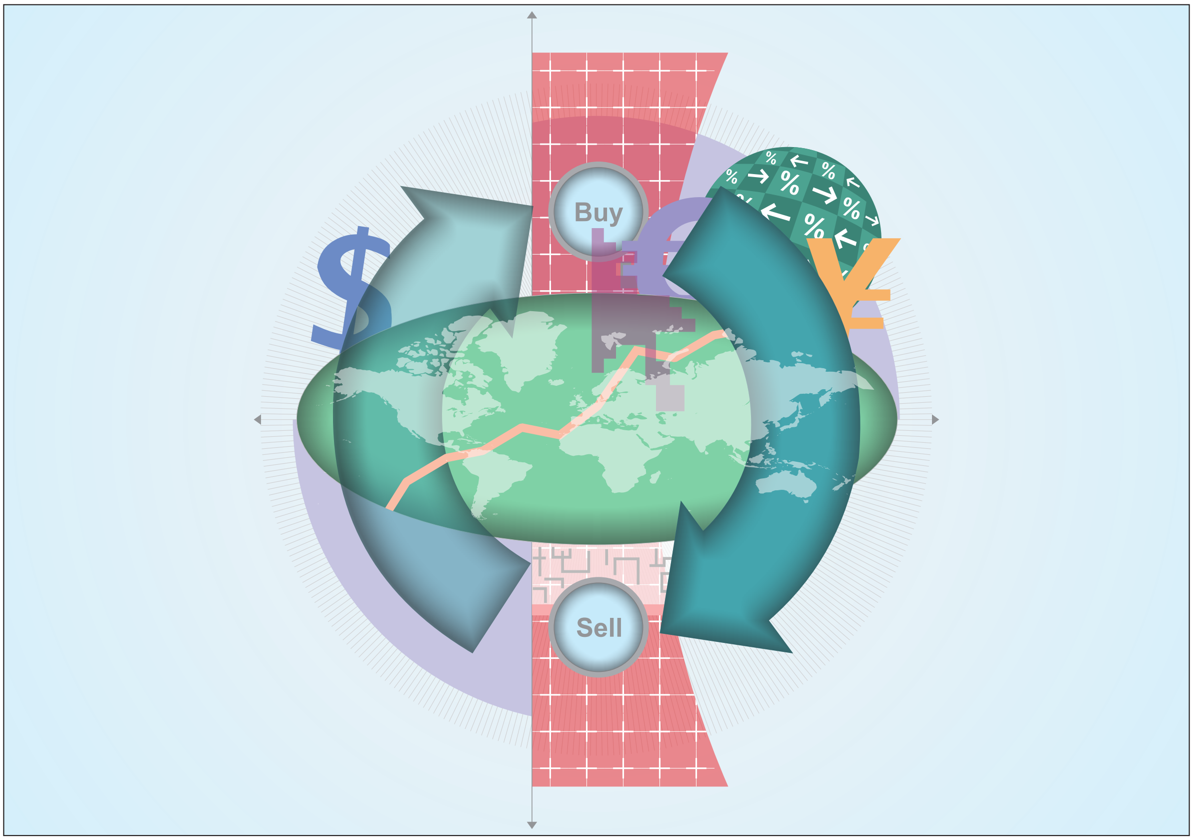

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Financial Crisis and Financial Market Volatility Spill-Over

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ABSTRACT
The inquiry into the dynamic relationship between the stock market and the foreign exchange market has increasingly become relevant for researchers, investors and policy makers, particularly after the global financial turmoil of 2007-08. The present study, using a multivariate Generalized Auto Regressive Conditional Heteroscedasticity (GARCH) model, contributes to the literature by bringing into focus, the volatility contagion among the financial markets around the financial crisis of 2007-2008. The study covers the period from January 2006 to December 2010 and considers three sub-periods namely pre-crisis, crisis and post crisis periods. To explore the nature of volatility spillover around the crisis, the study selects three exchange rates, namely, Rupee-US Dollar; Rupee-Pound, Rupee-Yen and four related stock markets namely, BSE SENSEX, DJ 30, FTSE 100 and Nikkei 225. The results indicate presence of volatility spillover but no asymmetric impact between stock to exchange rates and vice-versa during the three sub-periods. Own market innovation plays a decisive role in foreign exchange market than the cross market innovation emanating from stock markets during pre-crisis and crisis period. However, both own and cross innovations have become insignificant during post-crisis period. The study thus reveals the changing nature of volatility contagion between the financial markets and explores its possible impact on investment and policy making.

Key words: Volatility spill over, foreign exchange market, stock market, financial crisis, multivariate GARCH

INTRODUCTION
The dynamic linkage between a nation's stock market and the foreign exchange market has always been of interest to researchers and analysts. The issue with its changing nature is particularly relevant in the present era of strong global financial market integration. An extensive body of literature probing into the issue thus developed around the Asian crisis of 1997-1998. The rapid increase of the cross border transactions during the first few years of this century and the global financial crisis of 2007-08 might motivate the researchers to revisit the issue extensively.

The inter-linkage between the stock price and exchange rate is suggested by the Goods Market approach (Dornbusch and Fisher, 1980) and the Balanced Portfolio Approach (Krueger, 1983). The stock prices are influenced by the cross border movement of funds as well as by the trade flows resulting in foreign exchange earnings of the firm. The fluctuation in the exchange rate would influence the value of the firm's earnings in case of international trade on one hand and the cost of funds on the other if the firm raises funds from the international market. Thus, the competitiveness of the firm would depend on the fluctuation of its currency against the foreign currency, in which the billing is done or the fund generated. Depreciation in rupee would make the exports attractive, leading to a greater demand for the exported goods. This in turn would boost the earning of the firm and ultimately be reflected by an increase in stock prices. However, an appreciation in Rupee would make the exported goods more expensive resulting in a decrease in demand followed by a decrease in earnings and have a negative impact on the stock prices of the firm. The sensitivity of an importing firm to a change in exchange rate is just opposite to that of an exporting firm.

Portfolio balance approach (Krueger, 1983) justifies the impact in reverse direction. The foreign exchange market is also governed by the forces of demand and supply. A booming stock market would attract more investments from the foreign investors leading to an increase in demand for rupees and hence in its appreciation. Similarly a falling stock market would lead to an increase in supply of rupee due to the propensity of the foreign investors to sell and move out of the market. This would result in depreciation in rupees. Hence, we conclude that the stock market performance would impact the investor's wealth and liquidity demands and affect the money demand and the exchange rate in turn.

