Spillovers and Transmission in Emerging and Mature Markets Implied Volatility Indices

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Abstract

Purpose: The present study examine 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.
Methodology: The asymmetries in Implied Volatility (IV) indices of selected countries are examined using Engle and Ng (1993) test. The spillovers and transmission are examined in multivariate-GARCH framework using BEKK and DCC model. The analysis is done using weekly data for period spanning from Nov, 2007 to Oct, 2011March.
Findings: The main findings of study document asymmetries in the IV indices exist for the Indian, American and French markets. The BEKK-GARCH model results show that conditional variances of implied VI of India, Germany, French and Switzerland strongly affected by their own past shocks and volatility effects. The DCC model reveals that there is a moderate-level of correlation between the selected markets.
Practical Implications: The results of the present study can be used by the portfolio managers and market participant for yielding the diversification benefits in short-run by including IV indices as an asset in their portfolio.

Keywords: Implied Volatility Index, Indian Stock Market, BEKK-GARCH, DCC, VIX, VSMI

1. Introduction

The study of dynamic spillovers and transmission of the large shocks between the international stock markets is becoming essential to understand the mechanism of market integration, cycles of boom and stress and analysis of financial crisis. Majority of studies in the past have focused on the price of an asset, thus innovations in price of volatility is becoming a promising area to explore. (Wagner and Szimayer, 2004). The price of an option reflects market participants' consensus views about the expected future volatility of an underlying asset over its remaining life. The implied volatility imbedded in the option prices acts as a forward-looking measure of the expected volatility and help in the assessment of the risk over a given time period (Mayhew, 1995). Thus, on the basis of the past literature, it can be derived that the information content of implied volatilities is considered to be superior over ex post measures of volatilities (Fleming, Ostdiek, & Whaley, 1995; Moraux, Navettte, & Villa, 1999; Christensen & Prabbala, 1998 and Poon, & Taylor, 2001).

In 1993, Chicago Board of Options Exchange (CBOE) launched an implied volatility index *(hereafter VI)*, based on the implied volatilities of OEX options. VI provides not only short term stock volatility but also offers market volatility "standard" upon which derivatives contracts may be written (Whaley, 1993). This index soon became a benchmark for measuring risk in the US equity markets. A valuation model proposed by Whaley was used for the computation of the VIX; it is called a non-model free methodology. In 2003, CBOE introduced a new methodology for the computation of VIX index using not only just at-the-money call and put option but also out-of-money call and put options of the underlying index S&P 500. In this case, valuation model was not necessary for the computation of VI, thus, it is called model-free methodology. Following the footsteps of CBOE, many financial markets introduced their own implied VI for instance Eurozone markets constructed VDAX, VCAC, VSMI, VEL and many more.. This index is often termed as "investor fear gauge" as it indicates expected future stock volatility. Further, a negative contemporaneous relationship between underlying index and changes in

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the volatility index has been reported in the literature for different financial markets. Thus, market participants consider VIX as a world's premier barometer of investor sentiment and market volatility.

The purpose of this study is to provide new evidence on the stock market integration by examining the spillover and transmission of the newly developed implied VI in the Asian markets i.e. Indian Volatility Index (*hereafter IVIX*) on the VIX, VDAX, VCAC and VSMI. This study is motivated by earlier stock market studies on volatility transmission using historical volatility (Koutmos and Booth, 1995; and Cifarelli and Paladino, 2005); stock market integration based on the realized volatility, realized returns and implied volatilities (Hamao et al, 1990; Koutmos, 1996; and Nikkinen and Sahlström, 2004); and dynamic behavior of implied volatility transmission across the markets (Wagner and Szimayer, 2004; Skiadopoulos, 2004; Äjiö, 2008; Badshah, 2009 and Nousianinen, 2010).

Thus, the paper contributes to the existing market volatility literature by focusing on the newly developed VI of India. In this study, the prior literature is extended in the three important ways. Firstly, the asymmetric effects in the residual conditional variances for the international equity markets are examined. Secondly, the implied volatility spillovers and transmission effects in the India VI *vis-à-vis* the international volatility indices, using the BEKK-GARCH model are captured. Finally, the dynamic conditional correlations and volatilities (variance equation) between the volatility indices are examined. The study is in similar spirit with the work of Nousiainen, 2010 who analyzed the implied volatility spillover and asymmetric volatility effects for the four financial markets.

The paper is organized as follows. In the first section the review of literature on implied VIs and the research gap identified is given. Section two describes the research methodology including objectives, model specification and data adopted in the study. Section three is devoted to the empirical analysis and results of the study. Finally, Section four throws light on findings, conclusion and policy implication of the study.

2. Review of Literature

The primary research on Volatility Indices (VI) is based on explaining its uses, information content and characteristics. Earlier, the implied VI was merely a theoretical idea used in option pricing and risk management. But with the development of derivative based products of VI, it has become an important tool for hedging and portfolio management. A brief review on journey of VI is divided into two sections:

2.1 Volatility Indices Related Research

The early proposals which used VI as an underlying asset for trading volatility goes back to Gastineau (1977), Galai (1979), and Brenner and Gali (1993). Whaley (1993) showed how volatility derivative can be used by option market makers, portfolio managers and covered call writers for hedging the market volatility risk. Thus, in 1993, Chicago Board Options Exchange (CBOE) officially introduced its first implied VI, ticker symbol VIX, which has become the benchmark for risk measurement of the US Equity markets. Flemming et al (1995) investigated a strong contemporaneous negative correlation between the index returns and VIX changes. Whaley (2000) found that VIX as an indicator of expected future stock market volatility and hence termed it as "The Investors Fear gauge".

