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Contents

Volatility Indices: An International Comparison

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Volatility index is a measure of markets expectation of volatility over the near-term. It is a forward looking instrument and depicts the expected market volatility over the next 30 days. The constant ups and downs in the financial markets are a cause of concern for most investors. Thus, the volatility index helps them to keep track of market volatility and guide them in their investment decisions. The objective of this paper is to understand the dynamics of linkages between the volatility indices of US (VIX), Germany (VDAX), India (VIX), South Korea (VKOSPI) and China (VXFXI). The VAR model with impulse response function and variance decomposition analysis has been used to understand the linkage dynamics. The results suggest that the US VIX is the most influential index. Therefore, this index should be closely observed by overseas regulatory authorities as early warning signal for future turbulence in their domestic markets. The results for the Indian VIX reveal that there is a moderate level of influence of the US index on it. Further, the Indian VIX seems to be integrated minimally with its Asian equivalents.

Introduction

The study of volatility spillovers and transmission between international stock markets has assumed greater importance as it is essential to understand the mechanism of market integration, economic cycles and financial crises. Market integration in terms of implied volatility spillovers has been an issue of growing interest in recent times especially in the aftermath of events like the Asian and Russian crises at the end of 1990s, the subprime crises in 2008, eurozone crises and Chinese crises in 2015.

Implied volatility is a forward looking measure. It is the volatility imbedded in the option prices and acts as a futuristic measure of expected volatility and helps in the assessment of risk over a given period of time (Stewart, 1995). Thus, as it is revealed in all the previous literature, the information content of implied volatility is far superior over *ex post*, i.e., historical measures of volatility. The Chicago Board of Options Exchange (CBOE) was the first to introduce implied volatility index in 1993. It was based on the S&P 100 index options, but in the year 2003, the computation methodology of VIX was revised and the new VIX was based on the S&P 500 index options. Soon the VIX became a benchmark for measuring volatility

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in the US market. Following the footsteps of CBOE, many financial markets soon introduced their own volatility index (Narwal *et al.*, 2011). In India, the IVIX was introduced by NSE in the year 2008. It was based on the methodology of the US VIX. The volatility index is often termed as 'the investor fear gauge' as it indicates what volatility investors expect to see in the next 30 days. Further, a negative contemporaneous relationship is observed between the underlying index and the volatility index in different financial markets. Thus, the volatility index can be considered as the world's premier barometer of investor sentiments and market volatility (Narwal *et al.*, 2011).

In an integrated market, volatility spillovers in terms of implied volatility can have far reaching implications for risk managers, market regulators, traders and international portfolio managers. They need to understand which market leads the other and which market is the prime source of implied information. For constructing volatility forecasts and taking accurate investment decisions, it becomes essential to be well-informed about dependencies in implied volatilities. By investigating the degree of interactions between implied volatilities, one can examine the level of integration between equity markets (Padhi, 2011).

Therefore, the objective of the present paper is to study the linkages between selected developed equity markets and emerging markets, i.e., to investigate whether there is market integration in terms of implied volatility spillovers. This paper makes an effort to know the degree of volatility transmissions between markets; how does a shock to one market affect the other market; what is the scale, sign of the effect and for how long does the effect persists?

Literature Review

Whaley (2009) describes the VIX and its history and purpose. He also explains as to how it fits within the array of the indexes that help to understand where the economy stands relative to other points in recent decades. Aboura (2003) found that VX1, VIX and VDAX are good tools for predicting future realized volatility. She also shows that past implied volatility informs more about future implied volatility than past realized volatility. Moreover, she has also studied the volatility transmissions between VX1, VIX and VDAX, and it is found that French volatility index is more sensitive to a shock of the US volatility index (Badshah, 2009) investigated the asymmetric returns—volatility relationship with newly adopted robust volatility indices—VIX, VXN, VDAX, VSTOXX and the implied volatility transmission. He observed that VIX presents the highest asymmetric return-volatility relationship followed by the VSTOXX, VDAX, and VXN respectively. Secondly, there were significant spillover effect across the volatility indexes and the VIX influenced the other three volatility indexes considerable. However in the European context, the VDAX was found to be the dominant source of information (Siriopoulos *et al.*, 2009). Studied the information content of all publicly available implied volatility indices across the world. They further show that there is a statistically significant negative and asymmetric contemporaneous relationship between implied volatility changes and underlying equity index returns. They also contribute to the international equity market integration studies by investigating the linkages among major implied volatility of each market. Narwal *et al.* (2011) examined implied volatility spillover and transmission between emerging (India) and mature stock markets (US, France, Germany and Switzerland), measured by their respective implied volatility indices i.e., IVIX, VIX, VCAC, VDAX and VSMI. Their results show that there is moderate level of correlation between selected markets and information transmission and spillovers are running unidirectional from India to US markets and German to Indian market and bidirectional from Indian to French market.

