Spectral Analysis In Three Dimensions: The Examination Of Economic Interdependence Between New York, London, Tokyo And The Pacific Basin Equity Market Indices

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Abstract

This paper analyzes the use of three dimensional spectral analyses. We highlight the power of this technique by examining the economic interrelationships among Pacific Basin countries, Tokyo, New York and London equity markets. To the best of our knowledge, no research in financial economics has ever employed the spectral technique with greater than two dimensions. Our use of three way spectral analysis, or partial coherence measures, allows us to ferret out the influence of correlated variables, in this case, major world markets (New York, London, Tokyo) before examining the relationship among the variables of primary interest, the Pacific Basin markets. We hold constant the influence of New York, London, and Tokyo before examining the relationship among Pacific Basin Newly Industrialized countries equity indices to illustrate our methodology. Simulation techniques enable us to document the statistical power of our technique.

I. Introduction

Spectral analysis poses a major advantage over other financial economic methodologies (ARMA, ICAPM, IAPT). It allows the economic time series data to "speak for itself" and does not impose the risk of model misspecification on the data as do some other techniques.[1] A disadvantage of spectral analysis, may be the difficulty of thinking of economic time-series data in frequency concepts. This may be the reason that (to the best of our knowledge) there is no research actually employing three-way spectral analysis, or partial coherence to examine the relationship among economic time series data.

To illustrate our technique, we examine the relationships among Pacific Basin Newly

Industrialized Country (PBNIC) equity indices New York, London, and Tokyo.[2] One suspects that there is a great deal of economic interdependence among world equity indices. Casual empiricism suggests that when the NYSE Composite falls so does the Tokyo NIKKEI. Much of the research that focuses on the relationship between equity indices considers either the benefits of international portfolio diversification or the lead/lag relationships between two market indices.[3] There is, however a small body of research which uses the technique of spectral analysis to examine the relationship between two world market indices.[4] However, previous empirical research which uses this technique examines the cross-spectra between two markets and the results of such an analysis may be misleading or spurious. Once the Japanese, United States, or Great Britain market is held constant, an observed relationship between the two other equity markets may be modified or may even disappear. For example, an observed relationship between the Taiwan and Korean markets may really reflect the relationship each of them has with Tokyo, rather than the economic interdependence between the two of them.

The focus of this manuscript is the use of three way spectral analysis or partial coherence. We examine the relationship among seven market indices; Korea, Taiwan, Hong-Kong, Singapore, Japan, London and the United States to illustrate the technique. Section II describes the methodological technique of spectral analysis and Section III our simulation studies aimed at documenting the power of our statistical tests as their use is uncommon in financial economics. Data and our illustrative empirical results are presented in Section IV, while Section V contains our conclusions.

II. The Spectral Methodology

The spectral analysis technique produces a number of interesting statistics. Autospectrum, cross-spectral coherence, phase and partial coherence, are among them. Autospectra is simply the analysis of a single time-series. Estimation of the autospectrum allows the isolation of any cycles that may exist in the data. At a particular frequency interval, the autospectrum is a measure of the contribution of that frequency to the total variance of the series. The cross-spectral coherence measures the covariance relationship between two jointly stationary stochastic processes at a particular frequency or across frequency bands. Frequency may be a concept that is hard to interpret with financial economic data. However, frequency and period exhibit an inverse relationship and intuitively the concept of a periodogram may be more meaningful. For example, at low frequencies (equivalently long periods) a high cross-spectral coherence documents an important relationship between two time series data. The phase angle can be used to analyze leads and lags in the time-series data. The slope of the phase diagram tells us something about the lead/lag characteristics of the data. Specifically, a negative slope in the phase diagram corresponds to a leading input series; while conversely, a positive slope implies the output series is the leading variable.