Moraux et al. (1999), Gazda and Výrost (2003), Skiadoploulos (2004), Duestche Borse (2005), Maghrebi et al (2007), Siriopoulos and Fassas (2008), SIX Swiss Exchange Ltd (2010) studied the volatility indices of the French , Slovakia, Greek, European, Korean, London and Swiss stock markets respectively and examined their information content and forecasting abilities.

Giot (2005) dealt with the information content of the VXO, VXN and VIX and found future stock returns are positive and negative after high (low) levels of implied volatility index. Carr and Wu (2006) defined the new methodology of VIX and showed that the VIX can predict movements in the future realized variance when compared to the historic estimation of GARCH volatilities.

Fernandes et al. (2007) gave the parametric and semi-parametric heterogeneous autoregressive (HAR) processes for modelling and forecasting VIX. Similarly, Ahoniemi (2008) found that ARIMA (1,1,1) can be used for forecasting the direction of change in VIX correctly. Degiannakis (2008) used fractionally integrated ARIMA model for forecasting VIX. Gonazàlez and Novales (2009) and Sarwar, 2010 provide evidence for negative contemporaneous relationship between index returns and changes in the VI. A new dimension of relationship between fear gauge index and gold price in US markets was explored by Cohen and Qadan (2010).

2.2 Volatility Transmission and Spillovers: Aboura (2003)

Initiated the research on international volatility transmission by using *VIs* (VX1, VDAX and VIX). The interactions between implied volatility of different markets were captured using the multivariate-GARCH framework and mean-reverting jump diffusion model.

Wagner and Szimayer (2004) investigated the transmission of shocks for the US and German implied volatility indices using mean reversion model that allows for the Poisson jumps. Äjiö, (2007) present the stock market integration by examining the implied volatility term structures between the VDAX, VSMI and VSTOXX volatility indices. The correlation structures indicated that they are closely related to each other. In 2009, Badshah examined the dynamic implied volatility transmission across the VIs (VIX, VXN, VDAX and VSTOXX) using the Granger Causality, generalized impulse response functions and the variance decomposition method.

2.3 Research Gap

The insight to the past literature lays the foundation for present study. The India VIX being a newly developed index in the Asian markets, not much attention is given to this index. Till now studies have focused on the implied VI of the American and European countries. To the best of the knowledge no significant work is done to examine the volatility spillovers and transmission effects between the implied volatility indices of Indian stock markets and international equity markets.

3. RESEARCH METHODOLOGY

3.1 Objectives of the Study

The objective of the study is to examine the implied volatility spillover and transmission for the emerging (India) and the mature stock markets (US, France, Germany and Switzerland) as measured by their respective implied volatility indices i.e. IVIX, VIX, VCAC, VDAX and VSMI. In the present study, the volatility spillovers and transmission effects in the Indian markets are examined with respect to the US, France, Germany and Swiss markets.

The following hypotheses are formulated for the purpose of research:

Hypothesis I: Asymmetries exist in the volatility indices.

Hypothesis II: There are implied volatility and shock spillovers between Indian and the selected international markets volatility indices.

Hypothesis III: To account for the possibilities that volatilities and the correlation are dynamically changing over the time, for the Indian markets *w.r.t.* to international markets.

3.2 Model Specifications

3.2.1. Asymmetries in Volatility

The Engle and Ng (1993) sign and size bias test is applied to assess the asymmetric response of the variance to the past information. This test is based on studying the error terms generated from the standard GARCH (1,1) model:

$$y_t = \mu + \varepsilon_t y_t = \mu + \varepsilon_t \quad \text{where} \quad \varepsilon_t \sim N(0,\sigma_t^2) \; \varepsilon_t \sim N(0,\sigma_t^2) \qquad \text{(i)}$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \qquad \text{(ii)}$$

where, $\mu\mu$ is mean, y is return series at time t, $\sigma_t^2\sigma_t^2$ is the squared conditional volatility at time t, and $\varepsilon\,\varepsilon$ is the lagged and the square error terms of the mean equation, which are normally distributed with zero mean. The α and β are the non-negative coefficients, with α+β < 1 condition. Then the Engle-Ng-test is applied on the error terms is:

$$\hat{\varepsilon}_t^2 = \varphi_0 + \varphi_1 S_{t-1}^- + \varphi_2 S_{t-1}^- \varepsilon_{t-1} + \varphi_3 S_{t-1}^+ \varepsilon_{t-1} + \epsilon_t$$

$$\hat{\varepsilon}_t^2 = \varphi_0 + \varphi_1 S_{t-1}^- + \varphi_2 S_{t-1}^- \varepsilon_{t-1} + \varphi_3 S_{t-1}^+ \varepsilon_{t-1} + \epsilon_t$$

and $TR^2 \sim\sim \chi^2\chi^2(3)$ (iii)

Where, $\varepsilon\varepsilon$ are the before mentioned error terms, $\varphi\varphi$ are the coefficients, $S_{t-1}^- S_{t-1}^-$ and $S_{t-1}^+ S_{t-1}^+$ are the dummies for the negative and positive error terms and $\epsilon_t\epsilon_t$ is the new error terms. A significant coefficient $\varphi_1\varphi_1$ means existence of sign bias, which signifies that the return volatility is larger in the bearish phase as compared to the bullish period. Whereas, significant $\varphi_2(\varphi_3)\varphi_2(\varphi_3)$ reveals the (negative) positive size bias which means that magnitude of shocks have differing impacts.

