Capital market integration in a post crisis era: the case of India

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Abstract: Since the collapse of Lehman Brothers, the co-dynamics of the Rupee and the India stock exchange index, the Senex, have altered. Although emerging markets could have been shielded from the vagaries of financial flows that have plagued the developed world, it is shown that, in the post financial era, rather than a decoupling, India has been integrated further into global capital markets.

Keywords: contagion; integration; spectral analysis; India; exchange rates; stock exchange.

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1 Introduction

During the current financial crisis, less developed but very large emerging economies, such as Brazil, China, and India, may have became decoupled from the rest of the world, so that the growth-constraining crisis passed them by. It has been hypothesised that switching from external to internal consumption would allow them to grow independently of the developed world. This independence could be seen in the distinctly different issues facing them. Even with quantitative easing (QE), the growth in the developed world appears stagnant whilst, perhaps because their domestic stimulus policies worked too well, India, China and Brazil are attempting to constrain asset price bubbles.

Alternatively, one might suggest the reverse. Rather than a decoupling, the asset price bubbles could be a symptom of emerging economies being absorbed into the global capital market system. Granger et al. (2000) find that during the Asian currency crisis of

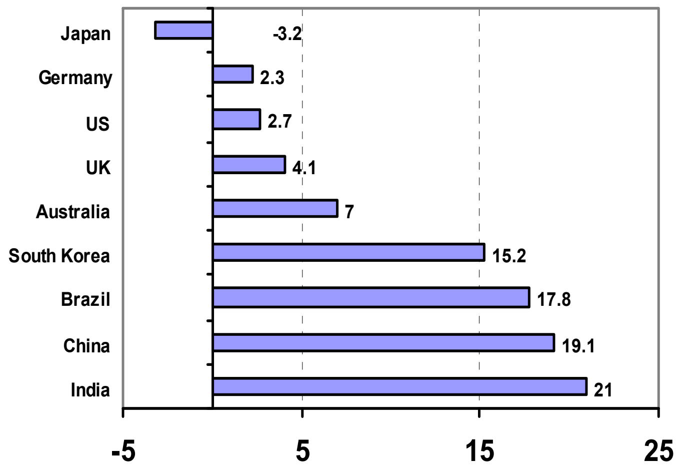
1997, with increasing capital market deregulation, there is a shift of emphasis from the exporting corporation to the role of portfolio investment, suggesting the crisis induced greater capital market integration of emerging economies. Evidence for absorption affecting India is considered in this article.

The article is compiled as follows. Section 2 provides a brief discussion of recent capital flows in India. There is a review of models of exchange rate – stock exchange interaction and a consideration of empirical work on contagion and asset market price co-movement in sections three and four. These are followed by discussions of the methods and data. It is shown in Section 7 that there has been an intensification of co-movement between the Rupee and the Senex pointing to integration rather than contagion, and it is concluded that there is only limited evidence that the portfolio model is favoured over the traditional one, three years after the crisis began.

2 The Indian context

Wigglesworth and Wagstyl (2011) report that, with modest returns in developed world currency and bond markets, investors have increased their holding of emerging market assets from \$17.3 bn at the end of 2008, through \$25.2 bn in 2009, to \$64.5 bn in 2010; an annual growth rate of 55%.

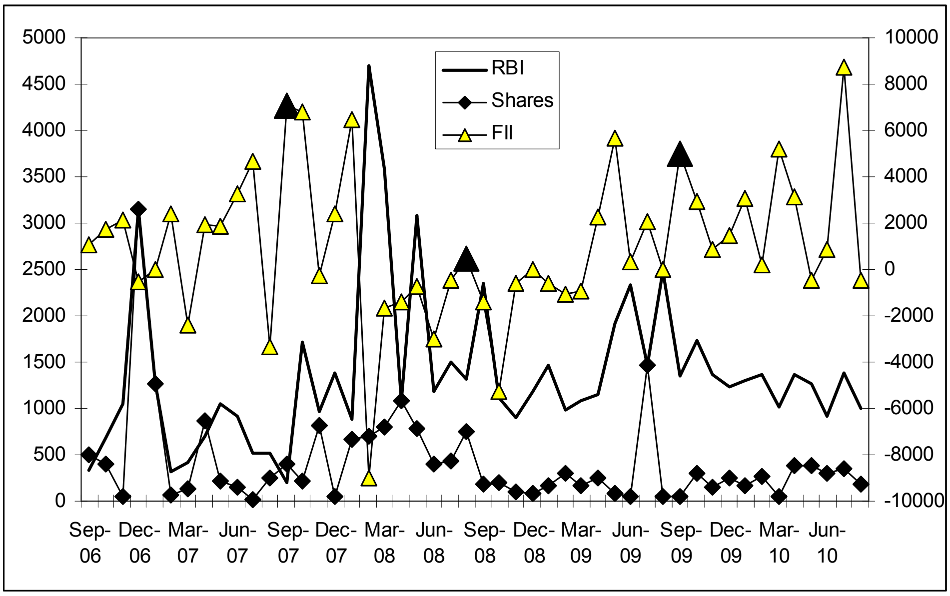
Figure 1 Shareholder annual returns over ten years, compounded (see online version for colours)



Source: Financial Times 10/6/11

Despite returns from investing in Indian shares being as high as anywhere, outstripping other BRIC country performances, with an annual rate of return of 21%, rather than increased flows, Siddiqui (2009) finds capital inflows to India decreased significantly from 2007/8 to 2008/9. This is not of a result of direct foreign investment (DFI); rather the culprit is financial institutional investment (FII). This flow reflects speculative currency purchases, which led to the Reserve Bank of India (RBI) building up reserves. Moreover, Siddiqui (2009) challenges the decoupling thesis even with goods alone, suggesting that the export-led growth that drove emerging economies so far would leave them dependent on the developed world. In Figure 2, monthly data concerning the acquisition of shares of Indian companies by non-residents, portfolio investment by FII and reserves held at the RBI. Share acquisition is generally steady and in decline. The RBI series becomes more stable in years 2 and 3. Siddiqui's (2009) claim about the RBI building up reserves is supported. Portfolio investment (right-hand scale) swings violently between net positive and negative flows. The larger triangles indicate the value for September 2007, 2008 and 2009. Interestingly, by eye, portfolio investment volatility appears in 2008/9 year, the post Lehman's year, to be lower than in 2007/8. However, 2006/7 seems much like 2009/10 in that portfolio investment becomes an increasingly larger share of net flows. Overall though, the net investment flows reflect the variation in portfolio investment, which is of a larger order of magnitude than the other flows.