A three variable partial coherence measure may be interpreted as analogous to partial correlation. It can be estimated by the causal model suggested by Granger (1964):

$$X_t = a_1(U)X_t + b_1(U)Y_t + c_1(U)Z_t + \varepsilon_{1,t}$$

$$Y_t = a_2(U)X_t + b_2(U)Y_t + c_2(U)Z_t + \varepsilon_{2,t}$$

and

$$Z_t = a_3(U)X_t + b_3(U)Y_t + c_3(U)Z_t + \varepsilon_{3,t}$$

where X_t, Y_t and Z_t are stationary time-series with zero mean, $a_i(U)$, $b_i(U)$ and $c_i(U)$ are polynomials in U, the shift operator, and $\varepsilon_{i,t}$, I = 1,2,3 are uncorrelated white-noise series. Variance is denoted $\varepsilon_{it} = \sigma^2_i$.

X_t, Y_t and Z_t, t=0, ± 1.... are univariate processes with spectral density function, $f(\lambda)$. The process can be observed for times, t, $1 \le t \le N$, where N is the sample size. The finite Fourier transform of the data can be normalized:

$$Z_V^{(N)} = \frac{1}{(2\pi N)^{1/2}} \sum_{t=1}^{N} X(t)\, e^{-i\lambda_V t}$$

where: $\lambda v = 2\pi V/N$

and $-[(N-1)/2] \leq V \leq [N/2]$[5]

The distribution theory for the Z_V's is an asymptotic one and the results derived using it will be asymptotically correct if N is not too small.

When considering any economic time series data with a multi-peaked spectrum, the choice of window is important. The window bandwidth of a spectrum corresponds roughly to the narrowest peak. In general the effect of increasing the window is to increase the variance. Conversely, decreasing the window, decreases the variance but increases the bias of the results. The implication is that different windows lead to estimates with potentially different statistical properties. Indeed, Jenkins (1969) suggests that one of the biggest disadvantages of spectral analysis is that it is "necessary (desirable) to estimate a whole function...". To isolate the relevance of our window width choice we employ the simulation tests described in Section III below. In addition to the difficulty involved in choosing the proper window width, the assumptions involved in employing spectral analysis are: stationarity, linearity, and normality of the data.[6]

III. Simulation Techniques and Results

Unlike a discussion of radio wave frequency and bands, in the analysis of economic time-series data, the concept of bandwidth does not have any obvious physical interpretation. Likewise, the choice of the window width which makes the (results) resolution clearest is somewhat subjective. In order to select any window (time period) which make the results seem clearest, we must apply some "goodness criterion." But no (criterion) yardstick of merit seems to suffice for all possible underlying spectra.[7] Further, different (time periods) windows lead to estimates with different statistical properties. Priestley (1981) suggests a number of criterion or yardsticks for judging the merit of different windows (time periods). In our case, since the number of observations (N) in the empirical sample we use to illustrate this technique is fixed, the question reduces to the choice of window (time) parameter, labeled M, using a:) an auto-covariance function, b:) a window closing technique, or c:) choosing M as a fixed proportion of N.[8]

Consequently, the criteria we use for choosing a specific spectral window is based upon simulation experimentation.[9] The simulation experiments we conduct sets the data correlation coefficient, r equal to either 0 or .5. Each simulation sample has three variables, X, Y and Z with the "true" relationship determined by their imputed correlation coefficient.

$$X = Z + b_1 V_1$$

$$Y = Z + b_2 V_2$$

where V_1 and V_2 are uncomelated white noise as in the Granger (1964) model in the previous sections.

Table 1 provides, M "window width", the degrees of freedom which result from that value choice for M, and the customary F statistic.[10] The relationships among window width, (M), estimated degrees of freedom, (EDF), cut-off values, (CV) and F statistics can be seen from Table 1. As the window width decreases, the cut-off value and the F statistic also decrease, correspondingly the degrees of freedom increase.