3.2.2. BEKK-GARCH Model

To investigate the volatility spillovers, the BEKK (Baba, Engle, Kraft and Kroner) representation of multivariate GARCH (p,q) proposed by Engle and Kroner (1995) is applied. The BEKK (1, 1) representation is of the following form:

$$r_t = \mu + \lambda r_{t-1} + \varepsilon_t$$

$$\Sigma_t = C_0'C + \sum_{k=1}^{K}\sum_{i=1}^{q} A_{ik}\varepsilon_{t-1}\varepsilon_{t-1}'A_{ik}' + \sum_{k=1}^{K}\sum_{j=1}^{p} G_{jk}\Sigma_{t-j}G_{jk}'$$

$$\Sigma_t = C_0'C + \sum_{k=1}^{K}\sum_{i=1}^{q} A_{ik}\varepsilon_{t-1}\varepsilon_{t-1}'A_{ik}' + \sum_{k=1}^{K}\sum_{j=1}^{p} G_{jk}\Sigma_{t-j}G_{jk}' \quad \text{(iv)}$$

Where, $C_o\,C_o$ is the k×k lower triangular matrix and A_{ik} *and* G_{jk} A_{ik} *and* G_{jk} are the parameter matrices. The diagonal elements in matrices A and G measures the effect of the lagged volatility on its conditional volatility. The off-diagonal elements in matrices A(a_{ij}) and G(g_{ij}) capture the cross-market effects of shocks and volatility spillovers.

3.2.3. Dynamic Conditional Correlation Models

Bollerslev (1990) introduced a class of multivariate GARCH model based on the assumption of constant conditional correlations (CCC). A generalization of CCC model was proposed by Engle and Sheppard (2001); Engle (2002) and Tse amd Tsui (2002) in which the conditional correlation matrix is time dependent. This model is known as Dynamic conditional correlation (DCC).

The DCC model of Engle (2002) computes the time-variant conditional correlation matrix can be expressed as:

$$\Gamma_t = \text{diag}\,\{Q_t\}^{-1/2}\, Q_t\, \text{diag}\{Q_t\}^{-1/2}$$

$$\Gamma_t = \text{diag}\,\{Q_t\}^{-1/2}\, Q_t\, \text{diag}\{Q_t\}^{-1/2} \quad \text{(v)}$$

$$Q_t = (1-\theta_1-\theta_2)\bar{Q} + \theta_1\xi_{t-1}\xi_{t-1}' + \theta_2 Q_{t-1}$$

$$Q_t = (1-\theta_1-\theta_2)\bar{Q} + \theta_1\xi_{t-1}\xi_{t-1}' + \theta_2 Q_{t-1} \quad \text{(vi)}$$

Where, $Q_t Q_t$, is a k×k symmetric positive unconditional variance matrix, $D_t\, D_t$ is k×k diagonal matrix with time-varying standard estimated by univariate GARCH model applied to individual time series and $\xi_{t-1}\xi_{t-1}$ is the standardized residuals defined as $x_{i,t}/\sqrt{\sigma_{ii,t}}\,x_{i,t}/\sqrt{\sigma_{ii,t}}$ and θ_1 *and* $\theta_2\theta_1$ *and* θ_2 are the non-negative scalar parameters satisfying the condition $\theta_1 + \theta_2\theta_1 + \theta_2 < 1$.

Whereas, Tse and Tsui (2002) proposed a slightly different formulation:

Table 1: Market Data

Volatility Index Name	*Underlying Stock index*	*Market*	*Market Description*
IVIX (Indian Volatility Index)	S&P CNX Nifty	India	Largest emerging market and among world largest stock exchange in terms of market capitalization based on 50 major stocks
CBOE Volatility Index, or VIX	S&P 500	USA	Largest US option exchange, first organized market to began trading in options
CAC 40 Volatility Index, or VCAC	CAC 40	France (Paris)	One of the main national indices of the pan-European stock exchange group Euronext, index represents capitalization weighted measure of 40 most significant stock among top 100 active stocks.
VDAX-NEW Volatility Index	DAX	Germany (Frankfurt)	30 major German companies trading on the Frankfurt Stock Exchange, main European continental market
VSMI Volatility Index	SMI	Switzerland	Developed country market away from the hubs, the underlying index comprises 50 largest and most liquid stocks in the Swiss equity market.

Source: Authors

Table 2: Descriptive Statistics of innovations in VI

	IVIX	*VIX*	*VDAX*	*VCAC*	*VSMI*
Mean	-0.00217	0.001242	0.002399	0.001963	0.000606
Median	-0.00525	-0.01351	-0.00388	-0.00742	-0.01087
Maximum	0.39918	0.396445	0.475686	0.37877	0.472906
Minimum	-0.31818	-0.27027	-0.29489	-0.27281	-0.2998
Std. Dev.	0.096773	0.103397	0.106315	0.106725	0.10773
Skewness	0.429527	0.681813	0.784823	0.552204	0.713827
Kurtosis	5.30508	4.466709	5.463107	4.403862	5.218151
Jarque-Bera	52.69733*	34.9266*	74.28802*	27.78431*	60.59594*
Observations	209	209	209	209	209
LB(4)	1.4626	3.5602	0.8234	0.5318	1.4461
LB(8)	15.559**`	10.02	6.4899	9.5719	8.6287
LB(12)	19.938***	20.733***	14.029	15.165	19.293***
ARCH(4)	1.2367	9.7631**	30.3942*	21.4485*	29.6757*
ARCH(8)	3.5611	12.9542	31.9435*	23.9195*	32.9887*
ARCH(12)	4.8795	15.1142	39.8819*	28.3171*	36.2180*

*Note: *=1%, **=5%, ***=10% level of significance*

$$\Gamma_t = (1 - \theta_1 - \theta_2)\Gamma + \theta_1\Psi_{t-1} + \theta_2\Gamma_{t-1}$$

$$\Gamma_t = (1 - \theta_1 - \theta_2)\Gamma + \theta_1\Psi_{t-1} + \theta_2\Gamma_{t-1} \qquad \text{(vii)}$$