Figure 2 Capital movements over four years (see online version for colours)



Notes: RBI: change in currency reserves at the RBI
Shares: acquisition of shares of Indian companies by non-residents
FII: inflow of funds (net) by Foreign Institutional Investors (right-hand scale)
Source: RBI

It appears that portfolio investment was perturbating around an upward trend, with a dislocation, also found in the RBI time series, occurring in Q1 2008. This upward trend is indicative of financial integration.

3 Models of stock and foreign exchange prices

An efficient market in both renders the use of one, in the forecasting of the other to achieve greater returns, worthless. However, empirical evidence suggests that a statistical lead-lag relationship can be modelled, so that practitioners can profit from arbitrage, possibly during a severe financial crisis. Morley and Pentecost (2000) find that there are common cycles rather than common trends in the relation between exchange rates and stock prices for the G-7 industrialised countries over 1982–1994. There are two theoretical models relating the exchange rate and the stock prices of a country commonly found in the literature: the traditional and the portfolio.

3.1 The traditional model

The 'traditional', flow-oriented approach focuses on the current account and trade. The exchange rate affects, and is affected by, the relative competitiveness of the internationally traded goods and services. The stock exchange will reflect the returns from investing in large, internationally oriented, firms. This can be seen in terms of the assets and liabilities denominated in foreign currency, or of the competitiveness of exports and imports. Even non-international traders would be affected, indirectly, through costs of materials purchased from importers. Aggarwal (1981) argues that profit streams are strongly influenced by the impact of the exchange rate on the performance of multinational firms. Export-oriented firms benefit from a fall; importing ones, from a rise; whilst undertaking both leaves the sign of correlation between the exchange rate and the stock price arbitrary. Nevertheless, exchange rates should lead stock prices.

3.2 The portfolio approach

The stock-oriented approach reflects the operation of the portfolio manager. The exchange rate is a mediator between domestic and international markets for bonds and stocks. Expectations of future incomes from these assets are affected by relative currency values. Following a fall in the share price, such that a company is undervalued, foreign investors will switch to domestic currency to purchase the under-priced shares, causing an inflow of funds. Thus, there should be a negative relationship between stock prices and exchange rates, and the former should lead the latter. This view emphasises the capital account.

Patterns of exchange rate – stock price co-movements may be revised in the face of a crisis. Granger et al. (2000) consider whether the Asian currency crisis of 1997 induced greater capital market integration. Any decoupling of the developed and emerging worlds may not immunise countries like India from contagious financial effects. QE leakage may contribute to Indian, Chinese and Brazil asset price bubbles, and the appreciation of the Rupee against the Dollar would affect exports. Thus, as a result of the crisis, the co-movement of different classes of financial asset prices would alter.

The work covers the two years before and after Lehman Brothers collapsed (15 September 2008). A general definition of financial contagion could be the dynamics of co-variation of asset price alters following an event or shock. As such, contagion implies the existence of a tranquil, pre-event period, which acts as a benchmark for gauging change following the event. The year before the Lehman collapse could be used as the reference year. However, year 1 is characterised by a banking crisis, with a sudden halt to the normal workings of the London Interbank Lending system, resulting in the failure of Northern Rock in the UK, so an earlier year is chosen. Integration alone would have it that the degree of co-movement would increase year-on-year. Contagion implies a rapid and temporary rise in co-movement.

The issues considered are: first, does the Rupee per Dollar-Bombay Stock Exchange's Senex index relationship reflect a traditional or a portfolio model; second, were the

Rupee and the Senex index subject to contagion and, if so, is there evidence of a non-linear change? and third, was there a reversion back to a pre-Lehman relationship, or is there evidence of greater integration within global capital markets, as highlighted by the portfolio model.

The data analyses will be undertaken in the frequency domain. Coherence, cospectra, power spectra, gain and phase will be employed to reveal structural changes across the three years; phase will be used to establish delays, whilst integration will be assessed by gain, coherence and cospectra. The approach will entail a combination of techniques employed by Orlov (2009) and Hughes-Hallett and Richter (2004).

4 Crises and comovements

Orlov (2009) assesses nine Asian and five other currencies in the 1997, Asian flu era. Arguing that a time domain approach may provide misleading inferences if there is a structural change in what determines co-variations, Orlov posits that in a tranquil era, exchange rate co-movement may be based on the trend component of the series but there is a shift to the irregular component in the contagious period. Wong and Li (2010) find falling correlations in times of crises. For Orlov, there should be is a non-linear increase in the cospectrum during a contagious period with the higher end of the frequency cospectrum affected disproportionately, reflecting the greater volatility that fear and speculation precipitate.

Using standard Granger-causality tests and impulse response functions, a benchmark analyses the co-movements of nine countries' exchange rates and their stock indices during 1987-crash, post-crash and Asian flu eras. The tests are used, in part, to establish a directional flow, but also to consider whether the shock induced a greater degree of market integration. In the first period, the results are inconclusive for most countries. However, in the Asian flu period, there are clear lead-lag relations. The sign of the response is revealed by impulse response functions. So, for example, the South Korean Won leads stock prices by three days. Moreover, the results are consistent with an export-oriented version of the traditional model.

The impulse response functions suggest Taiwanese price indices exhibit a two-day lag with a negative sign in both directions. Although Thailand's indices also exhibit feedback, the delay is around three days but, uniquely in the results, the stock exchange responds to a one-unit exchange rate shock in the same direction, which is inconsistent with the portfolio model.

Overall, Granger et al. (2000) discover an improved forecastability of stock exchange indices using exchange rate movements. They also reveal a switch of emphasis from the traditional to the portfolio model of stock price movements in emerging markets.

4.1 India

Using an error correction model, Abdalla and Murinde (1997) find that India, Korea and Pakistan adhere to the traditional model. Abbas and Javed (2010) analyse, among others, the Bombay Stock Exchange-Rupee relationship, over the period 1997–2009 using monthly data. They also find the traditional approach is supported using Granger-causality. Smyth and Nanha (2003) find the same over the period 1995–2001, using daily data. In a study of Indian macroeconomic variables and the exchange rate, Ray (2008) finds a positive association between the exchange rate and stock prices and money supply but negatively related to output and FII in the long run and feedback between these four and the exchange rate in the short.

Agrawal et al., (2010) examine daily growth rate data for the Nifty and the Rupee: Dollar exchange rate in the period 2007–2009, a period falling within this study's focus. They find that the returns are non-linearly distributed. They reveal a small negative correlation coefficient between the exchange rate and the stock exchange and that there is uni-directional causality from the stock exchange to the exchange rate. The Agrawal finding is in the portfolio camp, which is out of line with Abdalla and Murinde (1997), Abbas and Javed (2010), and Smyth and Nanha (2003). It covers a more recent period on a daily basis, including the collapse of Lehman, which could have resulted from a structural change within the data that may have distorted the results. Narayan (2009) uses an ARMA-EGARCH. He finds a positive relation between mean stock returns and the exchange rate. Subdividing the period into appreciating and depreciating Rupee to the Dollar, an appreciating exchange rate decreases the volatility of stock returns.