Table 2 provides our simulation results. Column one indicates window width with columns two and three providing the empirical results when the true correlation coefficient equals zero or one-half respectively. Column two can be interpreted as the familiar statistical concept of size. When the true correlation coefficient is zero and the window width is 80, in 15% of the cases we reject the null hypothesis that $\rho=0$ when, in fact, the population correlation coefficient is zero. Thus, column two can be read as the probability of committing a type I error.

It is standard in simulation tests of spectral analysis to choose ρ = .5 for a consideration of

Table 1
Tukey-Hamming Windows (N=300)

M	EDF	CV	F
80	9.4	0.7132	9.20
60	12.5	0.5846	7.39
40	18.8	0.4218	6.13

Where M is window width, EDF is the equivalent degrees of freedom, CV is cut-off value and F is the customary F statistic.

Table 2
Number of Significant Samples (Peak Partial Coherence)

M	RHO = 0.0	RHO = 0.5
80	.15	.75
60	.35	.85
40	.50	.95

Where M is window width and RHO is the true correlation coefficient between the simulated date.

power. Column three can be interpreted as the power of our test, or P(1-Type II error). For example, when the window width is 80, 75% of the time we reject the null hypothesis that the true correlation is zero, when in fact, the population correlation between X and Y is not zero. These results lead us to choose a window width of 80.

IV. An Illustrative Empirical Example Using Pacific Basin Newly Industrialized Countries

Based upon our simulation results, we choose a window width of 80 for calculating coherence and partial coherence at peak and average frequencies for our time series equity market prices in the Pacific Basin countries. Using daily observations on seven market indices, New York, Tokyo, London, Taiwan, Korea, Hong-Kong and Singapore, we examine the relationship between the Pacific Basin's newly industrialized countries equity indices from March 1987 to February 1988 (N = 307 observations).[11] We chose this time period because of the availability of data and because it covers the period of the October 19, 1987, NYSE crash. Ex-ante we would expect that if there is any relationship between these markets, it would be easiest to detect during this time period.12 This, of course, biases our results in favor of finding a relationship and consequently, if evidence of equity market interdependence is uncovered, future research would be necessary to determine if the relationship was generalizable to other time periods.[13]

Table 3 provides our estimates of the relationship between the Pacific Basin equity indices holding the effect of the New York stock exchange, the London stock exchange and the Tokyo stock exchange constant. The spectral relationship is documented at both peak and average frequency where average can be interpreted as across all frequencies between March 1987 and February 1988. The right hand side of either the peak or the average column calculates coherence as it has historically been calculated in financial economics research, simply the cross-sectional coherence between two equity market index pairs. The left hand side of either the peak or the average column provides our estimate of the partial coherence, that is, the relationship between two equity index pairs, while holding the effect of the New York, London, or Tokyo market constant. At the 1% level of significance, the cut-off value for a significant relationship is .7031.

Table 3 provides some interesting results. Note that when we examine the data across all (average) frequencies, the relationship among these Pacific Basin Newly Industrialized Countries is insignificant for the time period examined. Thus, spectral analysis as it has historically been employed in financial economics would suggest there is no economic interdependence among these newly industrialized countries. The same is true for the relationship among major market indices (see panel B of Table 3). In contrast, when we

Table 3 Peak and Average Coherence

A) Peak and Average Coherence ofNICs holding Major Markets Constant*

	Peak***				Average			
Pair*	Par. NY	Par. TK	Par. LD	Coherence	Par. NY	Par. TK	Par. LD	Coherence
TW,KR	.6455	.7345**	.6299	.5841	.2280	.2343	.2224	.1810
TW,HK	.6916	.7303**	.5639	.4481	.1792	.1961	.1827	.2010
TW,SP	.6025	.9012**	.9228**	.6664	.2779	.3188	.2814	.2865
KR,HK	.5569	.6896	.6526	.5134	.1920	.2254	.1834	.1763
KR,SP	.7576**	.8589**	.7110**	.7247**	.2647	.2671	.2391	.2138
HK,SP	.8650**	.9202**	.8101**	.9349**	.3056	.3101	.2784	.3307

