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On the Linkages among Selected Asian, European and the US Implied Volatility Indices

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Abstract

This paper examines the implied volatility linkages among the Asian, American and European stock markets. For this purpose, the study makes use of implied volatilities calculated from the market prices of stock index options from India (IVIX), Japan (VXJ), Hong Kong (VHSI), South Korea (VKSOPI), the US (VIX) and Germany (VDAX). The results of the study suggest that the US implied volatility index has substantial impact over the variations of other international implied volatility indices, thus raising the possibility of it constituting a usable risk factor for investors trading internationally; another issue here relates to abrupt changes in the VIX giving rise to potentially destabilizing contagion over volatility internationally. The implications of our results for India specifically at the market's current state of financial development are, at first glance, comforting, since none of the examined volatility indices bears a notable impact over their Indian equivalent, a fact perhaps indicative of the market's lag in terms of integration with the global financial system. However, as this integration expands with time, it is expected that this will change, as the results from the rest of the markets in this study suggest.

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On the Linkages among Selected Asian, European and the US Implied Volatility Indices

1. Introduction

Implied volatility is the market expectation about the future realized volatility of the underlying asset over the remaining life of an option. As implied volatility is forward looking, that is, implied by market prices of options, and options are the common consensus of the market participants about the expected future volatility, implied volatility may be regarded as the market participants' forecast of the average future volatility of the underlying asset over the remaining life of the option contract (assuming investors' rationality). Implied volatility should incorporate all the available information that is relevant for forming the expectation about the future volatility. Therefore, implied volatility may be considered as the best available estimate of market fluctuation or uncertainty (Merton, 1976). In other words an implied volatility index reflects the market expectations for the future volatility of the underlying equity index. Implied volatility provides a method to measure investors' expectation of uncertainty regarding future price movements. In integrated markets, the expectation of uncertainty in one market should be reflected in the respective expectations on other markets. Therefore, the degree of integration can be investigated by examining the interactions of implied volatilities across various equity markets (Nikkien and Sahlstrom, 2004). Information about the dependencies in implied volatility series is useful in the construction of better volatility forecasts. Measures of volatility expectations are essential in investment decision-making, risk-hedging and market regulation. Indeed, expectations can exert significant influence on market prices and can even affect the course of monetary policy, especially during periods of financial turmoil. But, empirical tests of *ex ante* market volatility remain impeded by the fact that expected volatility is rather difficult to ascertain with a high degree of accuracy (Whaley, 2000).

The use of implied volatilities as the basis of international integration stipulates confirmation of market participants' expectations about future uncertainty and not the actual price fluctuations. Implied volatility provides a method to measure investors expectation of uncertainty regarding future price movements. On integrated markets, expectation of uncertainty on one market should be reflected in expectations on another markets. Therefore, the degree of integration can be investigated by examining interactions in implied volatilities across various equity markets (Nikkien and Sahlstrom 2004).

International integration, in terms of implied volatility spillovers, has been an issue of growing interest in recent finance literature especially in the aftermath of events like the Asian and Russian crisis at the end of the 1990s, the September 11, 2001 attacks and the subprime crisis in 2008. The international integration literature, according to Gagnon and Karolyi (2006), may be divided into three classes: the first category focuses on the potential diversification benefits of investing internationally. The second class studies possible structural patterns in the co-movements of international markets, while the third category deals with the lead-lag relationships between markets across the globe. Conceivably, our effort falls into the latter group.

For most practical purposes, linkages in future stock market volatilities are of interest. Although several studies have examined implied volatilities in stock markets (see Mayhew, 1995 for a review), little is known about the dynamics of implied volatilities derived from stock markets. (see, e.g., Wagner and Szimayer, 2004; Nikkinen and Sahlström, 2004; Skiadopoulos, 2004; Nikkinen *et.al*, 2006; Äjiö, 2008). Äijö(2008) investigated the relation between the new European volatility indexes (VDAX, VSMI and VSTOXX). He found that the volatility indexes are highly correlated and indexes vary over time, the VDAX being the dominant source of information. VDAX Granger-causes both VSMI and VSTOX, and the variance of the forecast errors of the implied volatility term structure of the VSTOXX and VSMI explain 65% and 35%, respectively, of the implied volatility term structure of the VDAX. Nikkinen and Sahlström (2004) studied international equity market integration of the United States (US), United Kingdom (UK), German and Finnish markets with respect to implied volatility indexes using the VAR framework, testing for Granger causality, impulse responses and variance decompositions. Similarly, they found a high degree of integration among these markets: while the US market is the leading source of information transmitting to other markets generally, in the European context the German market leads other European markets, i.e., the UK and Finnish markets. Asset price volatility may be a major concern for global financial stability. Eun and Shim (1989), Booth *et al.* (1997) and Kanas (1998) use ex post volatility estimates to examine volatility linkages across exchange rates. This project uses *ex ante* volatility estimates extracted from option prices. This approach has several advantages. Most importantly, implied volatility may be considered as the best available estimate of market uncertainty. It is well known that market uncertainty may change considerably from day to day. Such changes in uncertainty should be immediately reflected in option prices, and hence, also in implied volatilities. On the contrary, volatility estimates obtained via ARCH modelling are based on past observations, and hence, are by construction constrained to reflect only past market reactions rather than current or expected future market uncertainty. Poon and Granger (2003) indicate that forecasts based on implied volatility beat forecasts based on historical returns. For the S&P100 index and VIX implied volatility index, Blair *et.al* (2001) show that historical returns do not provide much incremental information compared to the information given by the VIX index of implied volatility. For three classes of assets (stock indices, exchange rates and oil prices), Martens and Zein (2002) show that implied volatility measures do provide superior volatility forecasts compared to daily GARCH-type models.

If option markets are efficient, implied volatility should be an efficient forecast of future volatility, i.e., implied volatility should subsume the information contained in all other variables in the market information set in explaining future volatility. It has been maintained that implied volatility is as an efficient volatility forecast in a wide range of settings (e.g., Day and Lewis, 1988; Harvey and Whaley, 1992; Poterba and Summers, 1986; Sheikh; 1989).

On the other hand Day and Lewis (1992), who study S&P 100 index options with expiries from 1985-1989, and Lamoureux and Lastrapes (1993), who examine options on ten stocks with expiries from 1982 to 1984, conclude that implied volatility is biased and inefficient. Xu and Taylor (1995) focus on the informational efficiency of the PHLX currency options market. According to Jorion (1995) who deals with FOREX data, implied volatility is an efficient but biased forecast of future volatility. Canina and Figlewski (1993) show that there is almost no correlation between implied volatility and future realized volatility. Another class of finance literature focuses on the determinants of the smile pattern in the implied volatility (for example Rubinstein, 1994; Dumas *et.al* 1998; Peña *et.al* 1998; Corrado and Su 1996; Hafner and Wallmeier 2000). A further research category deals with implementable option pricing models that admit stochastic volatility, including Stein and Stein (1991), Heston (1993), Bates (2000), Bakshi *et.al.* (1997), and Das and Sundaram (1997).

If markets are efficient and the option pricing model is correct, implied volatilities calculated from options (both call and put) on the same underlying asset and with the same expiry but with different strike prices should be identical. However, in reality, the volatility implied by Black and Scholes' option pricing model exhibits a variation with respect to the strike price (known as a smile or skew), where deep-in-the-money or out-of-the-money options are associated with higher implied volatility than at-the-money options. Therefore, it is debatable as to which implied volatility or combination of implied volatilities provides the best measure of the market's volatility expectation over the life of the options. Starting with Latane and Rendleman (1976) various alternative weighting schemes have been proposed in the literature.