Padhi (2011) examined the implied volatility linkages among the Asian, European and US stock markets. Her results indicate that the US implied volatility index has substantial impact over the other international implied volatility indices but none of the examined volatility indices bears a notable impact over their Indian equivalent. Gonzalez-Perez and Novales (2011) developed a new daily volatility index for the Spanish markets using the model-free methodology. They further examine the relationship between this new index i.e., VIBEX-NEW and the Spanish stock market index i.e., IBEX and find that there exist a negative contemporaneous relationship between the two. Shaikh and Padhi (2015) examined the nature of IVIX, whether investor fear gauge or forward looking tool of expected stock market volatility. The study indicates that IVIX is the gauge of investor fear as the IVIX sharply increases when the market index falls. Gupta and Kamilla (2015) examined linkages between implied volatility indices of developed financial markets (US, UK, Japan) and emerging financial markets (BRIC countries) using VAR modeling and variance decomposition method. The study suggests that US VIX has substantial impact on all the other volatility indices. Thakolsri *et al.* (2015) investigated the impact of changes in the VIX on the changes in the implied volatilities of euro and the Thai stock markets through VAR model—Granger Causality Test, Impulse Response Analysis and Variance Decomposition Function. It is observed that the US index is the leading source of volatility transmission to all the other markets. Rejeb and Boughrara (2015) examined the relationship between emerging and developed markets in normal times and in times of financial crises with respect to volatility. The VAR methodology together with Bai and Perron's technique was used. It is reported that volatility spillovers are effective across financial markets. It may also be observed that geographical proximity plays a major role in amplifying the volatility transmission. Finally, it has been shown that financial liberalization is a significant and contributing factor in international transmission of volatility and the risk of contagion.

Data and Methodology

The sample consists of daily changes in the values of implied volatility indices from March 2009 to June 2015. This study makes an attempt to examine the dynamic linkages between implied volatilities of selected countries, i.e., US (VIX), Germany (VDAX), India (IVIX), China (VXFXI) and Korea (VKOSPI).

The motto of selecting the sample for this study is to examine the linkages between developed and emerging economies. In case of VXFXI i.e., the Chinese ETF index calculated by CBOE the data is available from March 2011. Therefore, some data points will be missing. The data for VIX, VDAX and VXFXI is collected from the CBOE website, whereas the data for IVIX and VKOSPI is collected from NSE and Yahoo Finance respectively.

Results and Discussion

The descriptive statistics of the five implied volatility indices is given in Table 1. It is observed from the table that the mean values of all the five volatility indices are negative. Standard deviation is low for all the five series. The test for skewness indicates that except for IVIX all other volatility indices are positively skewed. Further, all five series are highly leptokurtic with respect to the normal distribution.

Table 1: Descriptive Statistics of Volatility Indices from March 2, 2009 to June 30, 2015

	IVIX	VDAX	VIX	VKOSPI	VXFXI
Mean	–0.00062	–0.00031	–0.00070	–0.00080	–0.00012
Median	–0.00198	–0.00140	–0.00643	–0.00261	–0.00407
Maximum	0.23442	0.28339	0.40547	0.35147	0.24158
Minimum	–0.41438	–0.27034	–0.35059	–0.26401	–0.18514
SD	0.05213	0.05451	0.07239	0.05029	0.04977
Skewness	–0.09032	0.57365	0.66999	0.89176	0.70863
Kurtosis	7.01354	5.75106	6.38902	8.79027	6.14594
Observations	1512	1512	1512	1512	1007

Table 2 presents the results of Pearson correlation coefficient analysis on the implied volatility series. Moderate level of correlation can be observed amongst the five volatility

Table 2: Pearson Correlation Coefficients of Volatility Indices from March 2009 to June 2015

	IVIX	VDAX	VIX	VKOSPI	VXFXI
IVIX	1				
VDAX	0.302973	1			
VIX	0.188394	0.511967	1		
VKOSPI	0.330668	0.279321	0.113666	1	
VXFXI	0.247808	0.472846	0.6205	0.260854	1

indices. The lowest degree of correlation is observed between the US and Korean indices (0.113666). However, the highest degree of correlation is observed between US and China indices (0.6205).