B) Peak and Average Coherence of Major Markets

	Peak***				Average			
Pair*	Par. NY	Par. TK	Par. LD	Coherence	Par. NY	Par. TK	Par. LD	Coherence
NY,TK	--	--	.8704**	.8673**	--	--	.2970	.4593
NY,LD	--	.7716**	--	.8583**	--	.3153	--	.4546
TK,LD	.9167**	--	--	.9311**	.3725	--	--	.5191

*The time period of the data is March 1987 - February 1988 (N=307obs.) The window used is Turkey-Hamming with a window width of 80 days. NY-New York, TK-Tokyo, LD-London, TW-Taiwan, KR-Korea, HK-Hong Kong, SP-Singapore.
**The cut-off value for significance is 0.7031 at the 1% level.
***Note some peaks are at frequency 3.1416 which may have some bias.

examine the data at the peak frequency and hold constant the influence of the New York market, two of the Pacific Basin countries as well as all of the major market pairs exhibit a significant cross-spectral coherence. Panel A indicates that Korea and Singapore have a significant cross-spectral coherence as do Hong-Kong and Singapore, while the other country-pairs do not. However, while holding the affect of the Tokyo market constant, the partial coherence measures for all pairs except Korea and Hong-Kong are significant. Thus it appears that calculation of cross-spectral would not show evidence of a significant economic interdependence for six of the market pairs considered, whereas the partial coherence methodology allows us to document the existence of this economic interdependence for five of those six pairs. Only the Korea and Hong-Kong indices show no evidence of significant economic interdependence. The third column in the peak side hold constant the effect of the London market and can be interpreted in the same fashion as columns one and two.

Tables 4, 5, and 6 further clarify our results. Table 4 provides our estimates of the cross-spectral relationship between Tokyo and the Pacific Basin Newly Industrialized countries and New York. Column one indicates frequency. But perhaps column two, period, is most easily interpreted with financial economics data. Period can be interpreted as the time domain. For example, at 20 days, Tokyo and New York have a statistically significant cross-spectral relationship. This is also evident for approximately three and a half, four, and four and a half days. At two and a half, five days, forty and eighty days, Hong-Kong has a significant cross-spectral coherence with New York. At forty days and approximately seven days, Singapore was a significant cross spectral coherence with New York also. Note that only Tokyo, Hong-Kong, and Singapore show evidence of a relationship with the New York market. Conversely, Taiwan, and Korea, do not appear to have a significant relationship with the New York market, regardless of the period of the estimation for the 1987-1988 time period examined. This lack of economic relationship we might speculate has its roots in political considerations.

Table 5 provides evidence of our cross-spectral coherence estimates for these same countries and London with Tokyo. As can be seen, Tokyo and London have significant coherence at several periods, 2.16 days, 2.42, 2.76, 3.48, 4, 4.21, 4.71 and 6 days. All of these represent relatively short time periods. Tokyo and Taiwan have evidence of significant cross-spectral relationship at forty days. Tokyo and Hong-Kong have evidence of a significant relationship at shorter time periods of five, 4.44, 3.2 and 2.76 days. Singapore and Korea show no evidence of any significant economic relationship as do Tokyo and Hong-Kong. Table 6 presents our evidence concerning the cross-spectral coherence of the newly industrialized countries and London. London and Taiwan appear to have no relationship, whereas London and Hong-Kong do at periods of eighty, forty, 26.67, 11.43 and 2.76 and London and Singapore do at the same time periods of eighty, forty, 26.67, 11.43 and 4.44. From these results one could expect that Hong-Kong and Singapore have a significant relationship. Certainly from an economic development perspective, this is not a surprising result. For the first time in Table 6, Korea has evidence of a statistically significant cross-spectral coherence with London at 11.43 days. The paucity of this observation makes the authors skeptical about the economic significance of this result.[14]

Conclusions

We use partial coherence and three-way spectral analysis to examine the economic interdependence of the Pacific Basin newly industrialized countries market indices and major market indices. There is little history of using three-way spectral analysis with financial economics data. Consequently we first conduct simulation tests to determine the parameters and to document the power of our tests. The use of spectral analysis to examine the relationships among economic time-series data has perhaps an important advantage, that of avoiding the risk of model misspecification.