Objective and Justification of the Study

It is important to know whether implied volatility spills over from one market to another, due to market integration. However, implied volatility spillover phenomena across all markets have implications for risk managers, international portfolio managers and option traders. They need to characterize which market leads other markets and which market is a major source of implied information. More specifically, they need to know the volatility transmission from one market to another: How does a shock to one volatility index affect another volatility index? What is the magnitude and sign of the effect, and how long does the effect persist for? Finally, to what extent can the shock of one market explain the forecast error variance of another volatility index? These questions need to be addressed in the Asia-Pacific context with reference to developed market such as U.S and Germany. The motto of choosing the sample for this study in the context of Asia-Pacific is that: Asia-Pacific markets are among the emerging market in the world.

This project focuses on implied volatility linkages among the Asian implied volatility indices of India VIX[2] (IVIX), Hong Kong (Volatility Hang Seng Index - VHSI), Japan (Volatility Index Japan - VXJ), South Korea (Volatility Korea Composite Stock Price Index - VKOSPI), US (VIX) and Germany (Volatility Deutscher Aktien Index - VDAX). In this project an attempt has been made to answer the questions raised in the previous section. This study differs from previous works in two distinctive fashions: First, a longer volatility sample data has been used[3] and secondly, to the best of our knowledge, no work has been undertaken in the context of emerging market as in the case of Asia-Pacific with reference to developed market US and Germany to find linkages among the implied volatility indices. The remainder of the project is organized as follows. Section 2, discusses the concept of implied volatility and briefly discusses about implied volatility indices. The data and methodology are presented in section 3. The empirical analysis alongside concluding remarks is presented in section 4.

II. Implied Volatility and Implied Volatility Indices

According to option pricing theory, the option value, C_t, is usually defined as a function of five factors known as the direct determinants of an option value (Cox & Rubinstein, 1985):

$$C_t = f(S_t, K, T - t, r, \sigma)$$

where S_t denotes the underlying asset price at time t, K the strike price, r the risk-free interest rate, T-t the time to maturity of the option, and σ the volatility of the underlying asset returns over the remaining life of the option. Of these direct determinants all except volatility are observable in the market.

[2] "“VIX” is a trademark of Chicago Board Options Exchange, Incorporated ("CBOE") and Standard & Poor’s has granted a license to NSE, with permission from CBOE, to use such mark in the name of the India VIX and for purposes relating to the India VIX.

[3] Nikkinen *et.al* (2006) used the data from Jan 2 2001 to Sept 29 2003.

When the market price of an option is known, it is possible to find such a volatility value that makes the option value given by the option pricing model[4] agree with the market price of the option. This volatility value is called implied volatility σ_{isd} and it is given by

$$\sigma_{isd} = f^{-1} (C_t , S_t , K, T - t, r)$$

where f^{-1} denotes the inverse function of f. Implied volatility can be interpreted as the market's expectation of the underlying asset's average return volatility over the remaining life of the option as shown by Merton (1976) in the deterministic volatility case.

In the Black–Scholes framework, the volatility of the underlying asset price is the only unobservable determinant of the option price. Consequently, given the other variables, the price of an option, c_t, at time t can be expressed as a function of volatility, $c_t = f(\sigma)$, where σ denotes the volatility of the underlying asset price. Provided that option prices are observable in the market, the volatility implied by option prices, σ_{iv}, can be obtained by inverting the pricing function, $\sigma_{iv} = f^{-1}(c_t)$, where f^{-1} is the inverse function of f. This implied volatility estimate is the market's assessment of the future volatility over the remaining life of the option. By equating the market price of an index option to its model value and solving for volatility, we identify the implied (by the option price) volatility. This implied volatility is the market's "best" assessment of the expected volatility of the underlying asset (in this case, a stock index) over the remaining life of the option.

The calculation of the original volatility implied index (VIX which is the ticker symbol that CBOE currently uses) is described in detail in Whaley[5] (1993, 2000) and Fleming *et.al*. (1995). To understand VIX, it is important to emphasize that it is forward-looking, measuring the volatility that investors expect to see. It is not backward-looking, measuring the volatility that has been recently realized. The VIX is more of a barometer of investors' fear of the downside than it is a barometer of investors' excitement (or greed) in a market rally. It is important to note, however, that this evidence merely documents correlation and is not intended to express

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[4]E.g., the Black & Scholes (1973) model.
[5] See Whaley (1993, 2000 and 2008)

causality. It is based on the Black-Scholes/ Merton option valuation formula and constructed from the volatility implied by four pairs of call and put options on the S&P100. In particular, two near-the money (one above and one below the at-the-money strike price) call options and two near-the-money put options of the nearby expiry and respectively four near-the-money options for the second nearby expiry are used.

An implied volatility index is often referred to as the “investors’ fear gauge” (e.g., Whaley, 2000), because the level of the implied volatility index indicates the consensus view on the expected future realized stock index volatility. When the level of volatility index increases, as a consequence, fear in the market increases; alternatively, when the level of volatility index decreases, run-ups are triggered in the daily stock index prices. Additionally, the volatility index level indicates the degree of willingness of market participants to pay in terms of volatility in order to hedge the downside risk of their portfolios with put options or long positions in call options with limited downside risks instead of positions in the underlying asset.

The new VIX was introduced in September 2003. It differs from the old VXO in two respects. First, the two indices have different underlying indices; in particular, the new VIX calculation is based on options written on the S&P 500 index, while VXO uses options on the S&P 100. The rationale of the change was that, although the two indices are well correlated, the S&P 500 is considered to be the benchmark of the U.S. stock market. Second, the two indexes use different methods of calculation of the implied volatility. The new VIX is independent of any model and no longer relies on the Black-Scholes / Merton model. It is based on the concept of the fair value of the future variance developed by Demeterfi *et. al.* (1999a) and is calculated directly from market observables, which are independent of any pricing model, such as the market prices of call and put options and interest rates.

III. Data and Methodology

The sample consists of daily closing prices from April 2009 to February 2011. Because of different trading hours and different time zones, there is discrepancy between the closing times of the Asian, European and U.S. exchanges. The German market closes at UTC +1 (9.00 a.m.

local time), the Hong Kong market at UTC+8 (9.30 a.m. local time), the Japanese stock market at UTC+9 (9.00 a.m. local time), the Korean stock market at UTC+9 (9.00 a.m. local time), the Indian stock market at UTC+5.5 (9 a.m. local time) and the U.S. market is open at UTC-5 (9:30 local time). Thus, our empirical research will use a common data set from March 2009 to April 2011.But as the VKOSPI has been introduced on 13thApril 2009, some data points will be missing. In the case of VHSI data, it is available up to 18th February 2011. Details of the data employed here are discussed in appendix A

Descriptive statistics of implied volatilities and their logarithmic changes are presented in table 1.

Table 1 Descriptive Statistics of Volatility Indices (13/4/2009 to 18/2/2011) the table below.

	IVIX	VDAX	VHSI	VIX	VKOSPI	VXJ
Panel A: Levels						
Mean	27.1514	22.567	26.0949	23.7368	21.7575	25.8919
Median	24.32	22.19	24.05	23.19	20.405	25.735
Maximum	56.07	36.54	45.58	45.79	38.2	43.9
Minimum	15.22	14.4	16.19	15.45	14.5	16.37
Std. Dev.	9.0262	4.7213	7.1489	5.5175	5.0852	5.4872
Skewness	1.2001	0.6054	0.7637	0.7644	1.1597	0.4252
Kurtosis	3.7386	2.8685	2.5678	3.3565	3.8148	3.0264
Jarque-Bera	121.404 (0.000)	28.551 (0.000)	48.5 (0.000)	47.436 (0.000)	116.341 (0.000)	13.936 (0.001)
Panel B: Changes (log(Pt/Pt-1))						
Mean	-0.0014	-0.0019	-0.002	-0.0018	-0.0016	-0.0018
Median	-0.0038	-0.0038	-0.004	-0.0084	-0.0031	-0.0008
Maximum	0.1545	0.2834	0.2383	0.2752	0.197	0.2887
Minimum	-0.1631	-0.2703	-0.132	-0.3506	-0.1376	-0.1652
Std. Dev.	0.0514	0.0516	0.0469	0.0648	0.0451	0.0529
Skewness	0.2125	0.7469	0.8914	0.7047	0.6683	0.9113
Kurtosis	3.5595	8.6245	6.3934	7.2056	4.8571	7.2944
Jarque-Bera	9.483 (0.009)	650.518 (0.000)	282.235 (0.000)	377.896 (0.000)	100.564 (0.000)	418.057 (0.000)

The mean values of all six volatility index series are not statistically different from zero. The mean values are positive for the level series but negative for the differenced series. Standard deviations are high for the level series compared to the differenced series. The test for skewness confirms that all six volatility indices are positively skewed in both level and the first-difference form. Further, all six series in their first difference form are highly leptokurtic with respect to the normal distribution.