5 Methodology

Autocovariance of $X(t)$ in the time domain, is represented as the population [Power] spectrum, $s_X(\omega) = \frac{1}{2\pi}\sum_{k=-\infty}^{\infty} \gamma_X(k)e^{-ik\omega}$, in the frequency domain, where γ_X is the variance of X and ω is the periodicy or frequency, measured in radians. The theoretical spectrum divides up a time series into a set of components that are uncorrelated. It reveals the relative power at each frequency corresponding to the variance at each periodicy, so that sharp peaks denote a high concentration whereas a flat spectrum signifies a random variable. A shift in the spectrum upwards implies more turbulence. One would expect that the holding of shares to be over a longer period than foreign exchange, not least because equities bring an income, ownership rights and a capital gain. This implies stock price power spectrum favouring longer and an exchange rate one emphasising shorter cycles.

The cross spectrum is given by $s_{XY}(\omega) = \frac{1}{2\pi}\sum_{k=-\infty}^{\infty} \gamma_{XY}(k)\left(\cos(\omega k) - i\sin(\omega k)\right)$ where γ_{XY} is the covariance of $XY(t)$. This can be broken down in the real and imaginary parts, $s_{XY}(\omega) = c_{XY}(\omega) + iq_{XY}(\omega)$, where the cospectrum is defined as $c_{XY}(\omega) = \frac{1}{2\pi}\sum_{k=-\infty}^{\infty} \gamma_{XY}(k)\cos(\omega k)$. If the cospectrum coefficient is large at frequency ω_j, it indicates that $X(t)$ and $Y(t)$ have a high proportion of their covariance at that periodicy. The integrated cospectrum provides the unconditional covariance between $X(t)$ and $Y(t)$ (Hamilton, 1994).

Squared coherence is the frequency domain's equivalent of the [squared] correlation coefficient in the time domain. It shows the proportion of a linear relation of $X(t)$ and $Y(t)$ at any frequency (Bartels, 1977). If the coherence is large, it indicates the degree to which X and Y are jointly influenced at a common frequency ω_j. The theoretical squared

Coherence is given by $C_{XY}{}^2(\omega) = \frac{\left|s_{XY}(\omega)\right|^2}{s_X(\omega)s_Y(\omega)}$. An increase in the coherence following a shock, which corresponds with greater correlation, is taken to imply at least greater interdependence.

Beyond the general values, over time there can be a shift in the concentration of covariance, variance and correlation across the spectrum. In a time of financial contagion, Orlov (2009) contends that the Cospectrum should highlight greater covariance but with disproportionate increase at the higher end of the frequency range. The corresponding point could be made for the spectrum in the high frequencies: in periods of uncertainty, with heightened volatility there is likely to be a shift of emphasis to the higher frequencies. This is assessed by:

$$\Delta Cov^{high} = \frac{Cov^{high}_{contagious} - Cov^{high}_{tranquil}}{Cov^{high}_{tranquil}} sign\left(Cov^{high}_{tranquil}\right) \times 100, \quad (1)$$

where $Cov^{high}_{contagious} = 2\int_{\omega_1}^{\pi} \hat{c}_{XY}(\omega) d\omega$ is the part of the cospectrum for which the covariance is associated with the frequencies above ω_1. The sign element in the expression accounts for negative Cospectrum values which, if ignored, could present misleading statistics. Contagion is said to exist if there is a 10% increase in the cospectrum in the higher frequencies.

Gain is the equivalent of a regression coefficient in a two variable linear model in the time domain but at given frequencies, and is given by $G_{XY}(\omega) = \frac{\left|s_{XY}(\omega)\right|}{s_X(\omega)}$. Gain 2 explains how amplitude of the exchange rate power spectrum is translated into the amplitude of the stock exchange (after Sun et al. 2007). Gain 1 is the obverse. Like the regression coefficient, the value depends on the relative variances of the two variables. To account for this, the regression coefficient on the explanatory variable can be standardised so that beta is interpreted as the alteration in the dependent variable that results from a standard deviation change in the explanatory variable. Here, the stationary, raw data is standardised by dividing values by the standard deviation, removing the necessity of rescaling Gain 1 and 2 over the four years to make them directly comparable.

A value of 0 implies no sensitivity and corresponds to a coherence of zero. If gain is relatively high across a part of the spectrum, then the transfer of variation is focused in those cycles. Note that the product of Gain 1 and 2 cannot be larger than unity.

A phase value is defined as $P_{XY}(\omega_j) = \tan^{-1} \frac{-q_{XY}(\omega_j)}{c_{XY}(\omega_j)}$. If the two series are aligned or in phase at frequency ω_j, the phase value is zero. When phase is a linear function of frequency ω, the phase diagram can offer an interpretation of 'pure delay' that is independent of ω. The slope in the phase diagram ($-d$) is the measure of the delay $Y_t = X_{t-d}$. Hilliard et al. (1975) highlight linear segments of the phase diagram to reveal leads and lags in prices. Jenkins and Watts (1968) point out that you can get good phase estimates with poor coherence.

Estimating gain and phase spectra of British ten and two-year bond yields before the ERM crisis of 1992–2003, Hughes-Hallett and Richter (2004) use spectral analysis to compare the spectra with during and after. Plotting phase from three eras on the same diagram, they show that from 1993 the profile is flat. Using the confidence interval drawn from the tranquil era, gain values from the contagious, post-1993 periods are shown to be different, indicating a structural change had occurred. We draw elements from Orlov (2009) and Hughes-Hallett and Richter (2004) when exploring the Rupee-Senex relationship. Confidence intervals are outlined in the Appendix.

5.1 Propositions

As India is an emerging economy, one might posit that, in the tranquil era, it would be export-oriented, and be typified by the traditional model. The Lehman's crisis and the policy responses both internally and externally would result in greater flows of portfolio investment, which could be viewed as contagion in the short term, and/or as part of a trend towards greater capital market integration in the long that follows the development of a larger, more sophisticated financial sector. In both cases, a shift towards portfolio investment should be evident at some point.

The thesis is that a shock occurred when Lehman Brothers collapsed (15th September, 2008). Markets, such as the Indian stock exchange were subject to contagion from the developed world's banking crisis, resulting in further integration of Indian financial markets. The shock could have temporary effect, in which case, co-movements could return to around the tranquil levels, or, as is posited, there is a permanent increase in the degree of integration of Indian financial markets with the rest of the world. To judge this, a tranquil period (reference year 0), is compared with the contagious periods (year 2 in particular), and the accommodation era (year 3, mean revision). One could argue that the Lehman shock followed a year when financial markets were sclerotic, so an earlier tranquil period is used than the previous year (2006/7).