For the period we examine in our illustrative case, one year around the 1987 Wall Street crash, there is evidence of an economic relationship between the Pacific Basin's newly industrialized countries equity indices and that of the New York composite. Our choice of time period, of course, biases the results in favor of uncovering a relationship. It remains for future research to determine whether this integration is generally present. Further, countries within the Pacific Basin appear to exhibit a significant inter-market relationship. The exception appears to be Korea, which exhibits little relationships with other major markets or Pacific Basin markets. Viewed in a political context, this is not a surprising result. Also consistent with what we might expect based upon political considerations, Taiwan shows little evidence of index integration with New York or London. These results are not unlike those of

Table 4 Cross-Spectral Coherence, Tokyo and NICs vs. New York

Frequency	Period	TK	TW	KR	HK	SP
0.0785	80.00	0.2628	0.3568	0.0689	0.7228*	0.5733
0.1571	40.00	0.4220	0.2438	0.0335	0.8503*	0.7926*
0.2356	26.67	0.4226	0.5069	0.0006	0.5718	0.6210
0.3142	20.00	0.7133*	0.0227	0.2065	0.5392	0.0936
0.3927	16.00	0.5085	0.1686	0.0058	0.4062	0.0018
0.4712	13.33	0.2730	0.4384	0.2890	0.6471	0.4154
0.5498	11.43	0.2571	0.0271	0.1361	0.4172	0.3163
0.6283	10.00	0.8673	0.1662	0.0490	0.3997	0.0401
0.7069	8.89	0.5497	0.4911	0.1067	0.2239	0.4485
0.7854	8.00	0.5338	0.4219	0.1637	0.0526	0.6990
0.8639	7.27	0.6290	0.4374	0.0441	0.1114	0.7535*
0.9425	6.67	0.3912	0.4560	0.4151	0.5909	0.8743*
1.0210	6.15	0.4054	0.3445	0.3691	0.0410	0.4212
1.0996	5.71	0.6079	0.1830	0.0530	0.3290	0.3601
1.1781	5.33	0.4092	0.1248	0.1004	0.2502	0.1705
1.2566	5.00	0.7472	0.0991	0.0639	0.7048*	0.4509
1.3352	4.71	0.5038	0.1395	0.2093	0.5870	0.2151
1.4137	4.44	0.8000*	0.4989	0.1580	0.5491	0.3497
1.4923	4.21	0.4409	0.1438	0.1821	0.3907	0.1898
1.5708	4.00	0.7631*	0.1416	0.0220	0.2493	0.5018
1.6493	3.81	0.5810	0.0859	0.1550	0.0899	0.5617
1.7279	3.64	0.3937	0.1767	0.0878	0.4683	0.5847
1.8064	3.48	0.7390*	0.1900	0.1874	0.3676	0.5135
1.8850	3.33	0.5273	0.1251	0.3163	0.3846	0.1919
1.9635	3.20	0.4501	0.0073	0.2103	0.5763	0.0612
2.0420	3.08	0.0520	0.2522	0.3506	0.1642	0.2006
2.1206	2.96	0.3170	0.0224	0.1520	0.0741	0.3469
2.1991	2.86	0.5287	0.1726	0.1269	0.6788	0.2015
2.2777	2.76	0.6440	0.3488	0.1233	0.7345*	0.2325
2.3562	2.67	0.6728	0.0169	0.1182	0.5055	0.2222
2.4347	2.58	0.3731	0.1906	0.1733	0.4152	0.3483
2.5133	2.50	0.4047	0.1472	0.0934	0.4561	0.0786
2.5918	2.42	0.1137	0.2787	0.2058	0.0552	0.1253
2.6704	2.35	0.3088	0.0539	0.1928	0.1666	0.4222
2.7489	2.29	0.0979	0.2793	0.3404	0.0074	0.0162
2.8274	2.22	0.2572	0.1239	0.0737	0.2482	0.1800
2.9060	2.16	0.1896	0.1939	0.5099	0.0871	0.0520
2.9845	2.11	0.2846	0.1122	0.1418	0.0800	0.1044
3.0631	2.05	0.3547	0.2597	0.2557	0.5501	0.2154
3.1416	2.00	0.1249	0.1734	0.0058	0.1743	0.3270
Average		0.4593	0.2156	0.1624	0.3730	0.2779