Table 2. Pearson's Coefficient of Correlation

	IVIX	VDAX	VHSI	VIX	VKOSPI	VIJ
Table A: Levels						
IVIX	1.0000					
VDAX	0.8310	1.0000				
VHSI	0.9332	0.8932	1.0000			
VIX	0.6514	0.8892	0.7266	1.0000		
VKOSPI	0.9093	0.8943	0.9509	0.7806	1.0000	
VIJ	0.6656	0.8764	0.7587	0.9127	0.7942	1.0000
Table B: Changes (ln pt / pt-1)						
IVIX	1.0000					
VDAX	0.3296	1.0000				
VHSI	0.4241	0.3970	1.0000			
VIX	0.1306	0.5764	0.2396	1.0000		
VKOSPI	0.3314	0.3235	0.5423	0.1847	1.0000	
VIJ	0.2766	0.3138	0.5204	0.1901	0.6066	1.0000

The Pearson's correlation coefficient analysis on the implied volatility series and their changes are reported in table 2. It can be observed that, in the level form, the correlation coefficients between several pairs of indices are very high. The lowest degree of correlation, 0.6656, is between Japan and India and the highest, 0.9509, is between Malaysia and Hong Kong. However, in the first-difference form, the lowest correlation, 0.1306, is between the US and India and the highest correlation, 0.6066, between Japan and Malaysia.

IV. Results - Concluding Remarks

In this project, the VAR (p) system given by equation (1) is formulated to ascertain possible lead-lag effects in examining the transmission of shocks of the implied volatility series of one index over the other indices in the system.

We investigate the stationarity of our six sample series by applying the augmented Dickey Fuller (ADF) test and Phillips - Perron unit root test. The unit root statistics of the ADF and PP tests, by and large, reject the null hypothesis of stationarity of the series in their level form; conversely, the null of stationarity is not rejected in their first-difference form at the 1% level of significance. Given that the unit root tests indicate stationarity in the first differences of the implied volatility time series, vector autoregressive modeling is applied to ascertain the causal dynamics of the implied volatilities.

Table 3. Unit-root Test Results

	ADF		PP	
	LEVEL	FIRST DIFF	LEVEL	FIRST DIFF
IND	-2.128391	-10.98875	-2.183394	-22.73689
GER	-2.956021	-11.89418	-3.184108	-22.85575
USA	-3.144591	-12.47782	-3.410188	-23.40046
HNK	-2.414993	-12.6768	-2.487035	-24.3543
JAP	-4.301287	-12.30084	-4.739218	-21.81229
KRA	-3.149106	-12.71798	-3.293754	-21.34035

The ADF and Philips-Perron test statistics are computed with three lags and without a time trend. At the 1% level the critical value of ADF and PP is -3.44. $dy_t = \beta y_{t-1} + \varepsilon$, H_0: $\beta=0$ and H_1:$\beta<0$, Use the t statistic and compare it with the the table of critical values computed by Dickey and Fuller. If your t value is outside the confidence interval, the null hypothesis of unit root is rejected

Hence the implied volatility dynamics of the IVIX, VDAX, VHNK, VIX, VKOSPI and VXJ volatility indices are described by the following unrestricted VAR (p) model. The VAR (6) system of equations given in equation 1 is represented in Appendix B.

$$\boldsymbol{\sigma_t} = \boldsymbol{\alpha} + \sum_{i=1}^{P} \Phi i \, \sigma t - i + \varepsilon t \quad (1)$$

where $\sigma_t = (\sigma_{India}, \sigma_{Germany}, \sigma_{HongKong}, \sigma_{USA}, \sigma_{Korea}, \sigma_{Japan})$ is a covariance stationary 6 x 1 vector of implied volatility time series containing 3x503 observations, α the 6 x 1 vector of intercepts, φ_i {i=1, 2,….p} the 6 x 6 matrix of autoregressive coefficients, ε_t the 6 x 1 vector of white noise with zero mean and positive definite covariance matrix, and p denotes the lag order of the system.

Within the framework of the VAR system of equations, the significance of all the lags of each of the individual variables is examined jointly with an *F*-test. Since several lags of the variables are included in each of the equations of the system, the coefficients on individual lags may not appear significant for all lags, and may have signs and degrees of significance that vary with the lag length. However, *F*-tests will be able to establish whether all of the lags of a particular variable are jointly significant. Furthermore, the speed at which the volatility movements are transmitted from one market to another is tested and the extent that a movement in one market can explain a movement in another market is examined by using impulse response function and variance decomposition. Impulse response analysis is used to trace the impact of a shock in the implied volatility of one index on the future values of itself and the other implied volatility indices in the system. Moreover, impulse response analysis reveals the persistence of shocks in the system, and hence, enables an assessment of the dynamic structure of volatility transmission. In order to avoid problems with the ordering of the variables in the system, the generalized impulses proposed by Pesaran and Shin (1998) are applied in the impulse response analysis. Finally, variance decomposition analysis is used to assess the fraction of variation in implied volatility of one implied volatility index caused by innovations in the other implied volatilities in the system. The variance decomposition provides information about the relative importance of one implied volatility index in affecting the other implied volatility indices in the system.

Determining the appropriate lag order, p, for the VAR system is an empirical issue. In this project the order of the VAR is determined based on the standard lag length criteria. In addition, given that the residuals of the VAR should exhibit no serial correlation if there are enough lags in the model, the residual serial correlation is tested to confirm the adequacy of the lag order. Four different selection criteria, namely Akaike information criterion (AIC), Schwartz information criterion (SIC); Hannan-Quinn Information criterion (HQIC), and the Likelihood Ratio (LR) tests are employed to that end.

Table 4. VAR order selection tests

Lag	AIC	SC	LR	HQ
0	-20.201	-20.147	NA	-20.180
1	-20.616	-20.23271*	254.757	-20.46470*
2	-20.615	-19.904	69.650	-20.335
3	-20.62663*	-19.587	74.004	-20.217
4	-20.555	-19.188	37.678	-20.017
5	-20.571	-18.875	73.583	-19.903
6	-20.507	-18.483	39.636	-19.709
7	-20.460	-18.108	45.898	-19.533
8	-20.420	-17.740	48.284	-19.364
9	-20.380	-17.371	47.083	-19.194
10	-20.381	-17.045	62.92204*	-19.066

Table 4 reports the AIC, HQIC, SIC and LR criteria lag order selections. AIC suggests 3 lags, HQIC suggests 1 lag, LR suggests 10 lags, and SIC suggests 1 lag. Hence, the parsimonious AIC with lag 3 is chosen, and accordingly, analysis is conducted with lag 3 for the first equation of the VAR system which is of concern to us in the project.

Table 5 reports the summary statistics of the VAR (3) estimation results. The *F*-statistics indicate that the estimated VAR (3) model is statistically highly significant. Moreover, $\mathbf{R}^{\wedge 2}$ is ranging from 0.04 for the VIX USA to 0.281 for the Japanese index. The Ljung–Box statistic for 10 lags shows no sign of residual serial correlation in the model, thereby suggesting that the selected lag order is adequate.

