long term. *American Economic Review* **81**, 565-579.

Wolters, J. (1980): *Stochastic Dynamic Properties of Linear Econometric Models*. Springer Verlag. Berlin.

Figures US1-2; 1-61: The Individual Spectra and Cross-Spectra

Tables 1-21: The Statistical Results

<u>**Note:**</u> For reasons of space, the results quoted in the tables describe the final regression done and its diagnostic tests. But the figures which follow display the period by period spectral results implied by the underlying time-varying regressions.
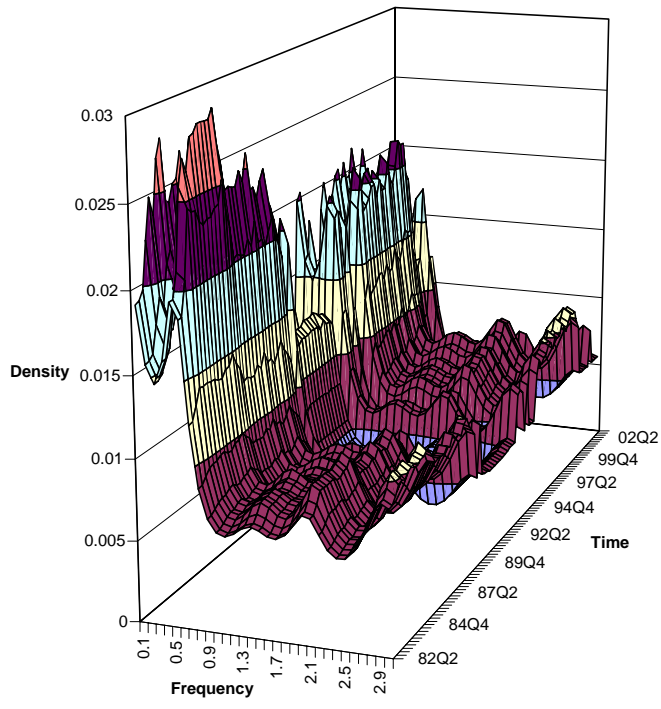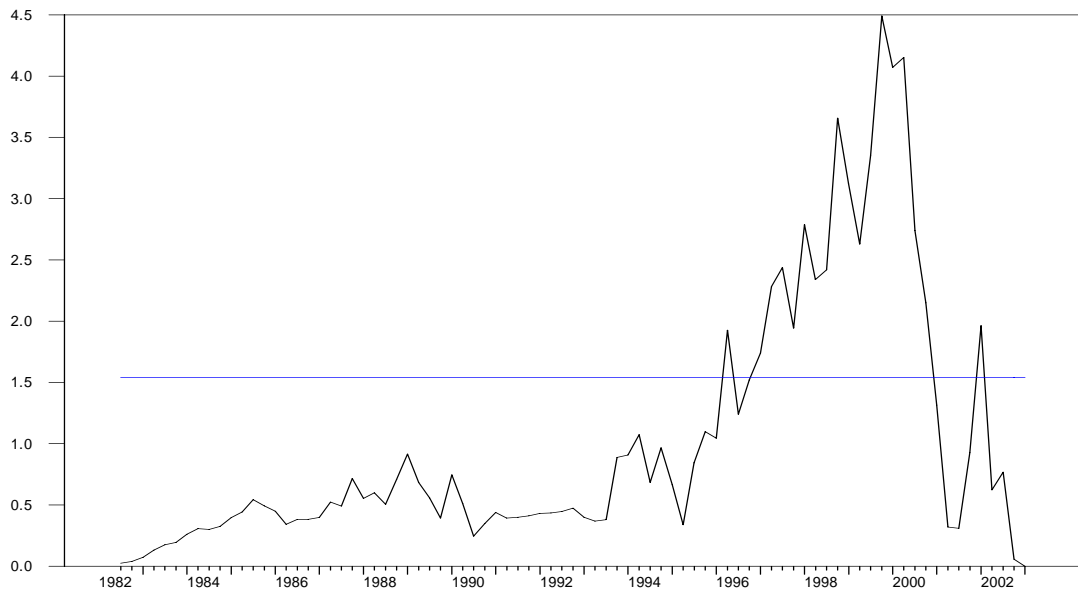
Figure US1: Spectrum of the US Growth Rate

Figure US2: Fluctuation Test of the US Growth Rate