Note: * denotes significant at 1% level (CV = 0.7031).
** denotes significant at 5% level (CV = 0.5558).

Table 5 Cross-Spectral Coherence London and NICs vs Tokyo

COHERENCES, WITH TK

Period	TW	KR	HK	SP	LD
80.00	0.4655	0.1823	0.1412	0.2130	0.0581
40.00	0.7186*	0.0994	0.5364	0.5036	0.3600
26.67	0.2824	0.1386	0.5787	0.5309	0.3833
20.00	0.0630	0.0645	0.5712	0.0470	0.6932
16.00	0.0434	0.1430	0.3468	0.1219	0.3542
13.33	0.5692	0.5436	0.2382	0.1248	0.5189
11.43	0.1461	0.3997	0.2061	0.1802	0.2546
10.00	0.2742	0.0182	0.2648	0.0024	0.1515
8.89	0.0753	0.1904	0.1371	0.0769	0.4097
8.00	0.2994	0.0196	0.0359	0.1698	0.3513
7.27	0.1617	0.0294	0.1045	0.3541	0.6395
6.67	0.2575	0.1526	0.3827	0.3670	0.8356*
6.15	0.4726	0.2638	0.4515	0.2157	0.4290
5.71	0.1687	0.0911	0.2949	0.3111	0.3609
5.33	0.1452	0.2258	0.4432	0.2909	0.3182
5.00	0.0674	0.0496	0.7792*	0.5463	0.5407
4.71	0.5824	0.0446	0.6545	0.5076	0.7085*
4.44	0.5778	0.1481	0.8297*	0.4893	0.6273
4.21	0.2277	0.2047	0.6284	0.2127	0.8438*
4.00	0.2358	0.0304	0.1366	0.4171	0.9311*
3.81	0.0652	0.0908	0.3203	0.5256	0.4355
3.64	0.0429	0.2292	0.0915	0.3152	0.6267
3.48	0.1246	0.2772	0.4875	0.5243	0.7531*
3.33	0.2281	0.1296	0.4661	0.4368	0.5825
3.20	0.2280	0.1904	0.7041*	0.1518	0.6256
3.08	0.0355	0.3385	0.4930	0.3422	0.0613
2.96	0.1186	0.2556	0.5084	0.3249	0.2016
2.86	0.1164	0.0163	0.7870	0.5872	0.0988
2.76	0.5041	0.0872	0.8327*	0.3006	0.7516*
2.67	0.0930	0.1850	0.4157	0.1879	0.6393
2.58	0.0932	0.0321	0.1738	0.1988	0.5560
2.50	0.1493	0.3373	0.0183	0.0897	0.6129
2.42	0.3139	0.0732	0.0912	0.3024	0.7799*
2.35	0.0977	0.2261	0.4739	0.3081	0.7024
2.29	0.1536	0.3308	0.4498	0.2764	0.5137
2.22	0.0894	0.3715	0.6655	0.2244	0.6977
2.16	0.0872	0.2048	0.4054	0.0288	0.8215*
2.11	0.0353	0.0455	0.1125	0.0523	0.4093
2.05	0.2123	0.5939	0.5824	0.2159	0.6233
2.00	0.0673	0.4833	0.4253	0.3464	0.5002
Average	.2172	.1884	.4067	.2855	.5191

Note: * denotes significant at 1% level (CV = 0.7031).
** denotes significant at 5% level (CV = 0.5558).