Where, $\Gamma_t \Gamma_t$ is the time-invariant positive definitive parametric matrix with unit diagonal element and Ψ_{t-1} Ψ_{t-1} is k×k is sample correlation matrix of the past standardized residuals. The log-likelihood estimator can be written as:

$$L(\theta) = -\frac{1}{2}\sum_{t=1}^{T}\log(2\pi + 2\log|D_t| + \log|\Gamma_t| + \xi_{t-1}\Gamma_t^{-1}\xi_{t-1}$$

$$L(\theta) = -\frac{1}{2}\sum_{t=1}^{T}\log(2\pi + 2\log|D_t| + \log|\Gamma_t| + \xi_{t-1}\Gamma_t^{-1}\xi_{t-1} \qquad \text{(viii)}$$

3.3 DATA

3.3.1 Data Collected

The daily closing values of implied VI running from 1 Nov, 2007 to 30 Oct, 2011 for the countries mentioned in Table I is used for the purpose of research. The problem of non-synchronies in the daily data is mitigated by converting it into weekly data. The average of the daily data of each week is taken to synchronise the series of different countries. The data is extracted from the respective authentic websites of various market indices.

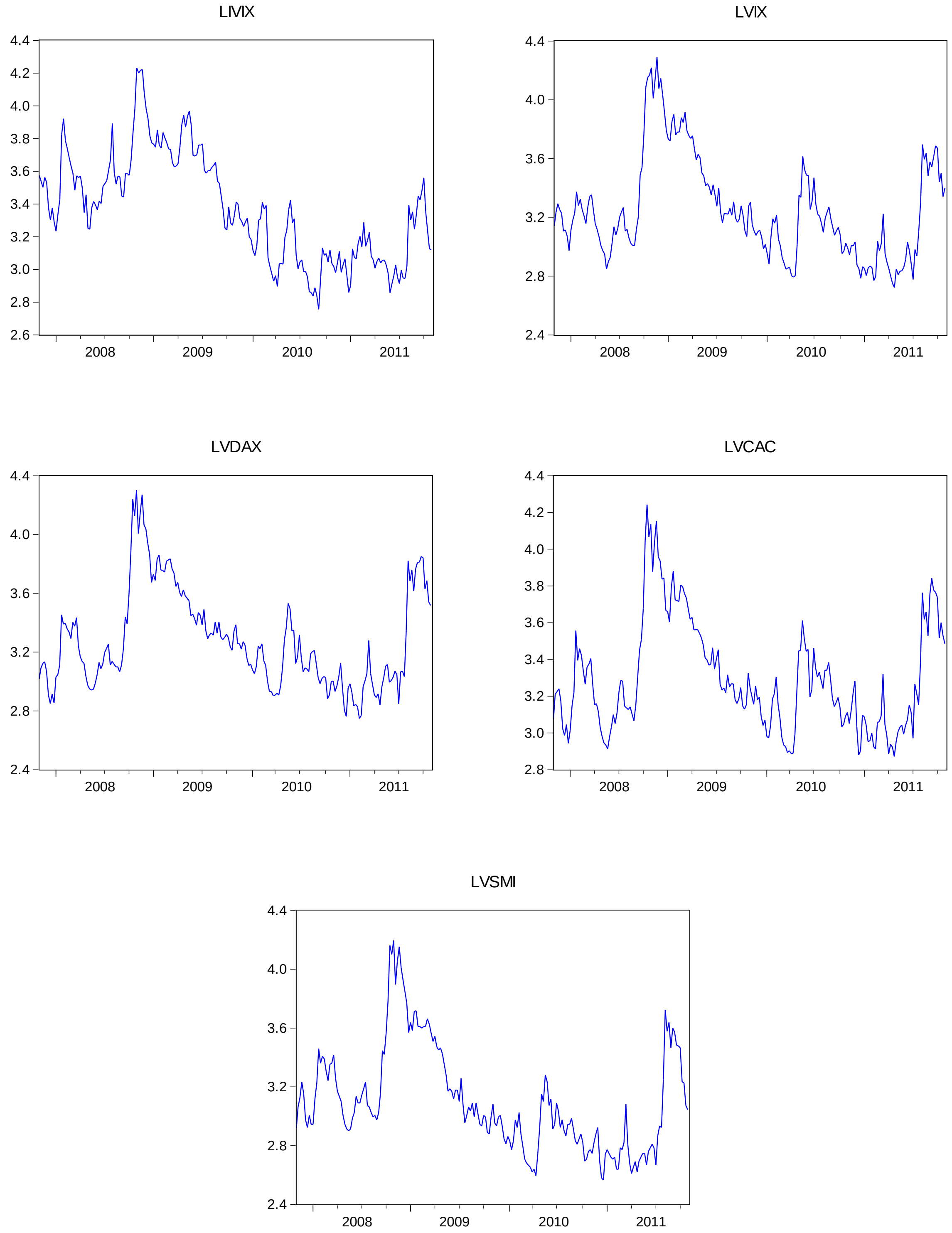
3.3.2 Properties of Data

The innovations (changes) in the weekly data of the volatility indices are calculated by:

$$\Delta y_t = ln(y_t) - ln(y_{t-1})\,\Delta y_t = ln(y_t) - ln(y_{t-1}) \qquad \text{(ix)}$$