In this paper, the VAR (p) system is employed to ascertain the 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 first investigate the stationarity of our sample by using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. From Table 3, it can be observed that the unit root statistics of the ADF and PP tests reject the null hypothesis of stationarity of the series in their level form at 1% level of significance.

Table 3: ADF and PP Stationarity Test Results

	ADF		PP	
	t-Statistic	p-Value	t-Statistic	p-Value
IVIX	–39.4443	0.000	–39.7447	0.000
VDAX	–38.9892	0.000	–42.7154	0.000
VIX	–43.9497	0.0001	–51.1449	0.0001
VKOSPI	–21.4364	0.000	–45.3351	0.000
VXFXI	–32.6581	0.000	–33.4491	0.000

Appropriate lag order determination, p, for the VAR system is an important issue. In this paper, 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, the Likelihood Ratio (LR) tests, Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC) and Hannan-Quinn Information Criterion (HQIC) are used to select the appropriate lag length for the model.

From Table 4, it is observed that AIC suggests 2 lags, HQIC suggests 2 lags, LR suggests 6 lags, while SIC suggests 1 lag. Hence, the parsimonious AIC with lag 2 is chosen, and accordingly, analysis is conducted with lag 2 for the equation of the VAR system.

Table 5 indicates the summary statistics of the VAR(2) estimation results. The F-statistics indicate that the estimated VAR(2) model is statistically highly significant, while the adjusted-R^2 ranges from 0.0136 for VXFXI to 0.182 for VKOSPI.

Table 4: VAR Order Selection Tests

Lag	LR	AIC	SC	HQ
0	NA	–15.7855	–15.761	–15.7762
1	363.0877	–16.1011	–15.95377*	–16.0451
2	115.3885	–16.16786*	–15.8977	–16.06518*
3	40.68921	–16.1592	–15.7663	–16.0099
4	46.53134	–16.1567	–15.641	–15.9607
5	55.77779	–16.164	–15.5255	–15.9213
6	43.56732*	–16.159	–15.3977	–15.8696
7	37.65057	–16.148	–15.2639	–15.812
8	24.25183	–16.1233	–15.1164	–15.7406

Note: * indicates lag order selected by the criterion.

Table 5: Summary Statistics of VAR(2) Model

Dependent Variable	Adjusted R^2	F-Statistic	*p*-Value
IVIX	0.057	7.092	0.000
VIX	0.035	4.687	0.000
VDAX	0.082	10.002	0.000
VKOSPI	0.182	23.35	0.000
VXFXI	0.0136	2.385	0.000

Impulse Response Function

We further employ the impulse response function to measure the responses of the variables—in our case IVIX, VIX, VDAX, VKOSPI, VXFXI—in the dynamic VAR system to a shock to each variable. In the impulse response function, 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 (Padhi, 2011). Figure 1 reports the impulse responses of implied volatility in one market to a shock in the implied volatility of other market. In Figure 1, Day 1 indicates contemporaneous effects, Day 2 is a 1-day lagged effect, etc. A total of 25 impulse responses could be calculated since there are five variables in the system. A unit shock is applied to