Table 6 Cross-Spectral Coherence
NICs vs London

COHERENCES, WITH LD

	Period	TW	KR	HK	SP
	80.00	0.3145	0.4263	0.9033*	0.7327*
	40.00	0.3857	0.0649	0.8329*	0.8441*
	26.67	0.1985	0.0419	0.8451*	0.8586*
	20.00	0.1091	0.2221	0.6251	0.0939
	16.00	0.1658	0.1138	0.3767	0.0537
	13.33	0.4018	0.4868	0.5361	0.4006
	11.43	0.2461	0.7264*	0.8626*	0.8976*
	10.00	0.0959	0.1862	0.1067	0.5276
	8.89	0.4814	0.2620	0.2006	0.3138
	8.00	0.3684	0.2672	0.0383	0.2061
	7.27	0.3406	0.057	0.1322	0.2831
	6.67	0.4174	0.2389	0.5443	0.3736
	6.15	0.4379	0.2181	0.0764	0.3290
	5.71	0.0724	0.2299	0.0868	0.4716
	5.33	0.1718	0.2777	0.3398	0.0609
	5.00	0.0908	0.0903	0.3173	0.1634
	4.71	0.2923	0.1754	0.6521	0.4971
	4.44	0.6784	0.1344	0.7900	0.7354*
	4.21	0.2279	0.1700	0.4734	0.2507
	4.00	0.2256	0.0580	0.1786	0.4574
	3.81	0.2318	0.2456	0.2431	0.3288
	3.64	0.3201	0.1778	0.1071	0.3110
	3.48	0.2535	0.2830	0.3994	0.4030
	3.33	0.0508	0.0476	0.1634	0.2040
	3.20	0.0388	0.0669	0.4300	0.1775
	3.08	0.1785	0.0039	0.2965	0.0860
	2.96	0.1132	0.1828	0.0089	0.6297
	2.86	0.1735	0.3456	0.3008	0.1879
	2.76	0.6150	0.2737	0.8394*	0.3883
	2.67	0.0290	0.0268	0.4739	0.1903
	2.58	0.0363	0.1070	0.1745	0.1116
	2.50	0.0034	0.3983	0.0981	0.0902
	2.42	0.1329	0.1471	0.0708	0.2261
	2.35	0.2799	0.2526	0.1638	0.3774
	2.29	0.4283	0.1350	0.1249	0.0878
	2.22	0.1420	0.3325	0.5897	0.0432
	2.16	0.0323	0.1222	0.5076	0.0419
	2.11	0.1101	0.2479	0.0320	0.0552
	2.05	0.3196	0.1940	0.6473	0.0570
	2.00	0.6755	0.2613	0.1680	0.7541*
Average	0	.2472	0	.3687	.3303

Note: * denotes significant at 1% level (CV = 0.7031).
** denotes significant at 5% level (CV = 0.5558).

Hilliard (1979).

Using either more "traditional" cross-spectral coherence, or three-way partial coherence measures, it can be concluded that all of the major markets (Tokyo, London, and New York) exhibit strong inter-market relationships. However, the use of partial coherence enables us to identify the strength of the associations between the Pacific Basin newly industrialized markets and between these markets and the major world markets with greatest clarity. This technique has the ability to isolate relationships among economic time series data when the relationship between those same series of data is obscured by their mutual association with a third series. Future research needs to focus on the strength of the historical association between these market indices as well as the current association. It would be interesting to discover whether market associations vary with political conditions and other major socio-economic events. Also worthy of exploration is the concept of N-dimensional spectral analysis which would allow us to hold constant all other indices influences and isolate the strength of integration between an index pair. The current manuscript as well as future extensions have implications for international portfolio diversification as well as economic policy.