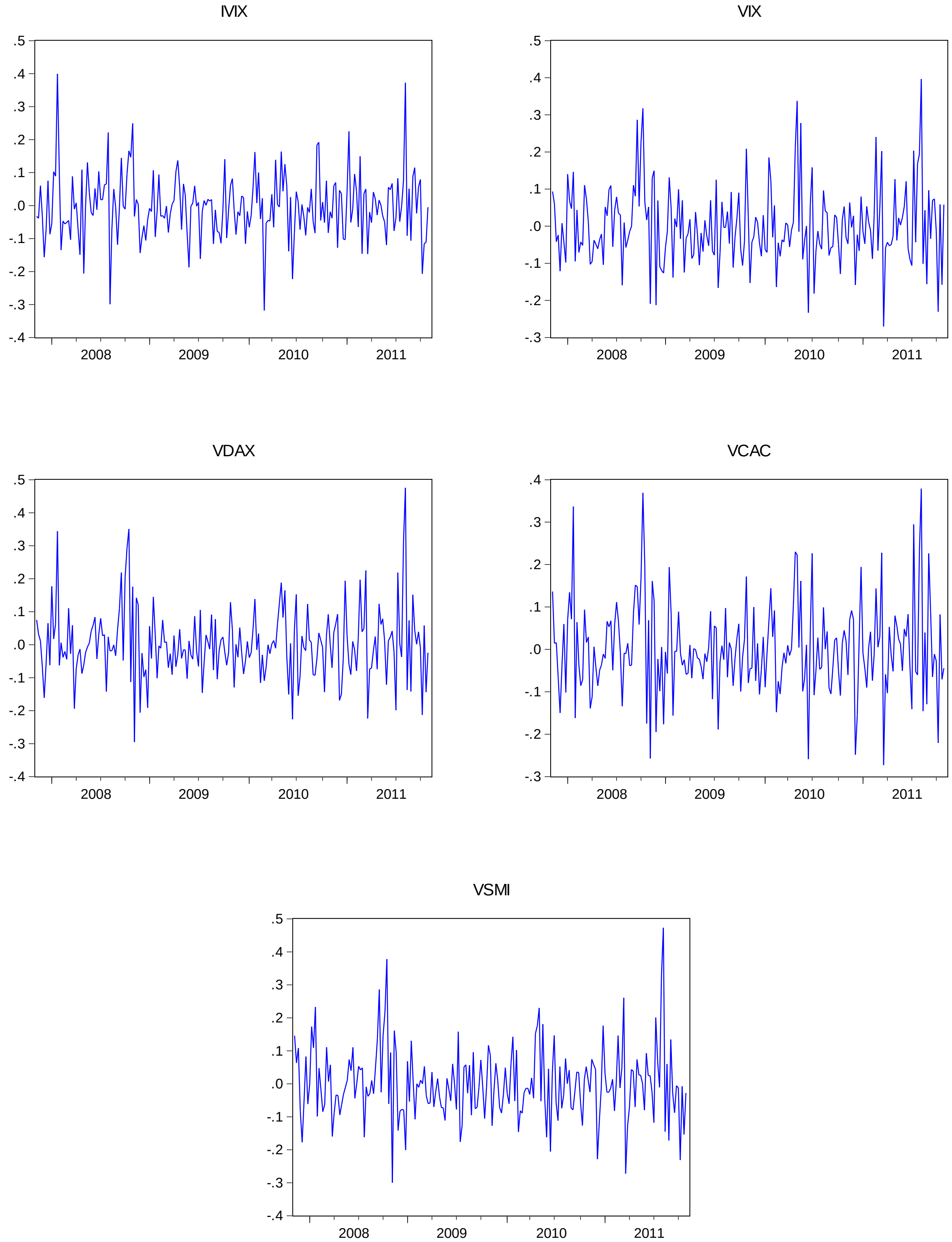
Descriptive Statistics: The descriptive statistics for the changes in weekly univariate VI series are presented in the Table 2. The mean values for the changes in the VIs are positive and small. All distributions are positively skewed where the IVIX and VSMI have the lowest and highest values respectively and leptokurtic where VCAC and VDAX have the lowest and highest values. The results of Jarque-Bera statistics indicates that the series are non-normally distributed. The joint Ljung-Box Q-statistics with different lags reveals weak evidence of autocorrelations and heteroscedasitictiy for IVIX at 8 and 12 lags whereas for the VIX and VSMI is shown at 12 lag. The ARCH LM test for the autocorrelations in the standardized residuals reveals ARCH effects exist for VDAX, VCAC and VSMI at 1% significance level for different lags. There is weak evidence for the presence of ARCH-effects in the VIX and no ARCH-effect or heteroscedasticities is determined in the Indian VI, the latter finding of which is surprising.

Figure 1: Logarithms of Volatility Indices



Source: Authors

Figure 2: Graph showing Changes/Innovations in Volatility Indices



Source: Authors

3.3.3 Unconditional Correlations

The unconditional correlations *(Table 3)* of the change in VIs show that the American and European markets are highly correlated whereas Indian markets have shown low level of correlation with the other four markets. The main European markets i.e. German-French markets (0.895) and German- Swiss markets (0.926) are the most correlated. The Indian market has shown least correlation with the American market (0.408) and with European markets also the range of correlation is 0.421-0.488.

Table 3: Unconditional Correlations of change in Volatility Indices

	IVIX	*VIX*	*VDAX*	*VCAC*	*VSMI*
IVIX	1				
VIX	0.408*	1			
VDAX	0.488*	0.845*	1		
VCAC	0.421*	0.823*	0.895*	1	
VSMI	0.479*	0.832*	0.926*	0.878*	1

Source: Authors

*Note: *=1% level of significance*

Thezse properties of volatility indices can be also seen graphically. As the Figure 1 show that the overall counters of the logarithms-level VIs are almost identical, showing similar patterns during the bullish and bearish phase, as in the beginning and end of time series. The Figure 2 shows the innovations/ changes in the VIs.