As a measure of turbulence, the power spectrum should rise to peak in year 2 and then recede. Turbulence and market speculation would also be revealed by a shift of emphasis in gain, power, coherence and cospectrum spectra towards the higher frequencies.

As measures of co-movement, cospectrum and coherence should follow the same pattern. However, a rising cospectrum and stable coherence could signify more turbulence, common to each variable, but does not imply integration or contagion. This corresponds with Forbes and Rigobon's (2002) concern about using correlation coefficients to establish contagion. Contagion is taken to be a temporary phenomenon that occurs in a time of crisis. If coherence rises persistently, or remains high in a period of tranquillity, this signifies integration without contagion.

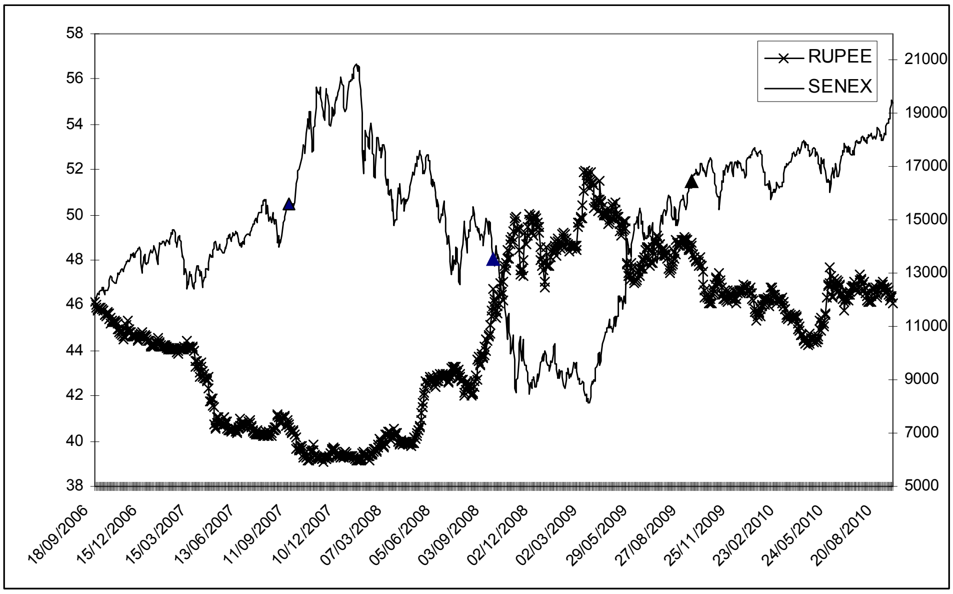
Under the assumption of the portfolio approach, phase should indicate that the Senex leads the Rupee over time and the cospectrum should be negative. However, as Granger et al. (2000) point out, a feedback loop between the foreign and stock exchange prices could emerge. In the time domain, the correlation sign could be arbitrary. In the frequency domain, it could lead to different signs and values of the delays across the phase spectrum and the cospectrum vacillating between positive and negative.

Using coherence as an indicator of interdependence permits an interpretation of the standardised gain as revealing a 'direction'. If portfolio investments become more prominent, the stock exchange should have a greater impact on the exchange rate. Gain 1 and 2 may both change shape, emphasising different ranges of the spectrum. In an era of turbulence, financial integration through short-term portfolio investment would be reflected in Gain 1 increasing relative to Gain 2, particularly in the higher frequencies.

6 Data

The exchange rate data from the European Central Bank are based on a regular daily concertation procedure between central banks across Europe and worldwide, which takes place normally at 2.15 p.m. Central European time (CET). The Bombay Stock Exchange closes at 4 p.m. local time, 4½ hours in front of CET. The gap for price determination at CET is 2¾ hours, or approximately 0.4 of a financial day. Figure 2 shows the raw data on two scales, with triangles highlighting the year breaks. There is a fairly clear inverse relationship between them. Growth rates are calculated by taking the natural logarithm of the series and then computing the rate of return as $r_t = \ln p_t - \ln p_{t-1}$.

Figure 2 Rupee and Senex data (see online version for colours)



From the measures of standard deviation, skew and kurtosis, displayed in Table 1 the data across the four years, they are least volatile in year 3 and most volatile in year 2. Both series in each year exhibit kurtosis. In year 2, the Senex data is actually bimodal. The Jarque-Bera test for normality is reported also. In line with Agrawal (2010), the growth data, with one exception, is found to be non-normal.

Correlation and covariance data is also supplied. The negative sign is consistent with the portfolio approach and the export orientation of the traditional approach. Interestingly, the correlation coefficient rises each year, ending up at twice the level in year 3 as in the reference year. Covariance does not mirror correlation. For there to be a schism, the decline in co-movement is more than matched by the decline in volatility. For later comparisons, ratios of the covariance in years one to three are contrasted with that of year zero. For example, covariance in year 3 is 2.217 that in year 0. This compares with a higher value of 8.747 for year 2, implying a decline in the co-movement tendency. This contrasts with an increase in the correlation coefficient (.559 to .609). This is indicative of the Lehman's shock leaving a contagious/integration imprint on the Senex-Rupee relationship.

Table 1 The distribution of the share and currency data

Year	*Series*	*Standard deviation*	*Skew (.152)*	*Kurtosis (.303)*	*Normality –B p-val.*	*Covariance*	*Correlation*
0	Senex	0.012794	–0.837	2.229	0.0000	–1.349E-05	–.288**
	Rupee	0.003664	–0.209	4.803	0.0000		
1	Senex	0.022018	–0.054	0.868	0.0169	–3.09E-05	–.337**
	Rupee	0.004162	0.295	2.925	0.0000	2.290	
2	Senex	0.028617	0.369	4.274	0.0000	–1.18E-04	–.559**
	Rupee	0.007385	–0.104	1.529	0.0000	8.747	
3	Senex	0.010274	–0.079	1.181	0.0005	–2.99E-05	–.609**
	Rupee	0.00478	0.513	1.082	0.0000	2.217	

Note: **sig. at the 1% level

As comparisons of spectra are based on particular frequencies, there is a problem with synchronising dates. National holidays and leap years can disrupt the synchronicity. To address this, the data is extended so that there is a value for every weekday, whether it is a working day or not. This is achieved by using the most recent rate in the levels of the data before the non-trading weekday. The four sets of 256 days are taken from 15th September 2008 and the equivalent weekday in 2006, 2007 and 2009.