Table 5. Summary of VAR (3) results

Depended Variable	Adjusted R^2	F-Statistics	*P* Value	Q(10)	*P* Value
IND	0.059	2.593	0.000	9.407	0.494
GER	0.057	2.526	0.000	14.994	0.132
HNK	0.144	5.264	0.000	11.355	0.331
USA	0.048	2.287	0.000	8.422	0.588
KRA	0.166	6.069	0.000	13.150	0.215
JAP	0.281	10.942	0.000	14.000	0.173

The contemporaneous residual correlations of the estimated VAR (3) model are shown in table 6. All residual correlations in table 6 are positive and statistically significant. The highest residual correlation is found between the VKOSPI (Korea) and the VIJ (Japan), with the correlation coefficient being 0.517. The residual correlations are somewhat lower between IVIX (India) and VIX (USA), the correlation coefficient being 0.16. The residual correlations indicate that the market expectations are contemporaneously and positively linked among our sample markets.

Table 6. Residual correlation

	IND	GER	HNK	USA	MAL	JAP
IND	1.0000					
GER	0.297(.000)	1.0000				
HNK	0.373(.000)	0.360(.000)	1.0000			
USA	0.160(.000)	0.648(.000)	0.290(.000)	1.0000		
KRA	0.276(.000)	0.297(.000)	0.483(.000)	0.241(.000)	1.0000	
JAP	0.183(.000)	0.278(.000)	0.425(.000)	0.248(.000)	0.517(.000)	1.0000

Generalised Impulse Response Function

An impulse response function measures the responses of the variables—in our case IVIX, VXJ, VHSI, VKOSPI, VIX and VDAX—in the dynamic VAR system to a shock to each variable. That is, a one standard error shock is applied to the error of a variable, and the effect on the dynamical VAR system over a specified period of time is recorded. The accumulated impulse responses of IVIX to a one standard deviation shock in the innovations of VXJ, VHSI, VKOSPI, VIX and VDAX are provided in figure 1. A unit shock is applied to IVIX, VXJ, VHSI, VKOSPI, VIX and VDAX and the corresponding impulse responses of IVIX on Day 1 are traced. Similarly, the same unit shock is applied to each volatility index and accumulated responses of IVIX on Day 2 are captured. As can be seen, the effects are positive. However, slight decreases from their previous levels are noticed on Day 1, and a similar increase is observed on Day 3 to the same unit shock. On Day 4, the accumulated impulse responses of IVIX to the same unit shock in each volatility index induce an increase in VIX. From Day 6 onward up to Day 10, the effect of the same shock each time gradually dies out and thus induces no more change in the IVIX index. Likewise a unit of shock is applied to each of the indices and its corresponding impulse responses are noted for each of the variables.

Figure 1, presents impulse responses of implied volatility in one market to a shock in the implied volatility in other markets. The 95% confidence intervals are reported. In figure 1, Day 1 indicates contemporaneous effects, Day 2 is a 1-day lagged effect, etc. In general, the results are in line with our previous results. A total of 36 impulse responses could be calculated since there are 6 variables in the system. Considering the signs of the responses, impulse responses to six implied volatility indices are both positive and negative. The effect of the shocks dies away after six days. Variance decomposition determines how much of the forecast error variance of each of the variables can be explained by exogenous shocks to the other variables.

Response to Generalized One S.D. Innovations ± 2 S.E.

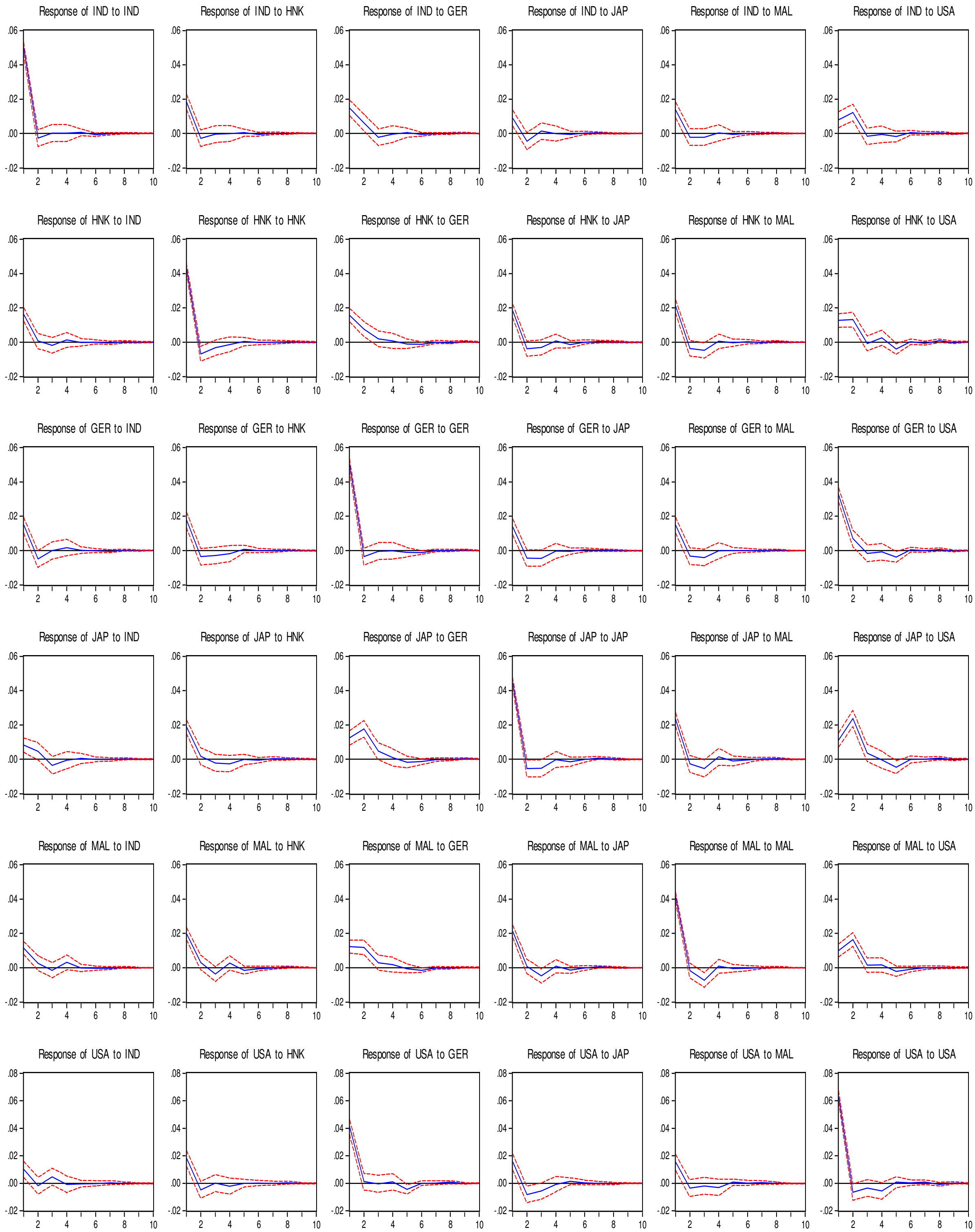

Figure 1. Impulse responses of implied volatility changes in one market to a unit shock in implied volatility change in another market based on the Pesaran and Shin (1998) method. Day 1 indicates contemporaneous effect.

Variance Decompositions

The impulses can be utilized in the derivation of the forecast error variance decompositions. An impulse response function captures the effects of a unit shock of one endogenous variable onto the other variables in the dynamic VAR system; the variance decomposition separates the variance of an endogenous variable into the component shocks to the dynamic VAR. Thus, variance decomposition analysis is important in providing information about the relative importance of each random innovation in affecting the variables in the dynamic VAR system, and more specifically, to determine how important the innovations of all endogenous variables in the system are in order to forecast error variances of each variable for the specified number of steps ahead (see, e.g., Koop *et al*., 1996; Pesaran and Shin, 1998; Mills, 1999).