3.3.4 Unit Root Tests

The unit root tests are applied to examine the potential diversions of the time series data from the stability. The standard Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1981) in addition with the Phillips-Perron (Phillips and Perron, 1988) and KPSS (Kwiatkowski *et al.*, 1992) test are applied to change in implied volatility indices examine stationarity (unit root) of the data series. Table 4, represents the results of three unit root test. The results for the ADF and PP-test denote that all first difference data series are stationary at 1% level of significance. Further, the KPSS test confirms that data series are stationary at first difference, as the null hypothesis for stationary series is accepted for all data series.

3.3.5 Asymmetries in the data

The potential asymmetries in volatilities are detected using Engle-Ng (1993) sign and size bias test (Table 5). There are existent traces of joint asymmetry in implied

Table 4: Unit root test statistics of changes in implied VIs

Test/ Series	*ADF*			*PP*			*KPSS*	
	1	2	3	1	2	3	1	2
IVIX	-7.750(5)*	-7.721(5)*	-7.767(5)*	-13.365(2)*	-13.332(2)*	-13.392(2)*	0.033(1)	0.032(1)
VIX	-9.159(1)*	-9.140(1)*	-9.182(1)*	-13.805(2)*	-13.773(2)*	-13.837(2)*	0.057(2)	0.057(2)
VDAX	-9.480(1)*	-9.457(1)*	-9.499(1)*	-13.986(1)*	-13.952(1)*	-14.015(1)*	0.062(1)	0.062(1)
VCAC	-10.425(1)*	-10.401(1)*	-10.449(1)*	-14.066(2)*	-14.032(2)*	-14.099(2)*	0.048(2)	0.048(2)
VSMI	-9.559(1)*	-9.535(1)*	-9.583(1)*	-13.527(3)*	-13.495(3)*	-13.560(3)*	0.056(3)	0.051(4)
Asymptotic critical values								
1% level	-3.463	-4.004	-2.576	-3.462	-4.003	-2.576	0.739	0.216
5% level	-2.876	-3.432	-1.942	-2.875	-3.432	-1.942	0.463	0.146
10% level	-2.574	-3.140	-1.616	-2.574	-3.139	-1.616	0.347	0.119

Source: Authors

Note: ADF is the Augmented Dickey-Fuller, PP is the Phillips-Perron, and KPSS is Kwiatkowski, Phillips, Schmidt, and Shin test.

Model Specification: 1.Intercept, 2. Intercept+trend, 3.None. The Null hypothesis for ADF and PP test: H_0 *= Variable is non-stationary and for KPSS:* H_0 *= Variable is stationary.*

, ** and * indicate the rejection of the null hypothesis at the 1%, 5% and 10% significance levels, respectively. The proper lag order for ADF test is chosen by considering Akaike Information Criteria, representing in parenthesis.*

For KPSS and PP tests, the bandwidth is chosen using Newey–West method and spectral estimation uses Bartlett kernel, representing in parenthesis.

Table 5: Engle-Ng (1993) Sign and Size Bias test

Variable	*IVIX*		*VIX*		*VDAX*		*VCAC*		*VSMI*	
C	1.13*	(0.34)	1.25*	(0.31)	0.81*	(-0.26)	1.27*	(0.25)	0.80*	(0.25)
S^-_{t-1}	-0.49	(0.35)	-0.25	(0.37)	0.41	(0.37)	-0.59**	(0.32)	0.41	(0.41)
$S^-_{t-1}\ u_{t-1}$	0.07	(0.09)	0.38**	(0.18)	0.48*	(0.27)	0.03	(0.28)	0.49***	(0.29)
$S^+_{t-1}\ u_{t-1}$	0.46	(0.33)	0.03	(0.30)	0.36	(0.28)	0.05	(0.21)	0.36	(0.27)
Joint - x^2x^2	12.93*		7.36***		6.04		7.87**		5.98	

Note: Standard errors are presented in the parentheses and the levels of significance with asterisks (= 1%, ** = 5% and *** = 10%). Estimated method is OLS with Newey-West correction for heteroscedasticity and autocorrelation. The joint test follows chi-square distribution with critical values (***1% = 11.345, **5% = 7.815 and *10% = 6.251)*

volatility indices of the India (12.93, significant at 1% level), America (7.36, significant at 10% level) and French (7.87, significant at 5% level) volatility indices, therefore, accepting the null Hypothesis I for these markets. The coefficient of S^-_{t-1} is significant for the American, German and Swiss markets, implying that, negative magnitude effect exist in these markets. This means that past events is of importance and confirmed by the preliminary findings of Carr and Wu (2006). The asymmetries in the volatilities of implied volatility indices could be the consequence of the leverage effect of the underlying stock indices.

4. EMPIRICAL RESULTS AND ANALYSIS

4.1 Spillover Effect Analysis

Table 6 summarizes the estimation results of bivariate-BEKK GARCH for the Indian markets with American and European markets in a pair wise manner. The matrices A and G reported in the equation (iv) are useful in examining the relationship in terms of volatility. The diagonal elements of the matrices A and G capture the ARCH and GARCH (also termed volatility persistence) effects. In the Table 6, out of 8 estimated diagonal parameters a_{11} and a_{22} in the each pair, 7 are statistically significant at 1% and 5% level except of a_{22} in the IVIX/VIX group implying the presence of strong ARCH effects in the stock markets of India, Switzerland, Germany and France. Whereas, the diagonal elements g_{11} is significant in 3 cases out of 4 suggesting the presence of GARCH effects in the Indian markets when analyzed with American, Swiss and French markets. The other diagonal parameter g_{22} is statistically significant for the stock markets of Germany, France and Switzerland, thus indicating that GARCH (1,1) process is driving the conditional variances of the three stock markets. This implies that the conditional variances of India, Germany, French and Switzerland in the implied volatility series are strongly affected by their own past shocks and volatility effects. Thus, implied VI is dependent on its own volatility in the past.