Within this backdrop, this study seeks to explore the presence of volatility spill over between stock market and foreign exchange market, if any and its changing nature in context of India around the financial crisis of 2007-08. Proper understanding of the relationship between the two markets around a crisis is important as this is the time when regulators play a decisive role in regulating the economy. During an economic crisis, exchange rates are often the easy target for policy intervention and therefore it is crucial to understand how exchange rates will affect the stock markets. It would be of further interest to explore the changing dynamics of the relationship around a financial crisis. This is the area where the present study contributes to the available literature. Moreover, the knowledge of the inter-market volatility would help the fund managers build and manage multi currency equity portfolios and formulate effective hedging strategies. Further, the study might help the policy makers formulate regulatory policies in an emerging market like India that is rapidly getting integrated into the global economy.

MATERIALS AND METHODS

To analyze the relationship between stock market and foreign exchange market, the study selects three exchange rates, namely the Rupee-US Dollar, Rupee-Pound and Rupee-Yen rates. The four stock market indexes used in the study are Bse Sensex (India), Dow Jones 30 (US), FTSE 100 (UK) and Nikkei 225 (Japan). While the Rupee-US Dollar exchange rate is likely to affect or to be affected by movements in SENSEX and/or DJ 30; association could be expected between Rupee-Pound exchange rate movements and the movements in SENSEX and/or FTSE 100. Similar association is possible between Rupee-Yen exchange rate movements and the stock market movements in India and/or Japan.

The study uses the daily closing price data on the four stock market indexes and the three exchange rate series to calculate daily return series as $[\ln.p_t - \ln.p_{t-1}]$. Data do not include dividends, as the data on daily observations on dividends are not available. The study covers a period five years ranging from January 2006 to December 2010. The sample is divided into three sub-periods based on the price movements in BSE SENSEX:

- Period 1 (Pre-crisis period): January 4, 2006 to January 11, 2008
- Period 2 (In-crisis period): January 12, 2008 to March 03, 2009
- Period 3 (Post-crisis period): March 04, 2009 to Dec 31, 2010

Since the stock market operates for five days while the foreign exchange market operates for six days in a week, the study makes use of a common data set where both stock price and exchange rate data are available.

The preliminary exploration into the stock market-foreign exchange market relationship will start from an analysis of correlation coefficients between the two market returns. Presence of any significant correlation, however, may be spurious and does not necessarily imply true existence of any dependency. Hence, further investigation is necessary to establish the inferences drawn from the correlation results.

To explore the presence and nature of the volatility spill-over between the two markets, the study makes use of multivariate GARCH model. Earlier studies have made extensive use of Autoregressive conditional heteroskedasticity (ARCH) and generalized ARCH (GARCH) type models that take into account the time-varying variances. Suitable surveys of ARCH modeling in general and its widespread use in finance applications may be found in Higgins and Bera (1993) and Bollerslev *et al.* (1988), respectively. Discussion on recent developments in this expanding literature could be found in Pagan (1996). More recently, the univariate GARCH model has been extended to the multivariate GARCH (MGARCH) case, with the recognition that MGARCH models are potentially useful developments regarding the parameterization of conditional cross-moments. Bollerslev (1986, 1990) used a MGARCH approach to examine the coherence in short-run nominal exchange rates, while Karolyi (1995) employed a similar model to examine the international transmission of stock returns between the United States and Canada. Dunne (1999) also employed a MGARCH model, though in the context of accommodating time variation in the systematic market-risk of the traditional capital asset pricing model. Kearney and Patton (2000) used a series of 3-, 4- and 5- variable MGARCH models to study the transmission of exchange rate volatility across European Monetary System (EMS) currencies prior to the introduction of the single currency. However, while the popularity of models such as these has increased in recent years, "...the number of reported studies of multivariate GARCH models remains small relative to the number of univariate studies" (Kearney and Patton, 2000).

The diagonal VECH model chosen in this study is of particular interest as it allows the conditional variance covariance matrix of stock market returns to vary over time and is more flexible compared to BEKK model if there are more than two variables in the conditional variance covariance matrix (Scherrer and Ribarits, 2007). Empirical implementation of the VECH model is, however, limited due to the difficulty of guaranteeing a positive semi-definite conditional variance covariance matrix (Engle and Kroner, 1995; Kroner and Ng, 1998; Brooks and Henry, 2000). This study uses the unconditional residual variance as the pre-sample conditional variance to overcome this problem thus guaranteeing the positive semi-definite of conditional variance covariance matrix of the diagonal VECH model.

The conditional variance-covariance matrix (H_t) has four dimensions with the diagonal and non-diagonal elements representing the variance and the covariance terms, respectively. In matrix notation, H_t can be written as:

$$H_t = \begin{bmatrix} h_{11t} & \cdots & h_{1nt} \\ \vdots & \ddots & \vdots \\ h_{n1t} & \cdots & h_{nnt} \end{bmatrix} \tag{1}$$

where, h_{iit} is a conditional variance at time t of the stock return of country i and h_{ijt} denotes the conditional covariance between the stock returns of country i and country j (where $i \neq j$) at time t.

Although there are different ways of specifying the MGARCH model, this study uses the diagonal VECH model of Bollerslev *et al.* (1988) as the model is more flexible when H_t contains more than two variables (Scherrer and Ribarits, 2007). The diagonal VECH representation is based on the assumption that the conditional variance depends on squared lagged residuals and the conditional covariance depends on the cross-lagged residuals and lagged covariances of other series (Harris and Sollis, 2003). The diagonal VECH model can be written as follows:

$$\text{Vech}\ (H_t) = C + \text{Avech}\ (\boldsymbol{\varepsilon}_{t-1}\, \boldsymbol{\varepsilon}^1_{t-1}) + \text{Bvech}\,(H_{t-1}) \tag{2}$$

where, A and B are:

$$\frac{N\ (N+1)}{2} \times \frac{N\,(N+1)}{2}$$

parameter matrices and C is a:

$$\frac{N\ (N+1)}{2} \times 1$$

vector of constants. The diagonal elements of matrix A (a_{11}, a_{22}, a_{33} and a_{44}) measures the influences from past squared innovations on the current volatility (i.e., own-volatility shocks) while non-diagonal elements (a_{ij} where, $i \neq j$) determine the cross product effects of the lagged innovations on the current volatility (i.e., cross-volatility shocks). Similarly, the diagonal elements of matrix B (b_{11}, b_{22}, b_{33} and b_{44}) determine the influences from past squared volatilities on the current volatility (i.e., own-volatility spillovers) and non-diagonal elements (b_{ij} where, $i \neq j$) measure the cross product effects of the lagged covolatilities on the current covolatility (i.e., cross-volatility spillovers).