Table 7, provides the variance decompositions for IVIX, VHSI, VKOSPI, VXJ, VDAX and VIX which are translated into graphical form in figure 2. There are six panels in Table 7; the first column of each panel shows the number of days ahead error variances; and the second column reports standard errors, i.e., the forecast error of the variable at a particular forecast horizon. This forecast error is the variation in the current and future expected values of the innovations to each variable in the dynamic VAR system. The remaining six columns in each panel of Table 7 provide the percentage forecast error variances due to specific innovations, each row adding up to 100 percent.The results of the variance decomposition for IVIX are reported in panel A of Table 6. IVIX explains all of its own 1-day ahead forecast error variance and 90.691% of its 10-day ahead forecast error variance. However, none of the other volatility indexes are able to explain even 1% of the forecast error variance in IVIX, except VIX, which explains 7% of the forecast error variance. The results of the variance decomposition for VXJ are presented in Panel B of Table 7. As can be seen, VXJ explains 96.367% of its own 1-day ahead forecast error variance and 68.960% values for 10-day ahead forecast error variance; likewise, for 10-day ahead horizons, the VIX explains 24.547% of the forecast error variance in VXJ. However, IVIX and VHSI volatility indexes are able to explain even 3% and 2% of the forecast error variance in VXJ.

The results of the variance decomposition for the VKOSPI volatility index are displayed in Panel C of Table 7. As can be seen, VKOSPI explains 69.778% of its own 1-day ahead forecast error variance and 57.776% of its 10-day ahead forecast error variance, while VIX explains 14% for 10-day ahead, and 31.250% for 10-day ahead forecast error variance in the VKOSPI index. It's 1 day ahead.

IVIX and VXJ explain 7.637% and 22% for 1 day ahead and 7% and 14% for 10-day ahead forecast error variance respectively. None of the other volatility indexes significantly explain the forecast error variance in VKOSPI. The result of the variance decomposition for the VIX volatility index is shown in Panel D of Table 7. As can be seen, VIX explains 91% of its own 1-day ahead forecast error variance. The other five indices explain 9% of VIX in forecast variance for 1 day-ahead. Similar pattern has been seen for the rest two indices VDAX and VHSI.

The main conclusion drawn from Table 6 is that the VIX volatility index can explain on average 7%, 24%, 14%, 31% and 11% of the forecast error variances of IVIX, VXJ, VKOSPI, VDAX and VHSI respectively. On the other hand, VXJ is the second most influential volatility index, particularly in the Asian context which can explain on average 19%, 7%, 5% and 11% of the forecast error variance of VKOSPI, VIX, VDAX and VHSI. 8% and 11% of the forecast variance of VDAX and VHSI is explained by IVIX (India).

Figure 2, presents the variance decompositions graph. It shows the percentage of forecast variance of implied volatility of each of the indices caused by innovations in itself and the other implied volatilities in the system.

Table 7: Variance Decomposition Table with Standard Error

Panel A: Variance Decomposition of IVIX

Period	S.E.	IVIX	VXJ	VKOSPI	VIX	VDAX	VHSI
1	0.049904	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
2	0.052173	91.75504	0.592704	0.014154	7.344610	0.000759	0.292731
		(2.51174)	(0.67892)	(0.33506)	(2.46450)	(0.27692)	(0.51186)
3	0.052356	91.11792	0.657386	0.436418	7.402581	0.093786	0.291913
		(2.63006)	(0.84671)	(0.72911)	(2.48987)	(0.51725)	(0.58847)
4	0.052362	91.09601	0.658306	0.443113	7.415397	0.095257	0.291913
		(2.58927)	(0.89767)	(0.77078)	(2.50441)	(0.56887)	(0.63844)
5	0.052458	90.77560	0.676617	0.448941	7.510654	0.269769	0.318423
		(2.74331)	(0.93398)	(0.77071)	(2.49834)	(0.63027)	(0.65822)
6	0.052481	90.72112	0.680839	0.449434	7.514153	0.308151	0.326304
		(2.76879)	(0.93696)	(0.77675)	(2.49851)	(0.63061)	(0.66936)
7	0.052483	90.71618	0.685035	0.449780	7.513654	0.309042	0.326310
		(2.77582)	(0.94095)	(0.77886)	(2.49977)	(0.63421)	(0.67057)
8	0.052486	90.70513	0.685050	0.450597	7.517801	0.314148	0.327276
		(2.78285)	(0.94119)	(0.77977)	(2.50237)	(0.63863)	(0.67043)
9	0.052490	90.69182	0.685426	0.450544	7.519172	0.324954	0.328082
		(2.78979)	(0.94145)	(0.78013)	(2.50270)	(0.64286)	(0.67063)
10	0.052490	90.69127	0.685425	0.450541	7.519207	0.325456	0.328100
		(2.79093)	(0.94179)	(0.78014)	(2.50278)	(0.64317)	(0.67066)

Panel B: Variance Decomposition of VXJ

Perio d	S.E.	IVIX	VXJ	VKOSPI	VIX	VDAX	VHSI
1	0.044911	3.362010	96.63799	0.000000	0.000000	0.000000	0.000000
		(1.67821)	(1.67821)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
2	0.052594	3.196560	71.91619	0.044492	23.98588	0.787835	0.069040
		(1.36825)	(3.31614)	(0.35149)	(3.33042)	(0.67414)	(0.25952)
3	0.053571	3.506268	70.10657	0.269947	24.27249	1.770549	0.074175
		(1.40924)	(3.21669)	(0.79882)	(3.23150)	(0.94291)	(0.43958)
4	0.053760	3.495708	69.61435	0.398647	24.11042	1.856909	0.523969
		(1.46118)	(3.15827)	(0.90092)	(3.19884)	(0.98204)	(0.57539)
5	0.054003	3.475072	69.07502	0.404070	24.58276	1.913283	0.549789
		(1.44735)	(3.19421)	(0.87765)	(3.20708)	(0.92049)	(0.64308)
6	0.054034	3.471560	68.99727	0.409157	24.55498	2.015957	0.551069
		(1.43939)	(3.20633)	(0.88187)	(3.20315)	(0.93586)	(0.64128)
7	0.054041	3.471548	68.99648	0.409122	24.54930	2.020931	0.552613
		(1.43795)	(3.20285)	(0.88010)	(3.19787)	(0.93314)	(0.64216)
8	0.054050	3.471718	68.97525	0.411976	24.55066	2.037547	0.552842
		(1.43808)	(3.20389)	(0.87950)	(3.19745)	(0.92992)	(0.64621)
9	0.054055	3.470975	68.96116	0.411888	24.54675	2.055670	0.553560
		(1.43759)	(3.20453)	(0.87928)	(3.19643)	(0.92895)	(0.64657)
10	0.054056	3.470954	68.96074	0.411890	24.54706	2.055762	0.553599
		(1.43765)	(3.20405)	(0.87920)	(3.19631)	(0.92906)	(0.64678)

Panel C: Variance Decomposition of VKOSPI

Perid	S.E.	IVIX	VXJ	VKOSPI	VIX	VDAX	VHSI
1	0.041289	7.637428	22.58408	69.77849	0.000000	0.000000	0.000000
		(2.36588)	(3.33413)	(3.96784)	(0.00000)	(0.00000)	(0.00000)
2	0.044911	6.784278	19.09141	59.44676	14.38701	0.282755	0.007781
		(2.05510)	(3.00970)	(3.91604)	(3.01308)	(0.40332)	(0.26889)