7 Results

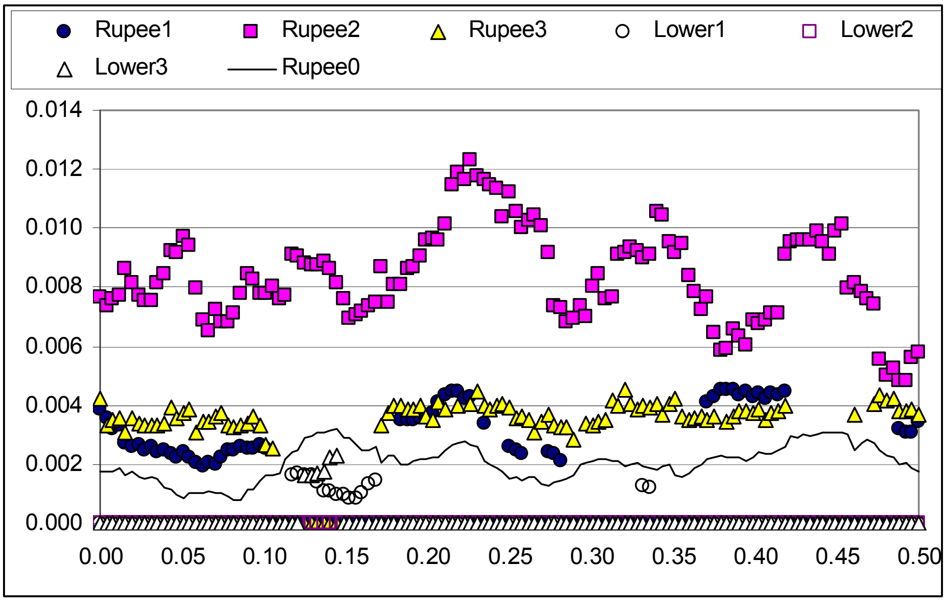
The variables as considered individually across the four years and then in pairs. The values for the spectra are estimated by SPSS using a 15-point Parzen lag window for each of the four periods. A spectrum comprises 128 (angular) frequencies (f), presented as 0.00390625 to 0.5 radians, which corresponds to 256 to 2 periods (days) plus the long run, zero frequency. A radian $\omega_j = 2\pi f_j$. In addition, there is the long run coefficient at zero frequency.

7.1 Power spectra

The first set of consideration is of the power spectra for the four years. The profiles should lead to the same 'ranking' as the standard deviations in Table 1, with the values for the Senex being higher than for the Rupee.

Attempting to plot four lines plus two confidence intervals proved messy. A solution to this display conundrum is to plot the reference series from year zero against fractions of π. The values of other series are plotted where they fall outside the 95% confidence interval for the reference series. The general pattern in Figure 3 is that the reference year values (Rupee0) are the lowest of the four. However, there are portions of the spectra where values from year 1 are lower. Year 3 values are generally above the upper band of the confidence interval for Rupee0. By some margin, the values of the power spectrum of year 2, the Lehman's contagion year, are above the other series, at all frequencies.

Figure 3 Rupee power spectra (see online version for colours)



The Senex power spectra are displayed in Figure 4 in the same manner as Figure 3. The reference year spectrum, StockExch0, is fairly uniform with a peak at 0.1 radians (two weeks) which corresponds with a Treasury Bill auction cycle, and another 0.38 radians (around two days and 4½ hours), frequencies where speculation might be expected to dominate. This is clearer in year 1. In year 2, there does seem to be a change of emphasis, with a particular peak at around 0.226 radians (approx. four days and three hours) emerging. The year 3 spectrum seems to be below the profiles of years 1 and 2. Not every value is below that of the lower confidence interval of year0, but, in general, the values in year 3 below 0.35 radians are smaller than those in the tranquil era, suggesting a more stable environment.

From the above, following Hughes-Hallett and Richter (2004), we conclude that the values of the spectrum in the years before and after the Lehman's event fall outside the confidence interval boundary of the spectrum values of the reference year. However, the spectra in the reversion year appear more similar to the reference year's than the intervening two, suggesting that Indian markets may have been subject to contagion. Hughes-Hallett and Richter (2004) find that, following the ERM crisis, there is a shift towards shorter-term trading. With stock prices in year 1 there does seem to be a shift in emphasis after around 0.35 radians (or three days), where the spectrum appears rise.

Figure 4 Senex power spectra (see online version for colours)

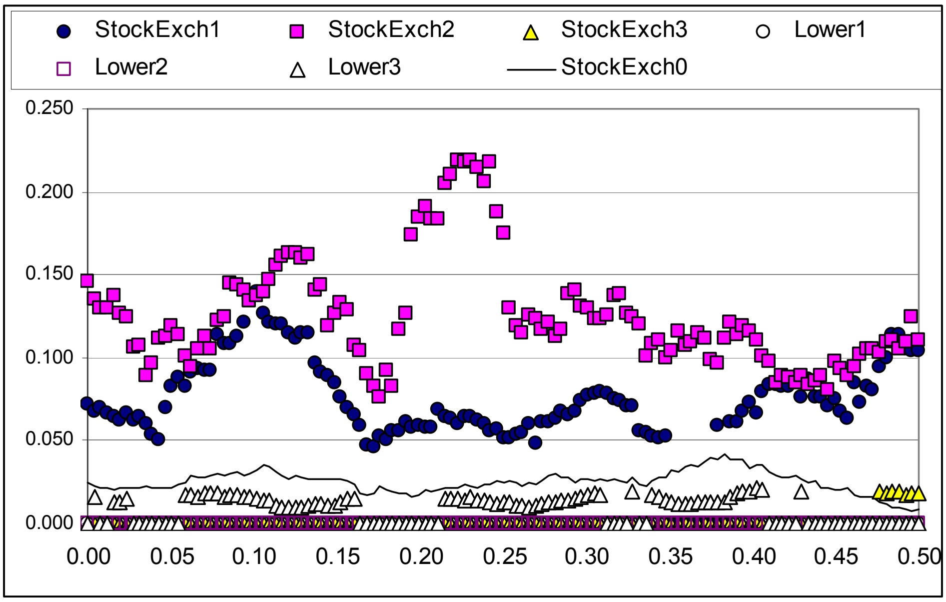
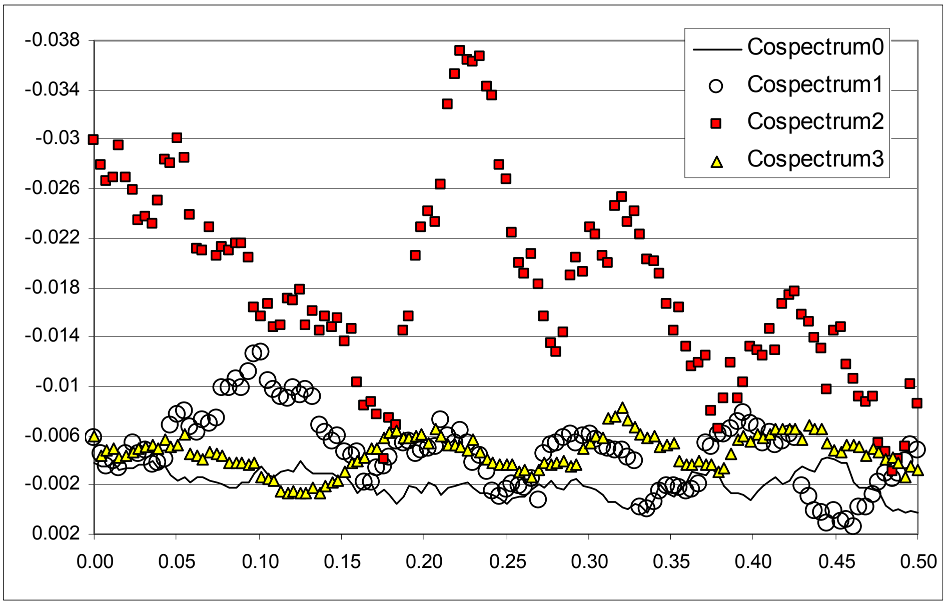