The study has incorporated a threshold term in the variance-covariance equation to capture asymmetric volatility spill-over. Volatility responses are said to be asymmetric when volatility changes dissimilarly with good and bad news in any market. In presence of asymmetric volatility spill over, volatility responses of any market towards good or bad news in any other markets will be different. The model used in this study could be represented as:

$$\begin{aligned} &\text{VECH}\,(H_t) = C + \text{A.VECH}\ (\in_{\downarrow} (t-1) \in_{\downarrow} (t-1)^{\uparrow}) + \text{B.VECH}\,(H_{t-1}) + \\ &\text{D. VECH}\ (\in_{\downarrow} (t-1) \in_{\downarrow} (t-1) < 0) * ((\in_{\downarrow} (t-1) \in_{\downarrow} (t-1)^{\uparrow}{}') < 0)) \\ &{}'\text{D} * \text{VECH}\,((\in_{\downarrow} (t-1) \in_{\downarrow} (t-1)^{\uparrow}{}') < 0 \ * (\in_{\downarrow} (t-1) \in_{\downarrow} (t-1)^{\uparrow}{}') < 0)) \end{aligned}$$

A, D and B are:

$$\frac{N\,(N+1)}{2}\times\frac{N\,(N+1)}{2}$$

parameter matrices. C is:

$$\frac{N\,(N+1)}{2}\times 1$$

vector of constant. a_{ii} in matrix A, that is the diagonal elements show the own innovation impact and the cross diagonal terms (a_{ij}, $i \neq j$) show the cross innovation impact. Similarly, b_{ii} in matrix B shows the own volatility impact and b_{ij} shows the cross volatility impact. d_{ii} shows the volatility spillover with asymmetry from the i'th market to itself. d_{ij} shows the volatility spill over with asymmetric response from the i'th market to the j'th market.

Karunanayake *et al.* (2008) emphasized that in estimation of a diagonal VECH model the number of parameters to be estimated are crucial. Bollerslev *et al.* (1988) and Goeij and Marquering (2004) suggested use of a diagonal form of A and B. moreover, in the estimation process, one has to ensure the positive semi-definiteness of the variance covariance matrix. The condition is satisfied if all of the parameters are positive with a positive initial conditional variance covariance matrix (Bauwens *et al.*, 2006). Bollerslev *et al.* (1988) suggested some restrictions to be used in the estimation process that were duly followed by Karunanayake *et al.* (2008). They used maximum likelihood function to generate these parameter estimates by imposing some restriction on the initial value.

However, before we could employ a Multivariate GARCH model on our data set, the data will be checked for stationarity using the augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) and Phillips and Perron (1988). The Descriptive statistics of the raw return, particularly measures of skewness, kurtosis and Jarque-Bera statistics will be calculated to explore the nature of the selected return series.

RESULTS

Correlation coefficient: The correlation between four stock market returns and the three exchange rate returns for three sub-periods were shown in Table 1-3.

Table 1 showed the correlation pattern in the pre-crisis period. The Rupee-dollar exchange rate return series was negatively correlated with Dow-Jones 30 return and was positively related to SENSEX return. The Rupee-pound exchange rate return was negatively correlated with both SENSEX return and FTSE 100 return. The rupee-yen exchange rate return was negatively correlated with Nikkei 225 return but was positively related to SENSEX return.

Table 1: Correlation coefficients between stock market return and exchange rate return in pre-crisis period

	DJ30	FTSE100	NIKKEI 225	SENSEX	RS/POUND	RS/USD	RS//YEN
DJ30	1						
FTSE100	0.513	1					
NIKKEI225	0.141	0.3550	1				
SENSEX	0.135	0.3875	0.4303	1			
RS/POUND	-0.077	-0.0382	-0.0150	-0.0466	1		
RS/USD	-0.077	-0.0716	-0.0766	-0.0953	0.6818	1	
RS/YEN	-0.061	-0.0238	-0.2795	0.0081	0.5294	0.5625	1

Table 2: Correlation coefficients between stock market return and exchange rate return in crisis period

	DJ30	FTSE100	NIKKEI 225	SENSEX	RS/POUND	RS/USD	RS//YEN
DJ30	1						
FTSE100	0.6173	1					
NIKKEI225	0.3155	0.5794	1				
SENSEX	0.4002	0.4880	0.6128	1			
RS/POUND	0.0309	-0.0249	-0.0068	-0.0010	1		
RS/USD	0.0249	-0.1254	-0.3329	-0.2329	0.4398	1	
RS/YEN	-0.0775	-0.2291	-0.5366	-0.3903	0.2298	0.7847	1

Table 3: Correlation coefficients between stock market return and exchange rate return in post-crisis period

	DJ30	FTSE100	NIKKEI 225	SENSEX	RS/POUND	RS/USD	RS//YEN
DJ30	1						
FTSE100	0.7271	1					
NIKKEI225	0.2809	0.3498	1				
SENSEX	0.3810	0.5346	0.3865	1			
RS/POUND	-0.0905	-0.0724	0.0399	-0.0341	1		
RS/USD	-0.3008	-0.2714	-0.2964	-0.3054	0.3831	1	
RS/YEN	-0.2278	-0.2276	-0.4826	-0.2679	0.2884	0.6674	1

Table 2 described the correlation pattern during the crisis period. The rupee-dollar exchange rate return was positively related to both the SENSEX and Dow Jones 30 return. The Rupee-pound exchange rate return was negatively correlated to both SENSEX return and FTSE100 return. The Rupee-yen exchange rate return was negatively correlated with both SENSEX return and Nikkei 225 return.

Table 3 showed the correlation results during the post-crisis period. The rupee-dollar exchange rate return now was negatively related to both the SENSEX and Dow Jones 30 return. Like the two previous cases the Rupee-pound exchange rate return was negatively correlated to both SENSEX return and FTSE100 return. Moreover, the Rupee-yen exchange rate return was once again negatively correlated with both SENSEX return and Nikkei225 return.

Thus, the correlation pattern between the returns in the two markets had changed around the financial crisis. However, the results were not sufficient to explain the effect of economic shocks from one index to another as such effects were likely to be dynamic.