3	0.045859	6.613484	19.34380	58.46212	14.37304	1.132843	0.074708
		(1.97534)	(2.94788)	(3.87565)	(2.80535)	(0.89702)	(0.48875)
4	0.046009	7.023622	19.22104	58.08207	14.33295	1.126787	0.213535
		(2.00771)	(2.89941)	(3.85997)	(2.70180)	(0.94611)	(0.62939)
5	0.046103	6.996816	19.23417	57.85220	14.45305	1.195791	0.267974
		(1.99853)	(2.91231)	(3.80200)	(2.68876)	(0.92262)	(0.64091)
6	0.046127	6.995158	19.21497	57.79373	14.46957	1.257717	0.268851
		(1.99565)	(2.90712)	(3.77986)	(2.67762)	(0.93346)	(0.64492)
7	0.046131	6.996090	19.22291	57.78499	14.46734	1.258750	0.269929
		(1.99529)	(2.90344)	(3.77733)	(2.67575)	(0.93554)	(0.64781)
8	0.046134	6.996367	19.22107	57.77871	14.46582	1.265958	0.272069
		(1.99457)	(2.90304)	(3.77057)	(2.67383)	(0.93590)	(0.64994)
9	0.046135	6.996068	19.22038	57.77632	14.46522	1.269697	0.272316
		(1.99438)	(2.90280)	(3.76907)	(2.67317)	(0.93542)	(0.64966)
10	0.046135	6.996077	19.22032	57.77614	14.46528	1.269785	0.272393
		(1.99425)	(2.90286)	(3.76876)	(2.67314)	(0.93537)	(0.64985)

Panel D: Variance Decomposition of VIX

Period	S.E.	IVIX	VXJ	VKOSPI	VIX	VDAX	VHSI
1	0.063368	2.574386	4.958947	1.194345	91.27232	0.000000	0.000000
		(1.51851)	(2.00037)	(1.13835)	(2.62850)	(0.00000)	(0.00000)
2	0.064609	2.560175	6.274354	1.164361	88.30581	1.598809	0.096493
		(1.49380)	(2.18951)	(1.15350)	(3.02689)	(1.19243)	(0.43465)
3	0.065235	3.040240	7.222725	1.142105	86.81736	1.648725	0.128846
		(1.73201)	(2.20665)	(1.13752)	(3.10629)	(1.15219)	(0.69259)
4	0.065846	3.000052	7.097128	1.349498	85.84925	2.558084	0.145991
		(1.71552)	(2.15104)	(1.30765)	(2.84745)	(1.30814)	(0.73848)
5	0.066235	2.969035	7.068391	1.333854	84.84903	3.634775	0.144917
		(1.69088)	(2.13591)	(1.30944)	(2.93237)	(1.58695)	(0.74443)

6	0.066238	2.969220	7.073047	1.333785	84.84318	3.635860	0.144906
		(1.68464)	(2.13517)	(1.31171)	(2.93314)	(1.59047)	(0.75341)
7	0.066248	2.971302	7.071123	1.341456	84.82864	3.638479	0.149000
		(1.69087)	(2.13558)	(1.32422)	(2.94720)	(1.59379)	(0.75806)
8	0.066274	2.968946	7.065991	1.340380	84.77382	3.695213	0.155654
		(1.69150)	(2.13412)	(1.32364)	(2.95437)	(1.62262)	(0.75349)
9	0.066277	2.968754	7.065490	1.340532	84.76933	3.700178	0.155718
		(1.69132)	(2.13386)	(1.32458)	(2.95602)	(1.62641)	(0.75358)
10	0.066277	2.969121	7.065445	1.340858	84.76852	3.700329	0.155722
		(1.69129)	(2.13369)	(1.32472)	(2.95764)	(1.62805)	(0.75441)

Panel E: Variance Decomposition of VDAX

Perio d	S.E.	IVIX	VXJ	VKOSPI	VIX	VDAX	VHSI
1	0.050203	8.856103	5.170556	1.638645	31.43291	52.90178	0.000000
		(2.12765)	(1.83853)	(0.98729)	(3.16984)	(3.02988)	(0.00000)
2	0.052103	9.087791	5.264108	1.524848	32.16915	51.91375	0.040358
		(2.00299)	(1.72909)	(0.96479)	(2.96756)	(2.86857)	(0.31711)
3	0.052383	8.990991	5.949554	1.690590	31.83244	51.45703	0.079393
		(1.98155)	(1.87362)	(1.01654)	(2.91777)	(2.89792)	(0.39552)
4	0.052486	9.065391	5.938663	1.687176	31.73495	51.25580	0.318028
		(2.08700)	(1.88292)	(1.01142)	(2.89255)	(2.97336)	(0.56578)
5	0.052672	9.002417	5.904457	1.678482	32.02767	50.98264	0.404332
		(2.07565)	(1.86275)	(1.00828)	(2.88911)	(2.96325)	(0.63232)
6	0.052717	8.987418	5.901877	1.676007	31.97976	51.05112	0.403822
		(2.06939)	(1.86012)	(1.00332)	(2.88354)	(2.96135)	(0.63398)
7	0.052721	8.991849	5.906745	1.676685	31.97547	51.04545	0.403800
		(2.06419)	(1.86090)	(1.00557)	(2.88098)	(2.96245)	(0.63669)
8	0.052729	8.991215	5.905641	1.677509	31.97986	51.04160	0.404173
		(2.06358)	(1.86027)	(1.00610)	(2.87750)	(2.96012)	(0.63743)
9	0.052735	8.989059	5.905242	1.677126	31.97434	51.04957	0.404662

		(2.06344)	(1.86018)	(1.00635)	(2.87594)	(2.95923)	(0.63842)
10	0.052735	8.988958	5.905183	1.677105	31.97417	51.04988	0.404704
		(2.06343)	(1.86030)	(1.00635)	(2.87586)	(2.95935)	(0.63859)

Panel F: Variance Decomposition of VHSI

Period	S.E.	IVIX	VXJ	VKOSPI	VIX	VDAX	VHSI
1	0.043469	13.98339	13.17388	6.178389	1.642326	0.739278	64.28274
		(3.35286)	(2.77321)	(1.93875)	(0.91131)	(0.66994)	(4.20976)
2	0.046965	11.99575	12.01508	5.532293	11.35561	0.637924	58.46336
		(2.90449)	(2.56015)	(1.81887)	(2.54809)	(0.59291)	(3.87569)
3	0.047455	11.90292	12.11400	5.994310	11.13695	1.495820	57.35600
		(2.80412)	(2.59781)	(1.98144)	(2.53771)	(0.81408)	(3.79540)
4	0.047630	11.89182	12.03478	5.951444	11.30155	1.583753	57.23665
		(2.78386)	(2.59914)	(2.00625)	(2.49870)	(0.92936)	(3.66558)
5	0.047873	11.77178	11.99099	5.898322	11.85784	1.749446	56.73162
		(2.77060)	(2.57959)	(1.98465)	(2.60966)	(1.01450)	(3.66239)
6	0.047908	11.75522	11.97376	5.890344	11.84149	1.888601	56.65058
		(2.76688)	(2.57114)	(1.97859)	(2.61482)	(1.04917)	(3.65270)
7	0.047921	11.75770	11.97389	5.890031	11.84946	1.908207	56.62071
		(2.76472)	(2.56626)	(1.97633)	(2.61469)	(1.06898)	(3.64871)
8	0.047940	11.75073	11.96679	5.886304	11.86156	1.958219	56.57639
		(2.76688)	(2.56241)	(1.97039)	(2.61907)	(1.10186)	(3.64687)
9	0.047946	11.74781	11.96432	5.884798	11.86003	1.980442	56.56260
		(2.76791)	(2.56100)	(1.96890)	(2.61910)	(1.11575)	(3.64658)
10	0.047947	11.74750	11.96384	5.884678	11.86079	1.982550	56.56063
		(2.76823)	(2.56082)	(1.96840)	(2.61955)	(1.12019)	(3.64646)

Cholesky Ordering: IND JAP MAL USA GER HNK

Standard Errors: Monte Carlo (100 repetitions)