Suggestions For Future Research

This research has used an uncommon methodology (in business disciplines), partial coherence, to examine the strength of inter-market relationships around the time of the October 1987 market crash. Future research needs to focus on the strength of the historical association between these market indices for a more typical time period as well as the current association. It would be interesting to discover whether market interrelationships vary with political conditions and other major socio-economic events. Also worthy of exploration is the concept of N-dimensional spectral analysis which would allow us to hold constant all other indices influences and isolate the strength of integration between any index pair. As does the current manuscript, future extensions have implications for international portfolio diversification as well as public economic policy.🕮

Footnotes

1. As with other economic models, data stationarity is an important assumption made when using N-dimensional spectral analysis.
2. We use the term our *technique* loosely. N-dimensional spectral analysis is not new in engineering applications. However, its use in economics is here-to-fore absent.
3. For some examples of research on international portfolio diversification see Grubel (1968), Levy and Sarnat (1970), Solnik (1974), Watson (1978), Eaker and Grant (1990), Hunter and Coggin (1990), Bailey and Stulz (1990), Le (1991), French and Poterba (1991), Bailey and Lim (1992), Madura and Soenen (1992), Johnson and Walther (1992), Levy and Lim (1994) and Eun and Resnick (1994). For examples of research on the lead/lag relationship between world equity indices see Granger and Morgenstern (1970), Agmon (1974), Branch (1974), Oellermann, Brorsen, and Farris (1989), Hamao, Masulis and Ng (1990), Becker, Finnerty and Gupta (1990), Koch and Koch (1991), and Malliaris and Urrutia (1992).
4. For example, see Granger and Morgenstern (1970), Hilliard (1979), Fischer and Palasvirta (1990), Nachane, and Chrissanthaki (1991) and Erol and Balkan (1991).
5. See Koopmans (1974, Chapter 8, pg. 257-265) He shows that:

$$I_{N,V} = |Z_V^{(N)}|^2 = \frac{1}{2\pi N} \left| \sum_{t=1}^{N} X(t)\, e^{-i\lambda_V t} \right|^2$$

is a reasonable estimator for the spectral density function at λ_v for time series data and for a further discussion of the conditions under which estimation is consistent and unbiased.
6. For examination of inter-country economic time series data, there is some empirical evidence concerning inter-country stationarity. See Makridakis and Wheelwright (1974), Maldonado and Saunders (1981),

Watson (1980), and Wheatley (1988) for example.

7. See Koopmans (1974) pg. 308-309.
8. The choice of M as a fixed proportion of N has little intuitive appeal and its only theoretical justification is that it controls the value of the relative variance. See Koopmans (1974).
9. In our simulation tests, for convenience, we chose the Tukey-Hamming window with three different window widths, 80, 60, and 40.
10. The equivalent degrees of freedom (EDF) is dependent upon the window and the window width used. For the Tukey-Hamming window, the equivalent degrees of freedom is determined as:

    $$EDF = (2.5*N)/M$$

    where N is the number of observations and M is the window width.

    The cut-off value for the null hypothesis of zero partial coherence is:

    $$\frac{(EDF-2*P)*K^2}{2*(1-K^2)}$$

    which is F-distributed with 2 and EDF-2*P degrees of freedom.

    K denotes partial coherency (square root of partial coherence)and, P is the number of variables to be partialled out.
11. This data was obtained privately and the accuracy of it was randomly verified using the *Wall Street Journal* and the *London Times*.
12. For some evidence concerning market lead/lag relationships during the October 1987 crash period see Malliaris and Urrutia (1992).
13. We have reserved two additional time periods, before and after the NYSE crash for examination in the future.
14. A complete set of graphical evidence on these tabled results is available from the authors.

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