Stationarity test and descriptive statistics: Results for applying ADF and PP tests for the three sub-periods were shown in Tables 4 to 6. Table 4 provided the descriptive statistics and statistic for unit root testing in the pre-crisis period. The return series were found to be level-stationary. While mean stock returns had been positive in the US, UK and Indian market, it had been negative in the Japanese market. The return was maximum in the Indian stock market. The mean change in exchange rate however, had been negative in all the markets. All the series were stationary, non-normal, skew and had kurtosis values greater than three.

Table 5 showed the descriptive statistics and results for testing unit root in the crisis period. The mean stock returns and exchange rate changes were all negative during this period. All the series were stationary, non-normal, skew and had kurtosis values greater than three.

Table 6 showed the descriptive statistics and results for testing unit root in the post-crisis period. The mean stock returns were all positive during this period. Mean exchange rate changes were

Table 4: Descriptive statistics for pre-crisis period

	DJ30	FTSE100	NIKKEI 225	SENSEX	RS/POUND	RS/USD	RS//YEN
Mean	0.0003	0.0001	-0.0003	0.0017	-4.90E-05	-0.0003	-0.00018
Median	0.0008	0.0006	0.0001	0.0022	0	-0.0001	-0.0005
SD	0.0085	0.0102	0.0131	0.0174	0.0088	0.0045	0.0078
Skewness	-0.748	-0.3259	-0.2197	-0.3110	-0.2425	-1.2818	1.0489
Kurtosis	5.6207	4.6163	4.1669	5.0775	80.6910	31.1790	14.0501
Jarque-Bera	165.49	55.1805	28.2478	85.4367	109656.5	14544.85	2298.19
Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ADF	-22.47	-24.5898	-21.3503	-20.2952	-31.1132	-27.2913	-23.4577
Lag	(0)*	(0)*	(0)*	(0)*	(0)*	(0)*	(0)*
PP	-22.55	-24.9532	-21.3558	-20.2876	-32.1304	-27.4846	-23.4577
bandwidth	7*	9*	3*	4*	3*	2*	0*

*implies significance at 1% level of significance

Table 5: Descriptive statistics for crisis period

	DJ30	FTSE100	NIKKEI 225	SENSEX	RS/POUND	RS/USD	RS//YEN
Mean	-0.0025	-0.0036	-0.0022	-0.0027	0.0011	-0.0002	0.0015
Median	-0.0021	-0.0033	-0.0016	-0.0013	0	0.0005	0.0004
SD	0.0250	0.0321	0.0250	0.0313	0.0093	0.0120	0.0164
Skewness	0.0893	-0.5948	0.1157	-1.0777	0.3450	-0.9845	2.0637
Kurtosis	6.1869	6.6307	6.0657	10.0491	15.1639	9.0981	25.5143
Jarque-Bera	105.2845	150.8418	97.6724	561.4802	1533.859	424.3322	5413.953
Prob.	0	0	0	0	0	0	0
ADF	-19.1085	-13.0489	-13.7245	-16.3128	-18.0460	-14.9731	-14.7622
Lag	(0)*	(1)*	(1)*	(0)*	(0)*	(0)*	(0)*
PP	-19.9007	-16.2900	-17.0021	-16.6606	-17.9254	-14.9752	-14.9563
Lag	7*	9*	10*	13*	4*	3*	16*

*implies significance at 1% level of significance

Table 6: Descriptive statistics for post-crisis period

	DJ30	FTSE100	NIKKEI 225	SENSEX	RS/POUND	RS/USD	RS//YEN
Mean	0.0013	0.0012	0.0008	0.0022	-9.44E-05	-3.68E-04	8.22E-05
Median	0.0011	0.0013	0.0008	0.0018	-0.0005	-0.0003	8.34E-05
SD	0.0130	0.0135	0.0157	0.0167	0.0079	0.0057	0.0102
Skewness	0.9098	0.5920	0.5934	2.0762	-0.12	-0.6680	-0.1660
Kurtosis	10.6021	7.7197	7.3492	21.3305	4.13252	8.8474	4.9815
Jarque-Bera	1020.947	395.618	339.5831	5902.283	22.3928	601.1209	67.4512
Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ADF	-22.6505	-21.5632	-20.5774	-13.0596	-21.8839	-20.6965	-21.4187
Lag	(0)*	(0)*	(0)*	(1)*	(0)*	(0)*	(0)*
PP	-22.6033	-21.7193	-20.6352	-21.8810	-22.0791	-20.6962	-21.8297
Lag	4*	10*	10*	4*	9*	1*	11*

*implies significance at 1% level of significance

negative in case of Rupee-Pound and Rupee-US dollar exchange rate. All the series were stationary, non-normal, skew and had kurtosis values greater than three. These justified the use of GARCH family model on the selected data set.

Table 7: Results for applying diagonal VECH in for Pre-crisis period

Results	DJ30	FTSE100	NIKKEI225	SENSEX	RS/POUND	RS/USD	RS/YEN
a_{ij}							
DJ30	0.05261						
FTSE100	0.06255	0.13965*					
NIKKEI225	0.05403	0.08706*	0.08380				
SENSEX	0.05697	0.10627*	0.08921*	0.12367*			
RS/POUND	0.07083	0.14104*	0.10758*	0.13398*	0.17419*		
RS/USD	0.07815	0.15292*	0.10664*	0.13627*		0.17555*	
RS/YEN	0.05231	0.09266*	0.07879*	0.08923*			0.08710*
b_{ij}							
DJ30	0.93993*						
FTSE100	0.89453*	0.83584*					
NIKKEI225	0.91428*	0.86159*	0.89459*				
SENSEX	0.89525*	0.83742*	0.87000*	0.85650*			
RS/POUND	0.89881*	0.84406*	0.87158*	0.85071*	0.85949*		
RS/USD	0.86732*	0.81517*	0.83807*	0.82227*		0.7950*	
RS/YEN	0.90581*	0.84457*	0.87944*	0.85563*			0.86851*
d_{ij}							
DJ30	1.07E-06						
FTSE100	1.03E-06	9.90E-07					
NIKKEI225	1.06E-06	1.02E-06	1.06E-06				
SENSEX	1.04E-06	1.00E-06	1.04E-06	1.02E-06			
RS/POUND	1.02E-06	9.85E-07	1.02E-06	9.99E-07	9.81E-07		
RS/USD	1.01E-06	9.71E-07	1.00E-06	9.85E-07		9.54E-07	
RS/YEN	1.01E-06	9.68E-07	1.00E-06	9.82E-07			9.47E-07