Figure 5 Senex-Rupee cospectra (see online version for colours)



7.2 Cospectrum analysis

The identification scheme for the Rupee-Senex cospectra, displayed in Figure 5, is similar to the above. In general, the values are negative, indicating an inverse relationship between the two variables for all years. In the reference year, the values meander around –0.003, and increase in absolute terms in the following year to around –0.005, with some being greater than in 0. In year 2, as with the power spectra, there is notable change. The cospectrum values become more negative, especially around 0.226 radians. In year 3, they revert to around –0.005 but with a different, more stable profile. There is a notable emphasis in year 2 among the longer frequencies, especially lower than 0.1 radians, which is not consistent with contagion driven by speculation.

7.3 Orlov's measures

Orlov's focus is on changes in the profile of the cospectrum, but one could consider modification in the spectrum as well. For our purposes, higher frequencies are defined as above 0.375 radians (2 and ⅔ days) where there appears a rise in the Rupee power spectra, and 0.45 where there is a fall in the power spectra, but coincidentally, is in keeping with Orlov's spectrum divide. As indicated in Table 4, frequencies above 0.375 (0.45) radians account for 30.5% (11.9%) of total variance of the Rupee in the reference year in Figure 3. As with the Senex, the proportion of the variance in the higher frequencies appears no greater in year two than in the reference year. Interestingly, the shift of emphasis with the cospectrum seems to better mirror the stock exchange. However, overall the higher frequencies account for about a quarter of the variances and covariance of the financial variables considered.

Table 4 Distribution of variance and covariance

ω >	*Rupee0*	*Rupee1*	*Rupee2*	*Rupee3*
0.375	0.305	0.320	0.220	0.270
0.45	0.119	0.113	0.080	0.112
	StockExch0	StockExch1	StockExch2	StockExch3
0.375	0.235	0.270	0.199	0.295
0.45	0.054	0.124	0.084	0.116
	Cospectrum0	Cospectrum1	Cospectrum2	Cospectrum3
0.375	0.237	0.172	0.150	0.276
0.45	0.060	0.037	0.045	0.094

When comparing the reference year with the others using Orlov's measure of change, as displayed in Table 5, there is a 440%+ increase in the cospectrum values in year 2 over the reference year at frequencies beyond 0.375 radians. This drops back to 151% in year three, but the ratios are much greater than the 10% threshold set by Orlov as a marker of contagion.

Table 5 Orlov's measures of non-linear change in the cospectrum

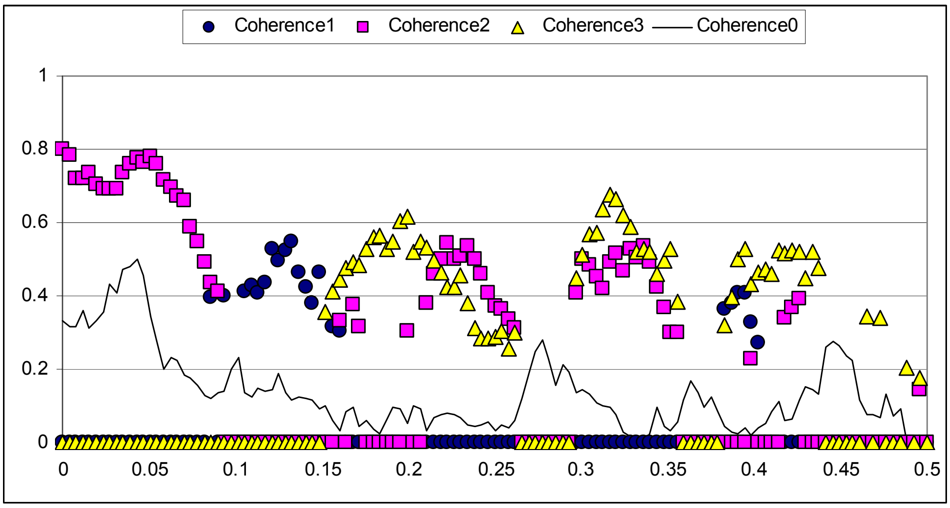
	ω > 0.375		*ω > 0.45*	
	% change	*Ratio of change*	*% change*	*Ratio of change*
Cospectrum1	66.4	0.5	13.4	0.1
Cospectrum2	439.9	0.6	497.2	0.6
Cospectrum3	151.3	1.2	203.6	1.7

Orlov's second measure entails comparing the time and frequency domain increases. Despite increasing by 440%, the increase in high frequency cospectrum values in year 2 is smaller than for covariance as a whole. In other words, the source of co-movement intensification is not consistent with volatility and speculation in year 2. However, in the expected 'revision' year, year three, the 1.2 multiple of the corresponding time domain figure, again above the 1.1 multiple threshold, supporting the proposition of a non-linear change in the relationship between the Rupee and the Senex.

7.4 *The coherence patterns*

The Rupee-Senex coherence spectrum is displayed in Figure 6 in the same manner as Figure 3. The reference year spectrum, coherence0 is fairly uniform with peaks at 0.043 (23 trading days), 0.277 (3⅔ days) and 0.45 (2¼ days). There are considerable portions of the spectrum in all three years where coherence is greater than in the reference year. In year 1, there are two segments (around 0.13 and 0.39 radians). The highest level of coherence is found in year 2 in the lowest frequencies. But most interesting is that the coherence is higher in year 3 in the range beyond 0.15 radians. In other word, there is heightened coherence in all three years but in different portions of the spectrum. Moreover, the contagion that cospectrum2 points to is not evident: all years appear to have greater coherence than the reference year, a sign of integration.