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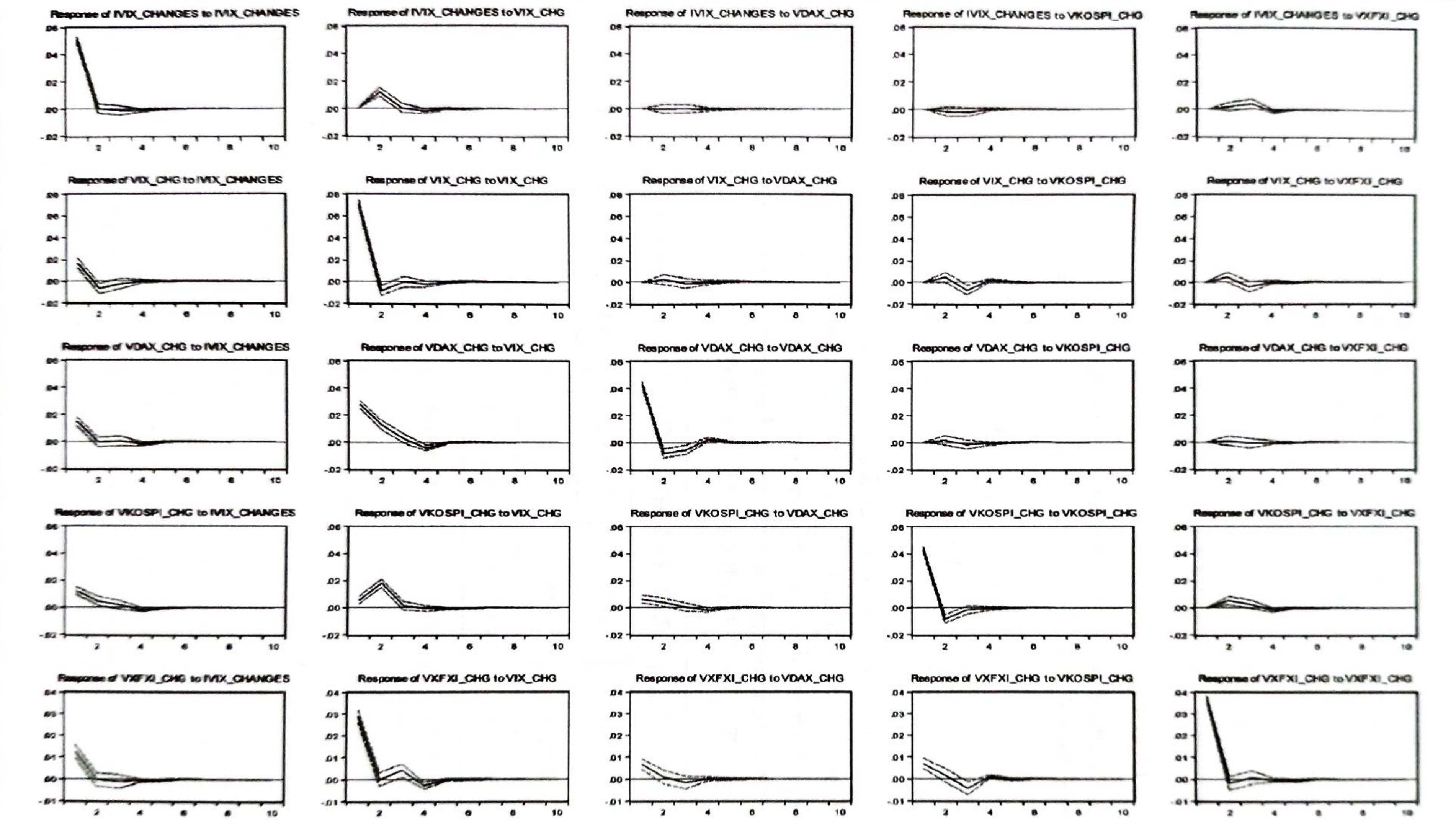
Figure 1: Impulse Response Function



Note: The graphs report the impact of one standard deviation error in volatility index on itself and on the other indices in the VAR system. Two standard error confidence bounds are presented around each impulse response function.

IVIX, VIX, VDAX, VKOSPI, VXFXI and the corresponding impulse responses of IVIX on Day 1 are observed. Similarly, the same unit shock is applied to each volatility index and responses of IVIX on Day 2 are noted and so on. As can be seen, the effects of the shock on IVIX are both positive and negative. The IVIX seems to be affected most by the US index. The impulse response function confirms our previous results. From Day 4 onwards up to Day 6, 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.

Variance Decomposition

The effect of unit shock of one endogenous variable on the other variable in the VAR system is captured through the impulse response function. Whereas to know the importance of one endogenous variable in affecting the other variable the variance decomposition analysis is applied. These analysis enables one to understand how significant the innovations of all variables in the VAR system are to forecast error variance of each variable for specified number of days ahead.