*indicates significance at 5% level. Estimation Method: ARCH Maximum Likelihood (Marquardt), Covariance specification: Diagonal VECH. Sample: 1436 Included observations: 436 Total system (balanced) observations 3052. Convergence achieved after 22 iterations

Results for applying MGARCH: pre-crisis period: The results were reported in Table 7. In the pre-crisis period, the effects of own lagged innovation were significant at five percent level of significance for BSE SENSEX; FTSE 100 stock return and Rs/USD, Rs/Pound and Rs/Yen exchange rates indicating the presence of ARCH effects but the same was not significant for DJ 30 and Nikkei 225 stock markets. Among the stock markets, the own lagged innovation impact was highest (0.14) for FTSE 100, while it was highest for RS/USD (0.18) exchange rate. Based on the magnitudes of the estimated cross-innovation coefficients (a_{ij}; where $i \neq j$), it was observed that cross innovation impact between DJ 30 and RS/USD exchange rate was not significant at 5% level of significance while it was significant between SENSEX and three selected exchange rates against Rupee. Cross innovation coefficients between FTSE 100 and RS/Pound and between Nikkei 225 and RS/Yen remained significant at 5% level of significance.

The values of all the b_{ij} (where, $i = j$) coefficients were positive and significant at 5% level of significance, indicating the presence of GARCH effects. The values of b_{ij} (where, $i = j$) coefficients are higher than that of all a_{ij} (where, $i = j$) coefficients. Own past volatility impact was highest for DJ 30 (0.94) among the selected stock markets. Among the chosen exchange rates, it was highest for RS/Yen exchange rate. Moreover, the cross volatility coefficients (b_{ij}, where, $i \neq j$) remained significantly positive. The cross volatility spillovers from DJ 30 to RS/USD; SENSEX to RS/Pound; and from Nikkei 225 to RS/yen exchange rate had been stronger than that of SENSEX to RS/USD;

FTSE 100 to RS/Pound; and from SENSEX to RS/Yen exchange rate. No asymmetric volatility spill-over between the stock and foreign exchange market was found during pre-crisis period. ARCH-LM test suggested no remaining ARCH effect in the residuals.

Crisis period: The results for the crisis period were reported in Table 8. Own innovation impact coefficients (a_{ij}, i = j) remained significant at 5% level for FTSE 100, RS/USD and RS/Yen indicating the presence of ARCH effects, but the same was not true for DJ 30, Nikkei 225, SENSEX and RS/Pound return series. Cross innovation impact coefficients (a_{ij}, $i \neq j$) were not significant between DJ 30 and RS/USD. The same was true for the relationship between FTSE 100 and RS/Pound and between SENSEX and RS/Pound exchange rate. Significant cross-innovation impact however remained between SENSEX and RS/USD and between SENSEX and RS/Yen exchange rates. The same was true for the FTSE 100 and RS/Pound relationship.

All the b_{ij} (where, i = j) coefficients were positive and significant at five percent level of significance, indicating the presence of GARCH effects. The values of b_{ij} (where, i = j) coefficients are higher than that of all a_{ij} (where, i = j) coefficients except FTSE 100. Own past volatility impact was highest for FTSE 100 (0.86) among the four selected stock markets and it was the highest for RS/Yen exchange rate (0.95) among the three chosen exchange rates. Cross volatility coefficients (b_{ij}, $i \neq j$) remained positive and significant. Significant cross volatility spillovers could be found

Table 8: Results for applying diagonal VECH in for crisis period

Results	DJ30	FTSE100	NIKKEI225	SENSEX	RS/POUND	RS/USD	RS/YEN
a_{ij}							
DJ30	0.14083						
FTSE100	0.05697	0.10135*					
NIKKEI225	0.06844	0.10070	0.14181				
SENSEX	0.11945	0.07791	0.08977	0.11299			
RS/POUND	0.02355	-0.02496	0.00378	0.0591	0.05412		
RS/USD	0.07865	0.06514	0.09317	0.12117*		0.12367*	
RS/YEN	0.02833	0.08547*	0.12623*	0.13408*			0.15401*
b_{ij}							
DJ30	0.80263*						
FTSE100	0.90279*	0.85688*					
NIKKEI225	0.79808*	0.81950*	0.81741*				
SENSEX	0.75493*	0.76075*	0.83339*	0.82863*			
RS/POUND	0.86031*	0.85715*	0.83085	0.81170*	0.94594*		
RS/USD	0.85609*	0.86353*	0.82889*	0.85265*		0.89058*	
RS/YEN	0.77356	0.83064*	0.79267*	0.82578*			0.83658*
d_{ij}							
DJ30	3.73E-06						
FTSE100	1.30E-06	4.55E-07					
NIKKEI225	2.99E-06	1.05E-06	2.40E-06				
SENSEX	2.00E-06	6.99E-07	1.61E-06	1.07E-06			
RS/POUND	3.07E-06	1.07E-06	2.46E-06	1.65E-06	2.52E-06		
RS/USD	1.47E-06	5.12E-07	1.18E-06	7.87E-07		5.76E-07	
RS/YEN	8.70E-07	3.04E-07	6.98E-07	4.67E-07			2.03E-07

* indicates that the corresponding null hypothesis is significant at 5% level. Estimation Method: ARCH Maximum Likelihood (Marquardt). Covariance specification: Diagonal VECH. Sample: 1 248. Included observations: 248. Total system (balanced) observations 1736. Convergence achieved after 37 iterations

between DJ 30 and RS/USD; between FTSE 100 and RS/Pound and between SENSEX and RS/yen. The impact had been less strong in case of SENSEX and RS/USD; SENSEX and RS/Pound; and for Nikkei 225 and RS/Yen exchange rate. No asymmetric volatility spill over, however, was present between the stock market and foreign exchange market during the crisis period. ARCH-LM test suggested no remaining ARCH effect in the residuals.

Post-crisis period: Results for the post-crisis period were presented in Table 9. Own innovation coefficients (a_{ij}, i = j) remained significantly positive for DJ 30, FTSE 100, SENSEX and significantly negative for RS/Yen exchange rate. The only significant (however, negative) cross innovation coefficient (a_{ij}, i ≠ j) had been the one for Nikkei 225 and RS/Yen pair.