Figure 6 Senex-Rupee coherence (see online version for colours)



7.5 Gain

Gain 2 indicates the impact on the Senex as a result of a one standardised change in the Rupee, whereas Gain 1 is the impact of one standardised change in the stock exchange on the exchange rate. Again, following the pattern above, the gain in the reference year is displayed as a continuous line with the symbols representing those values that fall outside its confidence interval.

Figure 7 Gain of the Rupee from the Senex (see online version for colours)

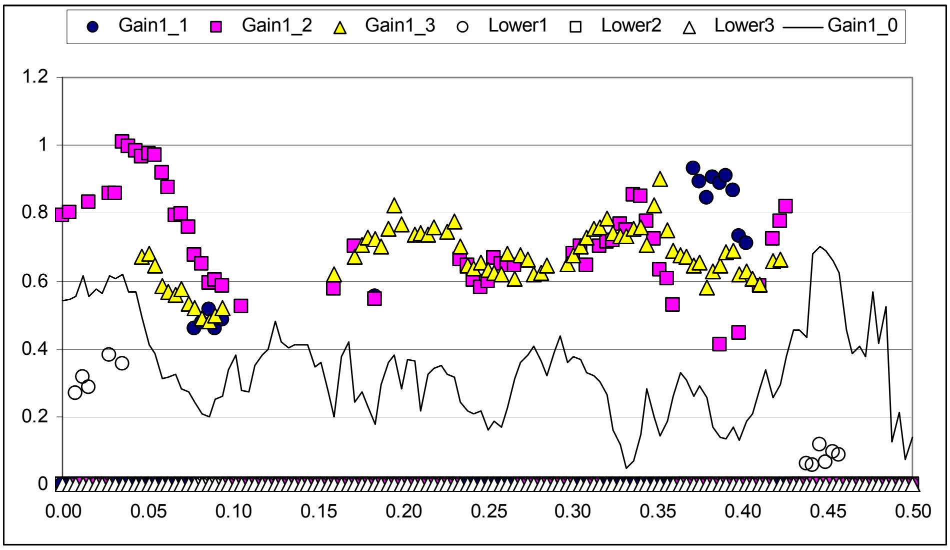
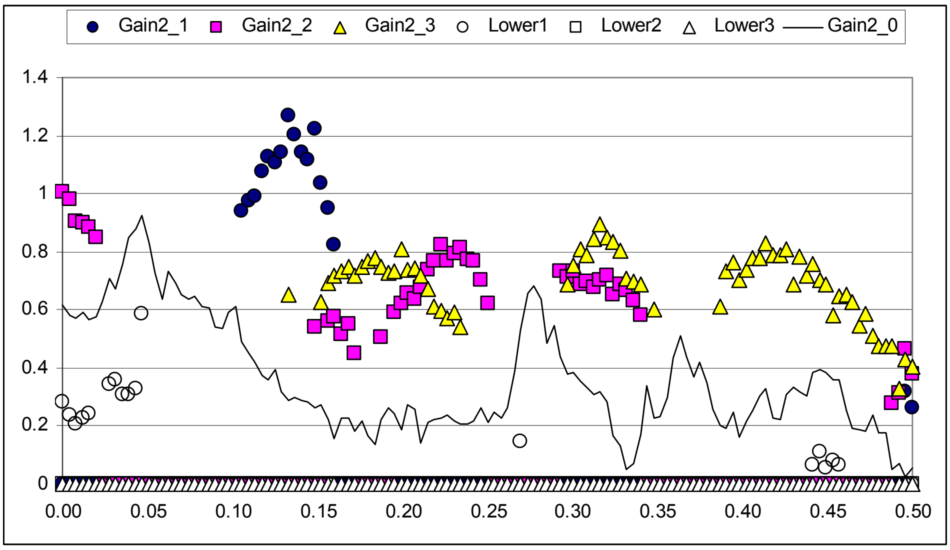


Figure 8 Gain of the Senex from the Rupee (see online version for colours)



In the reference year, Gains 1 and 2 fluctuate mostly in the range 0.2 to 0.4. In general, values increase to between 0.6 and 0.8 in years 2 and 3. As there is not the decline, it is suggestive of integration. One could point to a peak at 0.45 radians in Gain 1 and 0.0468 (1 month) 0.277 and 0.363 (2¾days) radians in Gain 2.

The average values for coherence, Gain 1 and Gain 2 are found in Table 6. The rise in all three appears gradual. In spite of the power and cospectra peaks in year 2 which would point to contagion, the contrasting coherence and gain profiles are more consistent with integration.

Table 6 Analysis of average coherence and gain values 1

Yr	*Coherence*	*Gain 1*	*Gain 2*
0	0.137	0.339	0.363
1	0.181	0.377	0.422
2	0.367	0.594	0.583
3	0.393	0.620	0.619

As a means of providing some structure to the analysis of the gain spectra, they are sub-divided in to four portions. The lower frequencies in Table 7 are defined as those below 0.1172 radians; the higher frequencies are those above 0.375 radians. In between, the spectrum is bifurcated at 0.179 radians (5½ days). As a benchmark, coherence is treated in the same fashion.

The average gain values in year zero in Table 5 are greater in the lower frequencies, particularly the case in Gain 2. As the crisis worsens, both Gain 1 and 2 increase, particularly in the middling frequency band. Interestingly though, by year 3, the average coherence values are smaller in the lower frequency bands; the middling band has the highest average values with Gain 1; and the highest average value is found in the higher frequencies with Gain 2.

As gain in both directions increases, it does not support a case for a shift from the traditional to the portfolio explanation of co-movement. Rather, this indicates greater integration. There does appear to be a greater emphasis on the higher frequencies with Gain 2, the measure of the impact of change of Senex on the Rupee. It was proposed that a shift towards the higher frequencies, and Gain 1 should increase relative to Gain 2 by year 3 would be evidence supporting the portfolio model. Only the former is found.