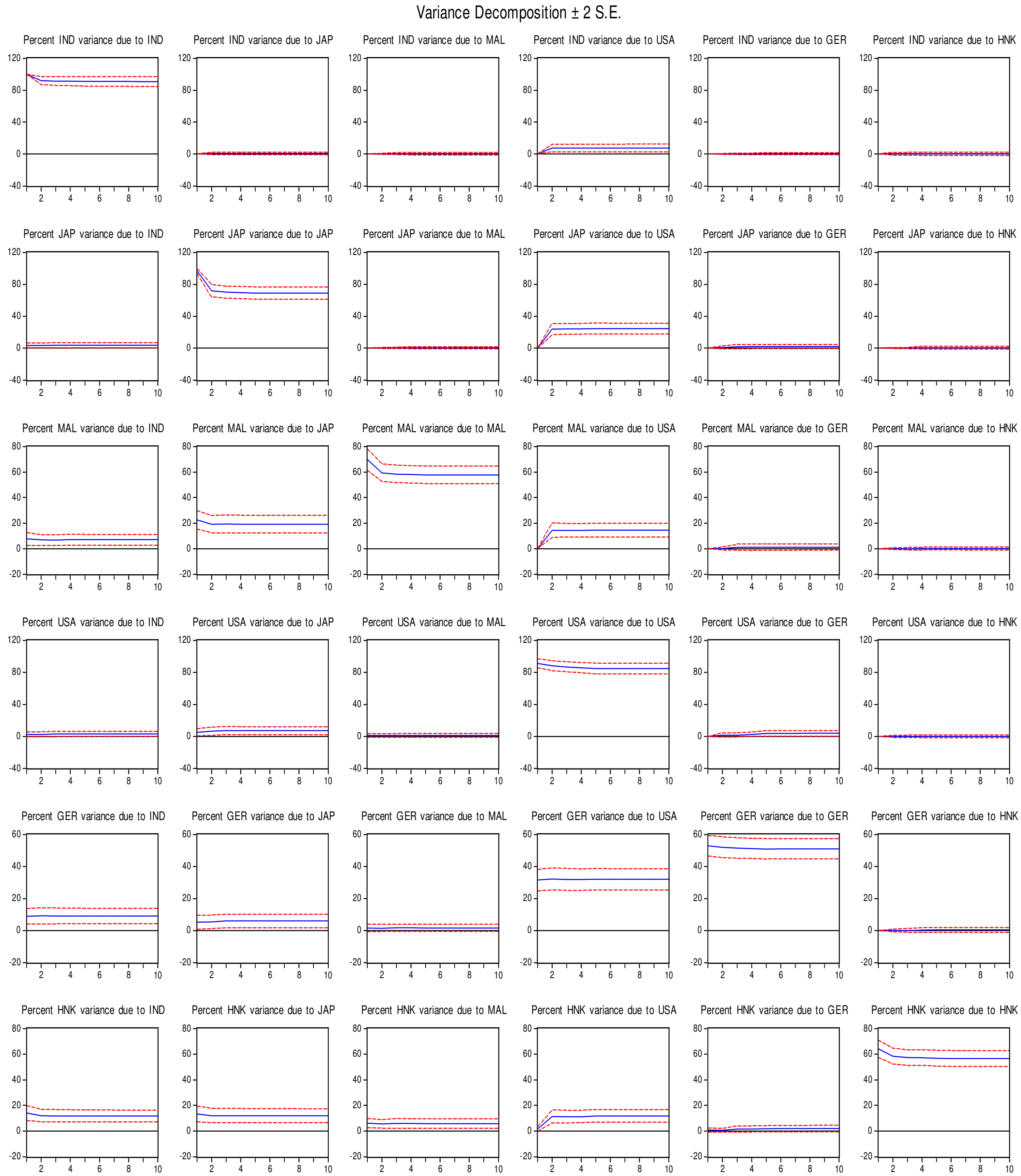

Figure 2: Variance decompositions. The graphs present the percentage of forecast variance of implied volatility of each of the indices caused by innovations in itself and the other implied

volatilities in the system. Two standard error confidence bounds are presented around each variance decomposition.

VII. Implications

We now turn to the implications emanating from our results. For a start, one might argue that such an interlinkage of volatility expectations is hardly surprising, since those mostly trading index options worldwide are institutional investors (funds) who are limited in numbers and relative homogeneous in their nature (De Bondt and Teh, 1997). In view of the post-1990s surge in international portfolio investment, the beliefs of fund managers are increasingly channeled globally, influencing both the overseas markets they invest into as well as their peers in these markets. Therefore, the existence of linkages in their expectations would come as an unsurprising finding in this context. The ever expanding globalization in the finance and investment industry is unlikely to reverse its course in the foreseeable future, so such linkages are anticipated to persist.

The implications for the investment community and the relevant authorities (regulators; policymakers) are rather multifaceted. The growing interconnection among international capital markets confirmed by our results initially suggests that diversification becomes more difficult to attain by going global. However, given that implied volatility indices constitute publicly available information, one might argue that investors should consider using them as part of their information-set (e.g. as risk factors) in order to gauge the expectations of informed traders (institutional investors – the key players in derivatives markets – have traditionally been deemed to be informed; see, for example, Barber et al, 2009). This is particularly the case with the US VIX, as it stands out as the one implied volatility index with the greatest causality-effect over its other peer-indices.

Turning now to the regulatory authorities and policymakers, these results bear serious implications because they raise the possibility of potentially destabilizing outcomes. The issue here relates to the fact that each market's VIX can be viewed as a forward reflection of its institutional investors' sentiment given the aforementioned dominance of institutional traders in the derivatives markets internationally. In an increasingly globalized environment where overseas institutional shareholder-ownership occupies higher percentages, it is highly likely that changes in the institutional sentiment in one market will affect other markets too, especially if these markets bear similar degrees of integration to the global financial system. To illustrate how this expectations-transmission can produce concerns, we assume our findings regarding the linkage between the US and the German VIX indices. If the US VIX can explain roughly 30% of the fluctuation of its German equivalent and volatility expectations in the US deteriorate, then the impact of this over the German VIX – and its underlying spot index, the DAX – is bound to be non-negligible. Since the US VIX appears to bear a high explanatory power as per other countries' VIX indices, this index may be used by overseas regulatory authorities as an early warning signal for future turbulence in their domestic markets, possibly leading them to assume regulatory measures in case extreme or prolonged adverse signals are emitted from the US index. So what do our results imply specifically with regards to India? If one thing stands out clearly from our results, it is that neither the US nor any other sample-market's VIX appears to exert any substantial influence over the Indian VIX. In other words, the formation of domestic volatility expectations in India is not heavily influenced by the equivalent expectations in overseas markets. A possible explanation for this is that Indian equity markets bear a lesser degree of integration to the global financial system[6]; if so, the latter's impact over volatility expectations in India would be anticipated to appear reduced. However, the findings and lessons drawn from this study are expected to grow in relevance to India as its markets enhance their exposure to the global financial system. With markets at comparable stages of development such as, for example, South Korea exhibiting heavier linkages to foreign markets in terms of volatility expectations, the issue of these linkages will inevitably have to attract more attention on behalf of Indian regulators in the years to come.

[6] For example, India at the moment bears no foreign listings on its domestic equity markets; also, despite the surge in foreign institutional investments during the past ten years, the low free-float of Indian markets produces limitations to the participation of foreign funds in its equity segment.