Tables 6 to 10 provide the variance decomposition analysis results for IVIX, VIX, VDAX, VKOSPI and VXFXI. The first column of the tables indicates the time duration (in terms of days), second column shows standard error and the remaining five columns report the forecast error variance of each variable in percentage due to specific innovations of the other variables in the system. The total of each row adds up to 100%.

Table 6: Variance Decomposition of IVIX

Period	SE	IVIX	VIX	VDAX	VKOSPI	VXFXI
1	0.050853	100	0	0	0	0
2	0.052331	94.4344	5.307594	0.000432	0.107563	0.150006
3	0.052557	93.67066	5.269118	0.00043	0.277	0.782791
4	0.052627	93.45831	5.380998	0.009444	0.27689	0.874353
5	0.052628	93.45697	5.380949	0.010669	0.276882	0.874525
6	0.052629	93.45192	5.383143	0.011688	0.278774	0.874476
7	0.05263	93.45111	5.383867	0.0117	0.27885	0.874469
8	0.05263	93.45099	5.383919	0.011707	0.278858	0.874524
9	0.05263	93.45099	5.383919	0.011707	0.278861	0.874526
10	0.05263	93.45099	5.38392	0.011707	0.278862	0.874526

Table 6 reports the variance decomposition results for IVIX. It can be noted here that the 1-day ahead forecast error variance of IVIX is explained by it alone and it explains 93.45099% of its 10-day ahead forecast error variance. None of the other variables play a significant role and are able to explain not even 1% of the forecast error variance, except for the US VIX which explains around 5% of the forecast error variance.

From the variance decomposition results for VIX (Table 7), it may be noted that VIX explains 94.87% of its 1-day ahead forecast error variance and 91.88% of its 10-day ahead forecast error variance. None of the other variables hold strong explanatory powers, except for IVIX, which explains 5.1-5.8% of forecast error variance in VIX.

Table 7: Variance Decomposition of VIX

Period	SE	IVIX	VIX	VDAX	VKOSPI	VXFXI
1	0.073078	5.126188	94.87381	0	0	0
2	0.074199	5.799099	93.24676	0.102657	0.410016	0.441468
3	0.074717	5.807403	91.95794	0.137873	1.327879	0.768908
4	0.074772	5.799052	91.89849	0.144158	1.390319	0.76798
5	0.074778	5.79969	91.88957	0.144517	1.391536	0.774686
6	0.07478	5.800894	91.88542	0.145443	1.391667	0.77658
7	0.07478	5.800933	91.8852	0.145464	1.391813	0.776588
8	0.07478	5.800926	91.88513	0.145489	1.391864	0.776591
9	0.07478	5.800925	91.88513	0.145492	1.391864	0.776591
10	0.07478	5.800926	91.88512	0.145492	1.391864	0.776593

Table 8 reports the variance decomposition results of VDAX. VDAX explains 65.63% of its 1-day ahead forecasts, followed by VIX explaining 26.96% and IVIX explaining 7.40%. If we look at the 10-day ahead forecast then it may be noted that VDAX explains 62.75% of its forecast error variance, whereas VIX and IVIX explains 30.12% and 6.85% respectively. None of the other indices play a significant role.

From Table 9, it may be noted that VKOSPI explains 89.36% of its own 1-day ahead forecast and 75.13% of its 10-day ahead forecasts. IVIX, VIX and VDAX explain 7.15%, 1.61% and 1.87% of 1-day ahead forecast of VKOSPI, and 6.90%, 14.19%, 2.24% of 10-day ahead forecast error variance of the Korean index respectively. VXFXI explains around 1.52% of 10-day ahead forecast error variance of VKOSPI.