Table 6: Parameter estimates for the BEKK-GARCH (1,1) Model

	IVIX/VIX		*IVIX/VSMI*		*IVIX/VDAX*		*IVIX/VCAC*	
c_{11}	5.311*	(5.950)	6.395*	(6.433)	7.393*	(10.250)	6.349*	(7.017)
c_{21}	-2.546	(-1.072)	-1.351	(-0.636)	0.112	(0.085)	-1.373	(-1.165)
c_{22}	5.988*	(2.578)	2.878	(0.824)	3.468*	(2.975)	0.000	(0.000)
a_{11}	0.502*	(5.733)	0.328**	(2.045)	0.351**	(2.119)	0.530*	(4.183)
a_{12}	0.237**	(2.552)	-0.286**	(-2.321)	-0.129	(-0.985)	-0.249***	(-1.914)
a_{21}	-0.143	(-1.109)	0.232*	(3.005)	0.216*	(2.618)	0.130**	(2.105)
a_{22}	0.321	(1.513)	0.586*	(6.471)	0.470*	(7.037)	0.485*	(5.571)
g_{11}	0.619*	(2.618)	0.519**	(2.266)	0.263	(1.009)	0.253**	(2.068)
g_{12}	0.550*	(1.976)	0.458***	(1.931)	0.197	(0.626)	0.741*	(18.645)
g_{21}	0.208	(0.613)	0.118	(0.759)	0.236	(1.418)	0.365*	(14.565)
g_{22}	0.025	(0.070)	0.517*	(4.067)	0.742*	(4.601)	0.342*	(10.232)
Log-Likelihood	-1521.250		-1513.564		-1514.424		-1523.245	

The off-diagonal elements of matrices A and G capture the cross-market effects such as shock and volatility spillover among the five stock markets. Firstly, according to the statistics in the Table 6, evidence of bidirectional shock transmission exists in IVIX/VSMI and IVIX/VCAC, as the pairs of off-diagonal parameters a_{12} and a_{21} are statistically significant in these stock markets. The two-way shock spillover is an indication of strong connection between the implied volatility indices of Indian-French markets and Indian-Swiss markets. The bidirectional cross-markets shock spillover indicates that shock related news in one stock exchange effects the volatility in the other stock market and vice-versa. There are traces of unidirectional shock spillover from IVIX to VIX and VDAX to IVIX as their respective a_{12} and a_{21} are significant (their counterparts are insignificant) in BEKK-GARCH Model for IVIX/VIX and IVIX/VDAX.

Secondly, the evidence of bidirectional volatility linkages is found only between the Indian and French markets as their g coefficients are statistically significant at 1 level. These bidirectional volatility linkages imply that a strong connection between them, as the conditional variance of one implied VI depends on the past volatility of the IV index of other country. In the meanwhile, there exists unidirectional volatility spillover from IVIX to VIX and IVIX to VSMI. Thus, the null hypothesis II that there exist implied volatility and shock spillovers between the Indian and international markets are accepted, when the ARCH (a_{11}, a_{12}, a_{22}, and a_{21}) and GARCH (g_{11}, g_{12}, g_{21} and g_{22}) parameters are significant.

4.2 Dynamic Conditional Correlations

The dynamic conditional correlations (DCC) table 7 and figure 3 are moderate and stable. The mean DCC is smallest between the IVIX-VIX and largest between the IVIX-VDAX. The mean and median of the DCC are coinciding for each group of countries and the standard deviations is also small. The DCC for the Indian markets versus global markets varies widely. The range between different volatility indices are: IVIX-VIX (0.05-0.703), IVIX-VDAX (-0.01913 to 0.75), IVIX-VCAC (-0.063 to 0.752) and from IVIX-VSMI (-0.036 to .740). These graphs show the possible existence of variations and structural breaks in the dynamic correlations. Thus, the null hypothesis III is accepted, the dynamic correlations between India and global markets are significantly changing over the time period, and exhibit high and low level of correlations at different time periods in the various markets.

The time-varying correlations during the period of study are positive for majority of the time, thus, indicating that Indian markets move in tandem with the American and the European markets. Further, most of the correlations have the tendency to fall more, than to grow, in the face of sub-prime crisis, which started with the American risk-based mortgage crisis in 2007. The European sovereign debt crisis in the start of 2010 and recent downgrade in the credit rating of US economy are the major events which affected the market's volatility across the world. Thus, a high level of conditional correlations (ranging between 0.70-0.75 in the period post 2010) for the implied volatility indices of Indian markets versus the American, German, French and Swiss market is observed.