APPENDIX A: Description about the six implied volatility indices

Chicago Board Options Exchange, in 1993, became the first organized exchange that officially introduced an implied volatility index, the renowned VIX. The particular index was based on the methodology of Whaley and very quickly became the benchmark risk measure of the US equity market. Following the exceptionally successful example of CBOE, other exchanges across the world developed their own respective indices; indicatively, Deutsche Börse introduced in 1994 the VDAX and French Marche des Options Negociables de Paris (MONEP) introduced, in 1997, two implied volatility indices, VX1 and VX6. In 2003, CBOE re-launched VIX (the new VIX) using a new methodology for pricing variance swaps that was essentially based on the work of Demeterfi et al (1999a). The latest addition to the world of implied volatility indices family was the FTSE 100 Volatility Index based on the UK benchmark equity index, which is calculated and disseminated, starting from June 2008, by NYSE Euronext.

KRX has developed a volatility index that suits the Korean market situation based on the results of research carried out by domestic specialists. Its volatility index was published on April 13, 2009. This volatility index is called VKOSPI (Volatility index of KOSPI200). The volatility index of KRX is the index providing the window into the volatility of KOSPI200 for the period of thirty days as currently expected by investors based on the KOSPI200 option price. A volatility index is an indexed measure of anticipated 30-day volatility implied in options prices, and as such is calculated using options expiring this month and the next. The VKOSPI can be used as a more objective measure of Korean stock market volatility—the KRX being also the official provider of the Kospi 200 index and Kospi 200 option prices.

The VXJ Research Group at the Center for the Study of Finance and Insurance presents the Volatility Index Japan (VXJ) as a benchmark of future volatility in the Japanese stock market. The VXJ index provides a measure of how volatile the Japanese stock market will be over the next month and is based on Nikkei225 index options. The VXJ is calculated following the new VIX methodology, as a model-free index of market volatility implicit in the prices of Nikkei 225 options traded at the Osaka Securities Exchange. The overriding advantage of the model-free estimation is that it does not assume, as traditional numerical analysis and weighting approaches based on option valuation models (e.g. Black-Scholes options pricing model) do, that volatility remains constant over the period of time remaining until expiration. Thus, the new approach avoids estimation errors due to model misspecification based on the invalid assumption of constant volatility.

India VIX a volatility index computed by NSE based on the order book of NIFTY Options. For this, the best bid-ask quotes of near and next-month NIFTY options contracts which are traded on the F&O segment of NSE are used. India VIX indicates the investor's perception of the market's volatility in the near term i.e. it depicts the expected market volatility over the next 30 calendar days. The higher the India VIX values, the higher the expected volatility is taken to be and vice versa. India VIX uses the computation methodology of CBOE, with suitable amendments to adapt to the NIFTY options order book.

The VDAX volatility index based on the German stock index options is used to represent implied volatility of DAX index options. The underlying DAX index consists of the 30 most actively traded German shares representing approximately 70% of the overall market capitalization of German-listed companies (Deutsche Börse, 2003). Its construction follows the principles of the VIX. According to Wagner and Szimayer (2000), the VDAX index is similar to the VIX except for the maturity, which is 45 calendar days for the VDAX. This difference does not cause problems since we measure the daily changes in each of the volatility indices in logarithmic form, i.e., relative changes of implied volatilities are used.

The HSI Volatility Index ("VHSI") aims at measuring the 30-calendar-day expected volatility of the Hang Seng Index implicit in the prices of near-term and next-term Hang Seng Index Options which are now trading on the HKEx's derivatives market. The Hang Seng Family of Indexes is managed and compiled by Hang Seng Indexes Company Limited (formerly HSI Services Limited), which is a wholly-owned subsidiary of Hang Seng Bank. On 21st February 2011 the Hang Seng Indexes Company Limited launched the HSI Volatility Index ("VHSI"). Hang Seng Index's published the historical value of the HSI Volatility Index ("VHSI"). The historical value includes data from 2 January 2001 to 18 February 2011.

Appendix B: VAR Equations

$$\mathrm{IND}_t = \alpha_1 + \sum_{i=1}^{n}\beta_{11\mathrm{i}}\mathrm{IND}_{t-1} + \sum_{i=1}^{n}\beta_{12\mathrm{i}}GER_{t-i} + \sum_{i=1}^{n}\beta_{13\mathrm{i}}HNK_{t-i} + \sum_{i=1}^{n}\beta_{14\mathrm{i}}\mathrm{USA}_{t-1} + \sum_{i=1}^{n}\beta_{15\mathrm{i}}\mathrm{KRA}_{t-1} + \sum_{i=1}^{n}\beta_{16\mathrm{i}}\mathrm{JAP}_{t-1} + \varepsilon_{1t}$$

$$GER_t = \alpha_2 + \sum_{i=1}^{n}\beta_{21\mathrm{i}}GER_{t-i} + \sum_{i=1}^{n}\beta_{22\mathrm{i}}\mathrm{IND}_{t-i} + \sum_{i=1}^{n}\beta_{23\mathrm{i}}HNK_{t-i} + \sum_{i=1}^{n}\beta_{24\mathrm{i}}\mathrm{USA}_{t-1} + \sum_{i=1}^{n}\beta_{25\mathrm{i}}\mathrm{KRA}_{t-1} + \sum_{i=1}^{n}\beta_{26\mathrm{i}}\mathrm{JAP}_{t-1} + \varepsilon_{2t}$$

$$HNK_t = \alpha_3 + \sum_{i=1}^{n}\beta_{31\mathrm{i}}HNK_{t-i} + \sum_{i=1}^{n}\beta_{32\mathrm{i}}GER_{t-i} + \sum_{i=1}^{n}\beta_{33\mathrm{i}}\mathrm{IND}_{t-i} + \sum_{i=1}^{n}\beta_{34\mathrm{i}}\mathrm{USA}_{t-1} + \sum_{i=1}^{n}\beta_{35\mathrm{i}}\mathrm{KRA}_{t-1} + \sum_{i=1}^{n}\beta_{36\mathrm{i}}\mathrm{JAP}_{t-1} + \varepsilon_{3t}$$

$$\mathrm{USA}_t = \alpha_4 + \sum_{i=1}^{n}\beta_{41\mathrm{i}}\mathrm{USA}_{t-1} + \sum_{i=1}^{n}\beta_{42\mathrm{i}}GER_{t-i} + \sum_{i=1}^{n}\beta_{43\mathrm{i}}HNK_{t-i} + \sum_{i=1}^{n}\beta_{44\mathrm{i}}\mathrm{IND}_{t-1} + \sum_{i=1}^{n}\beta_{45\mathrm{i}}\mathrm{KRA}_{t-1} + \sum_{i=1}^{n}\beta_{46\mathrm{i}}\mathrm{JAP}_{t-1} + \varepsilon_{4t}$$

$$\mathrm{KRA}_t = \alpha_5 + \sum_{i=1}^{n}\beta_{51\mathrm{i}}\mathrm{KRA}_{t-1} + \sum_{i=1}^{n}\beta_{52\mathrm{i}}GER_{t-i} + \sum_{i=1}^{n}\beta_{53\mathrm{i}}HNK_{t-i} + \sum_{i=1}^{n}\beta_{54\mathrm{i}}\mathrm{USA}_{t-1} + \sum_{i=1}^{n}\beta_{55\mathrm{i}}\mathrm{IND}_{t-1} + \sum_{i=1}^{n}\beta_{56\mathrm{i}}\mathrm{JAP}_{t-1} + \varepsilon_{5t}$$

$$\mathrm{JAP}_t = \alpha_6 + \sum_{i=1}^{n}\beta_{61\mathrm{i}}\mathrm{JAP}_{t-1} + \sum_{i=1}^{n}\beta_{62\mathrm{i}}GER_{t-i} + \sum_{i=1}^{n}\beta_{63\mathrm{i}}HNK_{t-i} + \sum_{i=1}^{n}\beta_{64\mathrm{i}}\mathrm{USA}_{t-1} + \sum_{i=1}^{n}\beta_{65\mathrm{i}}\mathrm{KRA}_{t-1} + \sum_{i=1}^{n}\beta_{66\mathrm{i}}\mathrm{IND}_{t-1} + \varepsilon_{6t}$$

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