Table 8: Variance Decomposition of VDAX						
Period	SE	IVIX	VIX	VDAX	VKOSPI	VXFXI
1	0.053545	7.406879	26.96002	65.63311	0	0
2	0.055579	6.88045	30.00635	62.98785	0.091403	0.033939
3	0.055933	6.799234	29.83101	63.14455	0.172888	0.052316
4	0.056166	6.852698	30.13096	62.77695	0.185266	0.054122
5	0.056171	6.853524	30.12988	62.76564	0.187476	0.063478
6	0.056177	6.85539	30.12711	62.75798	0.196026	0.063494
7	0.056177	6.855359	30.12691	62.75807	0.196028	0.063635
8	0.056177	6.855331	30.1268	62.75793	0.196265	0.063675
9	0.056177	6.855325	30.12678	62.75794	0.196274	0.063684
10	0.056177	6.855327	30.12678	62.75794	0.196274	0.063684

Table 9: Variance Decomposition of VKOSPI						
Period	SE	IVIX	VIX	VDAX	VKOSPI	VXFXI
1	0.04572	7.150515	1.617752	1.871397	89.36034	0
2	0.050547	6.697391	14.20269	2.14652	75.80287	1.150529
3	0.050703	6.800982	14.20023	2.137458	75.44381	1.417523
4	0.050797	6.897031	14.16415	2.246687	75.17357	1.518568
5	0.050805	6.901392	14.18433	2.246011	75.14968	1.518592
6	0.050809	6.900414	14.19135	2.248197	75.13981	1.520224
7	0.05081	6.90065	14.1932	2.248221	75.13771	1.520211
8	0.05081	6.900709	14.19321	2.248215	75.13758	1.520288
9	0.05081	6.900712	14.19321	2.248218	75.13758	1.520287
10	0.05081	6.900712	14.19321	2.248219	75.13758	1.520287

From the variance decomposition analysis of VXFXI (Table 10), we see that VXFXI explains 55.15% of its own 1-day ahead forecast error variance. VIX and IVIX explain 34.39% and 6.53% respectively, whereas VDAX and VKOSPI explain 1.91% and 1.99% of 1-day ahead forecast error variance respectively. If we look at the 10-day ahead forecasts for VXFXI then it may be noted that it explains 54.05% of its own forecast error variance. VIX explains 34.59%, IVIX 6.46%, VDAX 2.02% and VKOSPI 2.86% of 10-day ahead forecast error variance for VXFXI.

Table 10: Variance Decomposition of VXFXI

Period	SE	IVIX	VIX	VDAX	VKOSPI	VXFXI
1	0.049273	6.534218	34.39743	1.915866	1.995433	55.15705
2	0.049344	6.518581	34.29912	1.943105	2.090128	55.14907
3	0.049755	6.460571	34.41971	2.034466	2.818986	54.26626
4	0.049855	6.454083	34.60649	2.026336	2.860049	54.05304
5	0.049861	6.458681	34.59866	2.02583	2.863464	54.05336
6	0.049862	6.460218	34.59672	2.025988	2.86496	54.05211
7	0.049862	6.460224	34.59672	2.025983	2.865002	54.05207
8	0.049863	6.460213	34.59679	2.025975	2.865057	54.05197
9	0.049863	6.460213	34.5968	2.025975	2.865058	54.05195
10	0.049863	6.460214	34.5968	2.025975	2.86506	54.05195

Thus, from the variance decomposition analysis, we can conclude that VIX emerges as an influential volatility index which explains 5%, 26.96%, 1.62%, and 34.39% of forecast error variance for IVIX, VDAX, VKOSPI and VXFXI respectively. It is also interesting to note that the Indian VIX is not influenced much by other volatility indices as compared to China which though in the same stage of development as India is more integrated with the international markets.

Conclusion

The literature on international integration between markets is divided in to three categories (Gagnon and Karolyi, 2006). The first category mainly focuses on the potential diversification benefits of investing internationally; the second category 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. This paper is based on the third category of studies.

The findings of the study reveal that there exist linkages between all five international volatility indices. The ever-expanding globalization in the finance and investment industry is the main reason behind these linkages. From the five implied volatility indices, i.e., IVIX, VIX, VDAX, VKOSPI and VXFXI studied in this paper, the VIX appears to bear the highest explanatory power. Therefore, this index should be closely observed by overseas regulatory authorities as early warning signal for future turbulence in their domestic markets.

The results for the Indian VIX reveal that there is a moderate level of influence of the US index on it. The IVIX seems to be also integrated minimally with its Asian equivalents. But it is also observed that none of the sample market's volatility index has a substantial influence over the IVIX. A possible reason for this could be that Indian equity markets bear a lesser degree of integration to the global financial system. ❖

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