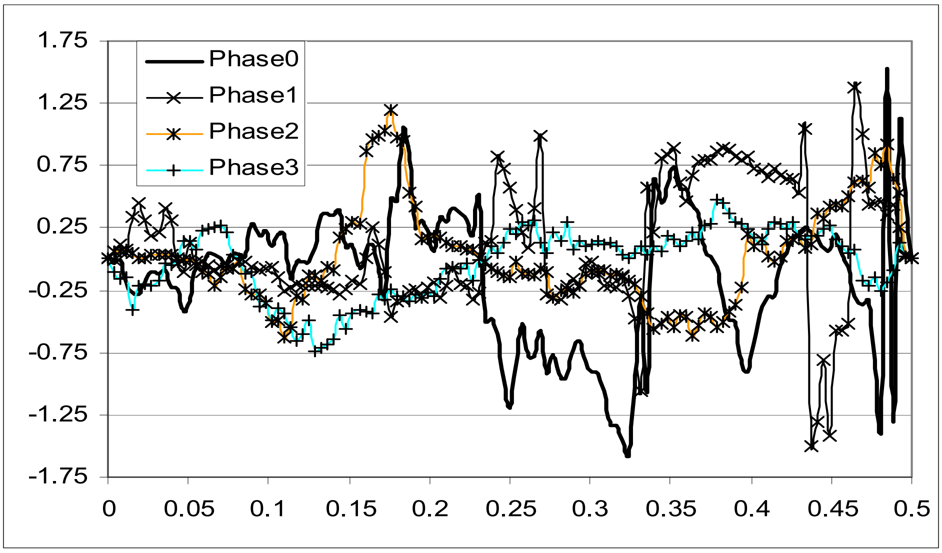
Table 7 Analysis of average coherence and gain values 2

	Coherence				*Gain 1*				*Gain 2*			
Yr	*< 0.117*	*0.117–0.179*	*0.179–0.375*	*> 0.375*	*< 0.117*	*0.117–0.179*	*0.179–0.375*	*> 0.375*	*< 0.117*	*0.117–0.179*	*0.179–0.375*	*> 0.375*
0	0.270	0.100	0.091	0.099	0.416	0.398	0.275	0.352	0.636	0.266	0.300	0.247
1	0.259	0.344	0.121	0.124	0.421	0.404	0.364	0.360	0.592	0.891	0.297	0.239
2	0.593	0.243	0.377	0.196	0.754	0.668	0.610	0.466	0.768	0.494	0.611	0.405
3	0.354	0.324	0.445	0.379	0.574	0.557	0.703	0.584	0.602	0.595	0.627	0.633

7.6 Phase

The stock exchange-exchange rate phase spectra are displayed in Figure 9. It was also proposed that, with integration, phase should shift to indicate that the Senex leads the Rupee over time. Potentially, examining the slopes of the Phase spectra can assess this.

Figure 9 Phase of the Rupee and the Senex (see online version for colours)



Start and finish points of approximately linear portions of the phase spectra are reported in Table 10. Accompanying them are the gradients that can be directly interpreted as leads and lags in the time domain. As the Rupee is inserted first, a negative sign indicates that the Senex leads, which is consistent with the portfolio approach. In the reference year, with the exception of longer cycles between two weeks and four months, the Senex leads Rupee by around 2½ days, supporting the portfolio approach. Interestingly, the delay is of the same order as those found by Granger et al. (2000).

In year 1, there appears to be a reversal of the direction, which is followed by further switching in years two and three. In all years, there is vacillation between leading and lagging, which could be interpreted as a feedback loop operating across different portions of the spectrum. Comparing these results with Figure 2 and drawing on Narayan (2009), one notices that when the Senex is rallying persistently, the Senex leads the Rupee in the long cycles (Phase0 and Phase3). When the Senex both rises and falls, the Rupee leads the Senex.

Table 10 Leads and lags

Phase line	*ω start*	*ω finish*	*Time delay*	*Lead*
Phase0	0.0000	0.0117	–2.601	SENEX
	0.0117	0.1758	0.659	RUPEE
	0.1758	0.4844	–2.49	SENEX
Phase1	0.0000	0.0195	3.613	RUPEE
	0.0195	0.1797	–0.775	SENEX
	0.1797	0.3828	0.963	RUPEE
	0.3828	0.4844	–0.848	SENEX
Phase2	0.0000	0.0351	0.173	RUPEE
	0.0352	0.1094	–1.435	SENEX
	0.1094	0.1563	3.119	RUPEE
	0.1563	0.3672	–0.616	SENEX
	0.3672	0.4844	1.966	RUPEE
Phase3	0.0000	0.0195	–1.504	SENEX
	0.0195	0.0703	1.558	RUPEE
	0.0703	0.1172	–3.159	SENEX
	0.1172	0.3789	0.686	RUPEE
	0.3789	0.5000	–0.624	SENEX

7.7 Inferences

Although the delays are similar to the ones revealed by Granger et al. (2000) phase vacillates between leads and lags, providing inconclusive evidence. One cannot reject either the traditional or the portfolio models on this basis. It may be that the vacillation reflects feedback loops that alter over the years. Alternatively, the stock exchange may drive the exchange rate where there is a bull run, which favours the portfolio model, but not lead when there is no clear trend.

There is general evidence of greater turbulence and co-movement in years 1 and 2 and then a decline in year 3. The decline in the cospectrum is less than in the power spectra leaving coherence in year 3 around, if not above that year 2. Gain 1 and 2 also indicate a persistent increase. This is indicative of integration. Furthermore, there appears to be some evidence in Gain 2 and the cospectrum that there is a shift towards the higher frequencies with the measure of the impact of change on the Senex on the Rupee, consistent with short-term portfolio investment. Thus, rather than subject to contagion, India could be further integrated into the global financial system as a result of the Lehman Brothers' crisis.

8 Conclusions

This article sets out to explore the Rupee per Dollar-Bombay Stock Exchange's Senex index relationship using spectral techniques. The aims were to reveal evidence for a traditional or portfolio model; and whether there was contagion or integration of Indian financial markets into the global system, with a focus on higher frequencies associated with speculative investors.

The results favour a conclusion that in the post-Lehman's world, India has been further drawn into global markets. Following the crisis period, there is significant increase in the co-movement of these two indicators by the last year of study, the proposed reversion year. Coherence and gain point to a persistent increase in co-dependence, particularly in the higher frequencies, which is interpreted as capturing the impact of speculation and some limited supporting evidence for the portfolio model. Concurrently, both the Senex and the Rupee turbulence are around or below that of the tranquil era. Thus, over the four years, the relationship has intensified, debunking a decoupling thesis. The results also provide limited support for Agrawal et al. (2010) in pointing to the portfolio model for India, and with Morley and Pentecost (2000) emphasising the higher frequencies. Rather than having to establish a new order, one, for India, has already emerged.

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Appendix

The confidence interval of the power spectrum is given by $\hat{s}_X(\omega_j)\left(1 \pm 1.96\sqrt{2/v}\right)^{-1}$ where with v the number of degrees of freedom, using a Parzen lag window is 3.71 T/M = 63. The coherence and gain spectrum intervals are given by:

$$\arctan h\hat{C}_{XY}(\omega_j) \pm 1.96\sqrt{2/v} \qquad \text{and} \qquad \hat{G}_{XY}(\omega_j)\left(1 \pm \sqrt{\frac{2}{v-2} f_{2,v-2}(1-\alpha)\frac{1-\hat{C}_{XY}{}^2(\omega_j)}{\hat{C}_{XY}{}^2(\omega_j)}}\right)$$

Jenkins and Watts, 1968).