All the b_{ij} (where, i = j) coefficients except for that of DJ 30 were positive and significant at five percent level of significance. The values of b_{ij} (where, i = j) coefficients were higher than that of all a_{ij} (where, i = j) coefficients. Own past volatility impact had been highest for Nikkei 225 (0.97) among the four stock markets and for the RS/Yen exchange rate (0.997) among the three exchange rates. All cross volatility coefficients (b_{ij}, i ≠ j) remained positive and significant. The cross volatility spillovers had been stronger between DJ 30 and RS/USD; FTSE 100 and RS/Pound and between Nikkei 225 and RS/Yen series. The relationship had been weaker in the context of SENSEX and RS/USD; SENSEX and RS/Pound and for SENSEX and RS/Yen series. No asymmetric volatility

Table 9: Results for applying diagonal VECH in for post-crisis period

Results	DJ30	FTSE100	NIKKEI225	SENSEX	RS/POUND	RS/USD	RS/YEN
a_{ij}							
DJ30	0.06441*						
FTSE100	0.04192	0.08068*					
NIKKEI225	0.00803	0.01953	0.00385				
SENSEX	0.03553	0.04868	0.01302	0.07017*			
RS/POUND	-0.00701	0.00242	-0.01253	0.00350	-0.01109		
RS/USD	-0.00995	-0.00154	-0.0118	0.00843		0.00095	
RS/YEN	0.00663	-0.00055	-0.02235*	-0.00603			-0.01289*
b_{ij}							
DJ30	0.871503						
FTSE100	0.877806	0.832775*					
NIKKEI225	0.943555	0.900209*	0.974244*				
SENSEX	0.895239*	0.895731*	0.895962*	0.886084*			
RS/POUND	0.945975*	0.919174*	0.95581*	0.917202*	0.995191*		
RS/USD	0.900535*	0.870924*	1.006545*	0.888265*		0.98361*	
RS/YEN	0.950589*	0.890672	1.00693*	0.879063*			0.997545*
d_{ij}							
DJ30	2.78E-06						
FTSE100	1.65E-06	9.79E-07					
NIKKEI225	4.14E-06	2.46E-06	6.16E-06				
SENSEX	2.97E-06	1.76E-06	4.42E-06	3.17E-06			
RS/POUND	2.74E-06	1.62E-06	4.07E-06	2.92E-06	2.69E-06		
RS/USD	2.35E-06	1.40E-06	3.50E-06	2.51E-06		1.99E-06	
RS/YEN	-3.16E-07	-1.87E-07	-4.70E-07	-3.37E-07			3.59E-08

* indicates that the corresponding null hypothesis is significant at 5% level. Estimation Method: ARCH Maximum Likelihood (Marquardt) Covariance specification: Diagonal VECH. Sample: 1 401. Included observations: 401. Total system (balanced) observations 2807. Convergence achieved after 30 iterations

spill over existed between the stock markets and the foreign exchange markets during post-crisis period. ARCH-LM test suggested no remaining ARCH effect in the residuals.

DISCUSSION

This study seeks to explore the volatility spill over channels between some selected stock markets and foreign exchange markets. Such exploration might be significant for global fund managers as well policy makers. In literature, some studies have shown that exchange rate movements provide little or no explanation for stock price movements (Jorion, 1990; Amihud, 1993; Bartov and Bodnar, 1994; Abdalla and Murinde, 1997; Ajayi and Mougoue, 1996; Bernard and Galati, 2000; Smyth and Nandha, 2003). However, significant relationship between stock returns and exchange rate fluctuations could be found in studies by Zietz and Pemberton (1990), Roll (1992), Ferson and Harvey (1993), Granger *et al*. (2000), Patro *et al*. (2002) and Hsing (2004). Adam and Tweneboah (2008) examined the impact of macroeconomic variables in the stock market movement in Ghana. Aggarwal (1981) has studied the US Capital market under floating exchange rates. Alexandra and Livia (2007) have explored the dynamic link between stock prices and exchange rate in the context of Romania. Murinde and Poshakwale (2004) considered the exchange rate and stock price interactions in European emerging financial markets before and after the introduction of Euro. Ibrahim (2000) analyses the stock prices and exchange rate interaction in the Malaysian Market using bivariate and multivariate cointegration and the Granger Causality test. His findings indicate that there is no long run relationship between the two in the bivariate model. However, he envisages a short term relationship of stock prices with monetary, exchange rate and reserve policies. Baharom *et al*. (2008) have a similar study in the context of the Malaysian market. Angabini and Wasiuzzaman (2011) have used GARCH models to analyse the impact of financial crisis in Malaysian financial market. Oh and Lee (2004) used EGARCH (1, 1) and GJR-GARCH (1, 1) models to conclude that depreciation of exchange rate does help enhance the asset value in the Korean won. They further observed that most domestic firms face asymmetric exchange rate exposure. Chiang *et al*. (2000) explored the relationship between stock return and exchange rate risk for the Asian stock markets using a bivariate GARCH model. Nagayasu (2001) explored the issue of currency crisis and contagion in Philippines and Thailand. Chandra (2005) found evidence of increasing co movement among the markets of Australia, Hong Kong, Japan and Singapore since the Asian financial crisis. The market correlation structure was examined using the Constant Correlation multivariate GARCH (CC-MGARCH) model, the Dynamic Conditional Correlation multivariate GARCH (DCC-MGARCH) and an Exponentially-Weighted Moving Average (EWMA) correlation measure. Wu (2001) explored the relationship between exchange rates, stock prices and money markets in Singapore. Abdulnasser and Roca (2005) examined the linkage between the stock prices and the foreign exchange rate in Malaysia, Indonesia, Philippines and Thailand. The two variables were found to be significantly linked in the non-crisis period but not at all during the crisis period. Kearney and Patton (2000) estimate a series of 3-, 4-, 5- variables multivariate GARCH Models of the EMS exchange rates. They conclude that the mark plays a dominant role as it transmits more volatility than the other currencies while remaining insulated from outside shocks. They also highlight that the ECU tends to transmit volatility through its covariance term rather than directly through its variance. Aquino (2005) uses a two-factor arbitrage pricing theory model to unveil the linkage between stock prices and foreign exchange rate. The evidences suggest that stock returns did not react significantly to foreign exchange rate fluctuations before the period of the crisis. After the onset of the crisis, however, Philippine firms started to exhibit cross-sectional differences in their reaction to exchange rate movements. Furthermore, during the post-crisis period, investors began to expect a risk premium on their investments for their perceived added exposure to exchange rate risk.