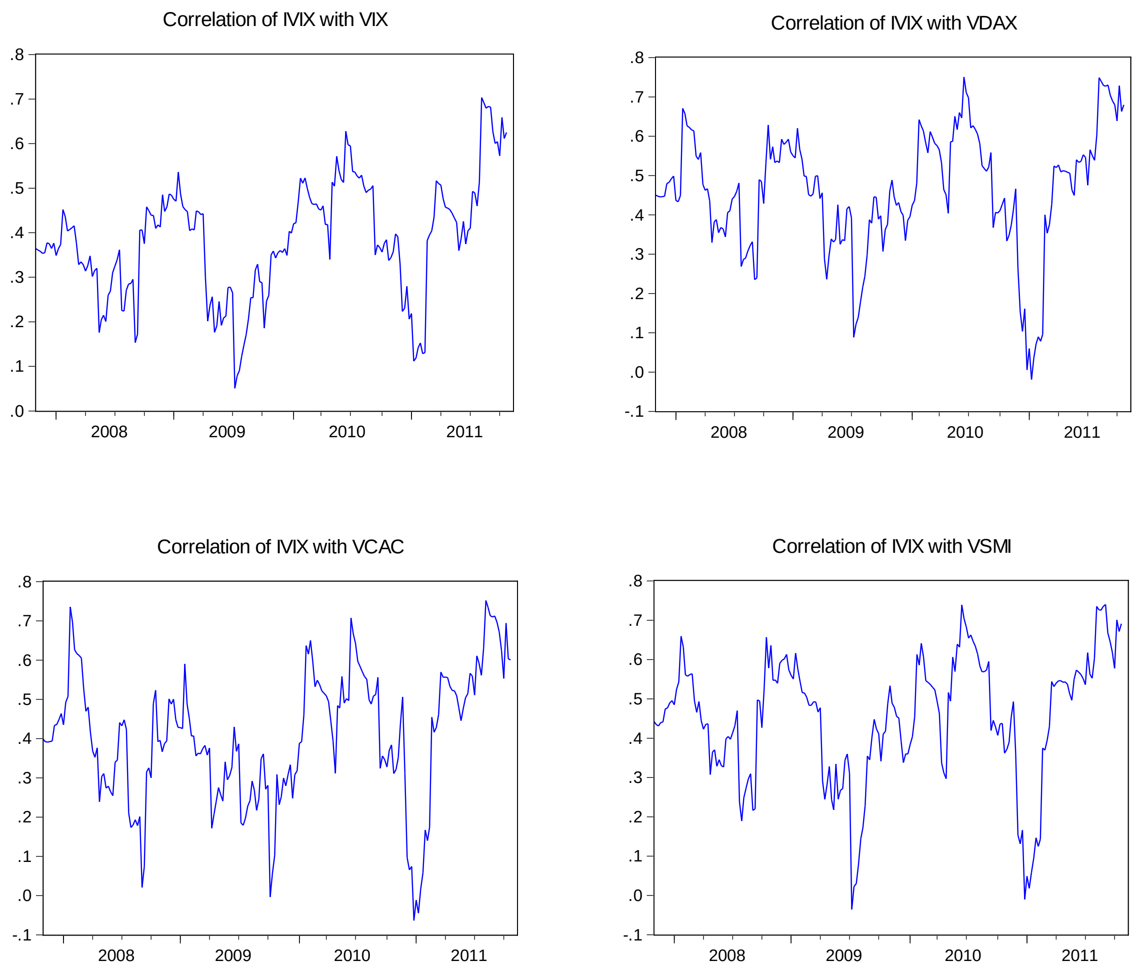
Table 7: Descriptive Statistics of the Dynamic Conditional Correlations

	CORRELATIONS			
	IVIX-VIX	*IVIX-VDAX*	*IVIX-VCAC*	*IVIX-VSMI*
Mean	0.384	0.458	0.404	0.450
Median	0.391	0.462	0.407	0.478
Maximum	0.703	0.750	0.752	0.740
Minimum	0.051	-0.019	-0.063	-0.036
Std. Dev.	0.131	0.154	0.167	0.162
Skewness	-0.095	-0.690	-0.354	-0.744
Kurtosis	2.865	3.588	2.927	3.326
Jarque-Bera	0.469	19.587	4.402	20.204
Probability	0.791	0.000	0.111	0.000
Observations	209	209	209	209

5. FINDINGS, CONCLUSIONS AND POLICY IMPLICATIONS

The study investigated the nature of financial integration among the emerging (Indian) and mature economies (America, Germany, France and Swiss markets) in using the implied volatility indices. The results describe the wider international systematic behaviour of the underlying Asian-Pacific and Western stock markets. The results obtained from the bivariate BEKK-GARCH model are surprising as volatility spillovers are outwards from the emerging to developed markets. But in the real world, the mature markets are the dominant players and the financial events happening in these markets affects the developing economies stock markets significantly. This increasingly

Figure 3: Dynamic Conditional Correlations for the Implied Volatility Indices



complex phenomenon is observed as a consequence of increased level of financial globalization.

The results of DCC-model shows that there is moderate level of correlation in the volatility indices of the international markets with Indian markets and carry a unified message of uncertainty in respective markets in the long run. These results also imply that theoretically there is possibility that of yielding diversification benefits in short-run by making investment in the volatility indices of Indian stock markets in combination with westerns markets.

In the light of the above findings, in short-run VIs of respective countries can be used for the international portfolio diversification, for cash protection and hedging through local market index would bring greatest efficiency. The fast changes in the volatility indices with respect to the underlying indices provide an efficient picture of the information dissemination in the markets. These facts support important properties of VI being used as a market indicator and market timing tool. Finally, the information transmission and spillovers are running unidirectional from Indian markets to US markets and German markets to Indian markets and bidirectional between the Indian and French markets.

5.1. Policy Implications and Future Research

The results of the present study can be used by the portfolio managers and market participant for yielding the diversification benefits in short-run including implied volatility indices as an asset in portfolio. The investors could also hedge their portfolios against volatility with an off-setting position in VIX futures and option contracts.

This also indicates that same methodology can be applied to the volatility indices of the other countries in the Asian and Western world, Euro currency areas in order to compare their results with this one. It would be interesting to conduct similar study on the volatility derivative products. Finally, it would be worth studying the impact of the leverage effect in the underlying index on the volatilities of the VI.

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