The studies, in the context of India, particularly after the recent financial crisis of 2007-08, have been limited in number. Mukherjee *et al.* (2011) have considered some stylized facts in Indian financial market. Chakrabarti and Sen (2011) have considered the volatility regimes in foreign exchange markets. Moreover, the available studies have hardly used the multivariate GARCH model. Apte (2001) investigated the relationship between the volatility of the stock market and the nominal exchange rate of India. Mishraa *et al.* (2007) assert that there exists a bidirectional volatility spillover between the Indian stock market and the foreign exchange market using GARCH (1, 1) and EGARCH (1, 1). Hence there is an information flow (transmission) between these two markets and both these markets are integrated with each other. The findings of the study suggest that the volatility in both the markets is highly persistent and predictable on the basis of past innovations. They envisage that there exists a long run relationship between these two markets which suggests that at least there is a unidirectional causality between two variables.

The results of the present study reveal the significant impact of the recent financial crisis of 2007-2008 on the volatility transmission mechanism between the selected stock markets and foreign exchange markets. This is in line with the some of the existing literature in the field and is not agreeable to the results of the other branch of studies that emphasized absence of volatility transmission mechanism between financial markets. It particularly contributes to the literature in the sense that unlike the earlier studies it has considered the impact of the most recent financial crisis on the relationship.

The results revealed the fact that as the markets recovered the variability of return, given by the standard deviation, declined significantly in some markets. The returns, however, have increased.

During the three sub-periods around the crisis, there had been no asymmetric volatility spillover between stock market and foreign exchange markets.

During the pre-crisis period own innovation impact remained significant for the three exchange rates namely, the Rupee-Dollar, Rupee-Pound and Rupee-Yen rates. The impact, however, was the strongest for the rupee-dollar exchange rates. The cross innovation impacts although significant in some cases, have always been less than the own innovation impacts. Thus, own market information plays a relatively more significant role in determining the present volatility in foreign exchange market than that of volatility stemming from other markets. For investors in the stock markets, it would imply that they can use the foreign exchange markets as effective hedge for their investment and vice versa during pre crisis periods. Significant cross innovation impact was found to exist between the stock market and the foreign exchange market. Innovations in the Indian stock market were found to affect volatilities in the three exchange rates against Indian Rupee and vice-versa. Moreover, innovations in Japanese and UK stock markets affected volatility of Rupee-Yen and Rupee-Pound exchange rates respectively. Further, the innovations in the Rupee-Yen and Rupee-Pound exchange rates had significant influence on stock market volatility of Japan and UK respectively. The US stock market movements, however, has remained dissociated from the Rupee-Dollar exchange rate movements.

During the crisis period, the extent of innovation impact has become less pronounced as compared to that in the pre-crisis period. Own innovation impacts were significant only for the Rupee-Dollar and Rupee-Yen exchange rates. The Indian stock market movements remained associated with Rupee-Dollar and Rupee-Yen exchange rates through cross-innovation impact. The same was true for the Japanese stock market and the Rupee-Yen exchange rates.

In the post-crisis period, only the stock markets were characterized by significant own-innovation impacts. Cross innovation impacts however were not very significant between stock market and foreign exchange market volatility. Hence, construction of a multi currency equity portfolio might lead to gains from diversification.

Past volatility impacts, however, have remained significant for the two types of financial markets over the three phases, the only exception being the US stock market in the post-crisis period. Moreover, over the entire study period, volatility spill-over from the Indian stock market to the three selected exchange rates has remained significantly positive.

Thus, as pointed out by the study, while cross-innovation impacts tend to disappear as the market enters a new phase of recovery after the crisis, past volatility effects remain. In this new phase of recovery, news about past volatility or any type of announcement in one type of financial market is less likely to affect future volatility of the other type. However, one must be cautious to recognize the impact of past volatility on the present volatility across the markets. This is particularly true for the Indian market. Present volatility in Indian stock market will always lead to increased volatility in the exchange rates against Indian rupee. Volatilities in other stock markets have relatively weaker effect on these exchange rates. Moreover, volatilities in these exchange rates will easily be transmitted to the Indian stock market.

Thus, particularly during the recent period of financial recovery, significant volatility transmission mechanism exists between the stock markets and foreign exchange markets in the context of India. The nature and extent of such spill-over, however, depend on the movements in the financial markets. The findings have significant policy implications. Any regulatory or deregulatory measures introduced by the government to contain volatility in any financial market should take such linkages into consideration. Moreover, while taking decisions investors should be cautious about the presence of such volatility transmission. The volatility spillover between the financial markets is likely to increase the risk of international diversification.

REFERENCES

Abdalla, I.S.A. and V. Murinde, 1997. Exchange rate and stock price interactions in emerging financial markets: Evidence on India, Korea, Pakistan and Philippines. Applied Financial Econ., 7: 25-35.

Abdulnasser, H.J. and E. Roca, 2005. Exchange rates and stock prices interaction during good and bad times: Evidence from the ASEAN4 countries. Applied Financial Econ., 15: 539-546.

Adam, A.M. and G. Tweneboah, 2008. Do macroeconomic variables play any role in the stock market movement in Ghana. MPRA Paper No. 9368. http://mpra.ub.uni-muenchen.de/9368/1/MPRA_paper_9368.pdf.

Aggarwal, R., 1981. Exchange rates and stock prices: A study of US capital market under floating exchange rates. Akron Bus. Econ. Rev., 12: 7-12.

Ajayi, R.A. and M. Mougoue, 1996. On the dynamic relation between stock prices and exchange rates. J. Finan. Res., 19: 193-207.

Alexandra, H. and I. Livia, 2007. On the dynamic link between stock prices and exchange rate: Evidence from Romania. Academy of Economic Studies, Bucharest, Lucian Blaga University of Sibiu, MPRA Paper No. 6429. http://mpra.ub.uni-muenchen.de/6429/1/MPRA-paper-6429.pdf.

Amihud, Y., 1993. Evidence on Exchange Rates and Valuation of Equity Shares. In: Recent Advances in Corporate Performance, Amihud, Y. and R. Levich (Eds.). Irwin, New York, USA., pp: 49-59.

Angabini, A. and S. Wasiuzzaman, 2011. GARCH models and the financial crisis-A study of the malaysian stock market. Int. J. Applied Econ. Fin., (In Press).

Apte, P., 2001. The interrelationship between stock markets and the foreign exchange market. Prajnan, 30: 17-29.

Aquino, R.Q., 2005. Exchange rate risk and philippine stock returns: Before and after the Asian financial crisis. Applied Finan. Econ., 15: 765-771.

Baharom, A.H., R.C. Royfaizal and M.S. Habibullah, 2008. Pre and post crisis analysis of stock price and exchange rate: Evidence from Malaysia. Int. Applied Econ. Manage. Lett., 1: 33-36.

Bartov, E. and G.M. Bodnar, 1994. Firm valuation, earnings expectations and the exchange-rate exposure effect. J. Finance, 49: 1755-1785.

Bauwens, L., S. Laurent and J.V.K. Rombouts, 2006. Multivariate GARCH models: A survey. J. Applied Econometr., 21: 79-109.

Bernard, H.J. and G.E. Galati, 2000. The co-movement of US stock markets and the dollar. BIS Quarterly Review, August, pp: 31-34.

Bollerslev, T., 1986. Generalized autoregressive conditional heteroskedasticity. J. Econ., 31: 307-327.

Bollerslev, T., 1990. Modelling the coherence in short-run nominal exchange rates: A multivariate generalized ARCH model. The Rev. Econ. Stat., 72: 498-505.

Bollerslev, T., R.F. Engle and J.M. Wooldridge, 1988. A capital asset pricing model with time-varying covariances. J. Political Econ., 96: 116-131.

Brooks, C. and O.T. Henry, 2000. Linear and non-linear transmission of equity return volatility, evidence from the US, Japan and Australia. Econ. Modelling, 17: 497-513.

Chakrabarti, G. and C. Sen, 2011. Volatility regimes and calendar anomaly in foreign exchange market. Int. J. Applied Econ. Fin., 5: 97-113.

Chandra, M., 2005. Estimating and explaining extreme co-movements in Asia-Pacific equity markets. Rev. Pacific Basin Fin. Markets Policies, 8: 53-79.

Chiang, T.C., S.Y. Yang and T.S. Wang, 2000. Stock return and exchange rate risk: Evidence from Asian stock markets based on a bivariate GARCH model. Int. J. Bus., 5: 97-117.

Dickey, D.A. and W.A. Fuller, 1979. Distribution of the estimators for autoregressive time series with a unit root. J. Am. Stat. Assoc., 74: 427-431.

Dornbusch, R. and S. Fisher, 1980. Exchange rates and the current account. Am. Econ. Rev., 70: 960-971.

Dunne, P.G., 1999. Size and book-to market factors in a multivariate GARCH-in-mean asset pricing application. Int. Rev. Financial Anal., 8: 35-52.

Engle, R.F. and K.F. Kroner, 1995. Multivariate simultaneous generalized ARCH. Econometric Theory, 11: 122-150.

Ferson, W.E. and C.R. Harvey, 1993. The risk and predictability of international equity returns. Rev. Financial Stud., 6: 527-566.

Goeij, P.D. and W. Marquering, 2004. Modeling the conditional covariance between stock and bond returns: A multivariate GARCH approach. J. Fin. Econometrics, 2: 531-564.

Granger, C.W.J., B.N. Huang and C.W. Yang, 2000. A bivariate causality between stock prices and exchange rates: Evidence from recent Asian flu. The Quart. Rev. Econ. Fin., 40: 337-354.

Harris, R. and R. Sollis, 2003. Modelling and Forecasting Financial Time Series. John Wiley and Sons, New York, USA.

Higgins, M.L. and K.A. Bera, 1993. A class of nonlinear ARCH models. Int. Econ. Rev., 33: 137-158.

Hsing, Y., 2004. Impacts of fiscal policy, monetary policy and exchange rate policy on real GDP in Brazil: A VAR model. Brazil. Elect. J. Econ., 6: 1-12.

Ibrahim, M.H., 2000. Cointegration and granger causality tests of stock price and exchange rate interactions in Malaysia. Asian Econ. Bull., 17: 36-47.

Jorion, P., 1990. The exchange rate exposure of US multinationals. J. Bus., 63: 331-345.

Karolyi, G.A., 1995. A multivariate GARCH model of international transmissions of stock returns and volatility. J. Bus. Econ. Stat., 13: 11-25.

Karunanayake, I., A. Valadkhani and M. O'Brien, 2008. Modelling Australian stock market volatility: A multivariate GARCH approach. Economics Working Paper Series, University of Wollongong.

Kearney, C. and A.J. Patton, 2000. Multivariate GARCH modeling of exchange rate volatility transmission in European monetary system. The Fin. Rev., 35: 29-48.

Kroner, K.E. and V.K. Ng, 1998. Modeling asymmetric aomovements of asset returns. The Rev. Finan. Stud., 11: 817-844.

Krueger, A.O., 1983. Exchange-Rate Determination. Cambridge University Press, USA., pp: 218.

Mishraa, A.K., N. Swain and D.K. Malhotra, 2007. Volatility spillover between stock and foreign exchange markets: Indian evidence. Int. J. Bus., 12: 343-359.

Mukherjee, I., C. Sen and A. Sarkar, 2011. Study of stylized facts in Indian financial markets. Int. J. Applied Econ. Finance, 5: 127-137.

Murinde, V. and S. Poshakwale, 2004. Exchange rate and stock price interactions in European emerging financial markets before and after the Euro. Birmingham Business School Working Paper, University of Birmingham, Birmingham.

Nagayasu, J., 2001. Currency crisis and contagion: Evidence from exchange rate and sectoral indices of the Philippines and Thailand. J. Asian Bus., 12: 529-546.

Oh, S. and H. Lee, 2004. Foreign exchange exposures and asymmetries in exchange rate: Korean economy is highly vulnerable to exchange rate variations. J. Fin. Manage. Anal., 17: 8-21.

Pagan, A., 1996. The econometrics of financial markets. J. Fin., 3: 15-102.

Patro, D.K., J.K. Wald and Y. Wu, 2002. Explaining exchange rate risk in world stock markets: A panel approach. J. Bank. Fin., 26: 1951-1972.

Philips, P.C.B. and P. Perron, 1988. Testing for a unit root in time series regression. Biometrika, 75: 335-346.

Roll, R., 1992. Industrial structure and the comparative behavior of international stock market indices. J. Fin., 47: 3-41.

Scherrer, W. and E. Ribarits, 2007. On the parameterization of multivariate GARCH models. Econometric Theory, 23: 464-484.

Smyth, R. and N. Nandha, 2003. Cointegration and causality in Australian Capital city house prices 1986-2001. J. Econ. Soc. Policy, 7: 35-50.

Wu, Y., 2001. Exchange rates, stock prices and money markets: Evidence from Singapore. J. Asian Econ., 12: 445-458.

Zietz, J. and D.K. Pemberton, 1990. The US budget and trade deficits: A simultaneous equation model. Southern Econ. J., 57: 23-34.