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GLOBAL MARKET UNCERTAINTY TRANSMISSION IN THE POST GLOBAL CRISIS PERIOD: AN EMPIRICAL EVALUATION USING VECTOR AUTOREGRESSIVE ANALYSIS

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ABSTRACT

Globalization and financial integration across global markets have increased degree of global stock market integration. It was evident from the global crisis that uncertainty in one market is reflected in other markets within short span of time. While previous literature has documented the dominance of the U.S. in the international markets during the global crisis period and pre-crisis period, this paper investigates the influence of the U.S. market during the post global crisis period. The transmission of market uncertainty across the eight global markets the U.S. Canada, Eurex, the U.K. Australia, Japan, Hong Kong and India is examined. Implied volatility index (VIX), the widely used measure for market uncertainty is used and Vector Autoregressive framework (VAR) is employed to observe the transmission across the implied volatility indices. The U.S. was found to be the leading source of uncertainty across all the global markets and Hong Kong was found to be the next dominant source of uncertainty among the global markets.

Keywords: Market uncertainty; volatility index; volatility transmission.

JEL classification: G13, G15.

1. INTRODUCTION

With the advent of globalization the nexus across the global financial markets has been significantly strengthened during the past two decades. The economic integration by means of trade and financial linkages across the globe has led to the increased degree of global stock market integration, which in turn has led to enhanced correlations of equity returns among the stock markets (Bekaert and Harvey, 2017). Moreover, the technological developments and

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financial deregulations has made the stock markets increasingly globalized and integrated. The stock market crash of 1987 in the U.S. and its subsequent impact on the other global stock markets has triggered several studies on the volatility transmission across the stock markets (Gagnon and Karolyi, 2006).

Volatility in stock markets may be defined as a function of uncertainty, the degree to which asset prices tend to fluctuate or simply the variability or randomness of asset prices. Volatility of financial securities has been extensively studied by several researchers, practitioners due to its impact on capital investment, consumption and other business cyclic variables (Schwert, 1989). Extensive literature have focused on transmission of stock price returns and variances (Karolyi, 1995; Kanas, 1998; Chou et al., 1999; Worthington and Higgs, 2004; Pisedtasalasai and Gunasekarage, 2007; Mukherjee and Mishra, 2010; Joshi, 2011 Natarajan et al., 2014; Li and Giles, 2015; Yarovaya et al., 2016) and subsequently on the transmission of volatility across various global stock markets. The burgeoning literature on volatility transmission (Aboura, 2003; Nikkinen and Sahlström, 2004; Äijö, 2008; Jiang et al.,2012; Padhi,2011; Kumar SSS, 2012; Narwal et al.,2012; Siriopoulos and Fassas,2013; Ding and Huang, 2014; Thakolsri et al., 2016; Badshah,2018) is for the reason that market volatility vary much more than market returns and hence inter-market volatilities would reveal the dynamics of market integration and spillovers effect much better than market returns (Peng and Ng, 2012).

The literature on international equity market integration is directed towards the volatility linkages among the global investor fear index, which are measured using implied volatility indices. The implied volatility index (VIX) 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) and the information content of implied volatilities are considered to be superior over ex-post measures of volatilities (Fleming et al., 1995; Moraux, et al., 1999; Christensen and Prabhala, 1998; Jiang and Tian, 2005 and Blair et al., 2010). According to Merton (1976) implied volatility can be considered as the best available estimate of market fluctuation or uncertainty. The implied volatility index reflects the market expectations for the future volatility of the underlying equity index and measures investors' expectation of uncertainty regarding future price movements. In integrated markets, the expectation of uncertainty in one market would 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 (Nikkinen and Sahlstrom, 2004).

The integration of global stock markets can be either beneficial or unfavorable to international investors. According to Bae and Zhang (2015), the integration of global stock markets has multifold benefits specifically the decrease in cost of capital, increase in real investment, and economic growth. Furthermore, information about the dependencies in implied volatility series is

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useful in the construction of better volatility forecasts. Measures of volatility expectations are essential in investment decision-making, risk-hedging and market regulation and expectations can exert significant influence on market prices and can even affect the course of monetary policy, especially during periods of financial crisis (Padhi, 2011). However, Badshah (2018) records that the high degree of stock market correlation would evaporate the benefits of diversification available in the investment opportunity set to international investors. The examination of transmission across global stock market volatility indices thus becomes vital.

In this context, this paper examines the volatility transmission across Volatility index (VIX) between the U.S. and the key global markets Eurex, U.K., Canada, Australia, Hong Kong, India and Japan. In particular, this paper examines the international stock market integration during the post global crisis period, the sample period spanning from 2011 to 2018. The global implied volatility transmissions across the implied volatility indices are examined using techniques such as Granger causality, Generalized Impulse response function and Variance decomposition of the Vector Autoregressive (VAR) framework.

The contribution from this paper is threefold. First, while previous literature has documented the dominance of the U.S. market in the international markets during the global crisis period and pre-crisis period, this paper investigates the influence of the U.S. market during the post global crisis period. Second, to the best of our knowledge studies on the few of the key global markets namely Canada, Hong Kong and Australia are very limited and in the globalization era, literature on these markets and their role in the global scenario has become imperative. In view of this, the market uncertainty of these markets along with the other key markets in the global context is investigated in this paper. Third, as a considerable body of literature have studied extensively on the volatility transmission across global markets, this paper has focused on the linkages of the market uncertainties using the volatility indices. The results of the study will be of interest to international traders, portfolio managers and institutional investors who may consider trading volatility derivatives based on VIX.

2. LITERATURE REVIEW

Over the past two decades, research in international stock market integration has focused on the transmission across global stock market volatility indices. Aboura (2003) examined the returns and implied volatility spillovers of the French VX1, the German VDAX and the American VIX from March 31, 1994 to January 31, 1999 and established that U.S. VIX was the influential market, VX1 reacted strongly the first day, VDAX reaction spanned for the first two days among the three volatility indices. Nikkinen and Sahlström (2004) examined the U.S., German, U.K. and Finnish volatility indices for the sample period July 1996 to February 2000 and found that a high degree of integration existed among the U.S., U.K. and German markets and the U.S.

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market being the leading source of uncertainty to all markets, German being the leading source among European markets. Äijö (2008) investigated VDAX, VSMI and VSTOXX indices and found that the volatility indexes were highly correlated, the VDAX was the dominant source of information, VDAX Granger-causes both VSMI and VSTOX. Jiang et al. (2012) examined the effect of U.S. and European news announcements on the spillover of volatility across the U.S. (VIX) and European (VDAX-NEW, VCAC, VAEX, VBEL and VSMI) for the period July 1, 2003 to December 31, 2010 and reported that significant spillovers of implied volatility between the U.S. and European markets as well as within European markets existed and U.S. was the leading source.

While the above mentioned studies documented the influence of the U.S. market on the European markets, several studies showed the influence of the U.S. market on the Asian markets as well. Padhi (2011) examined the India (IVIX), Japan (VXJ), Hong Kong (VHSI), South Korea (VKSOPI), the U.S. (VIX) and Germany (VDAX) indices and found that U.S. VIX was the most influential index and Japan VXJ was the second most influential volatility index, in the Asian context for the sample period April 2009 to February 2011. Kumar SSS (2012) examined the volatility spill-overs between Indian (India VIX) and U.S. (VIX) , U.K. (VFTSE) and Japan (VXJ) from November 1, 2007 to May 31, 2010 and found that volatility from the U.S. was transmitted uni-directionally to the India VIX and VXJ was found to neither influence nor was influenced by India VIX. Narwal et al. (2012) found that implied volatilities of India, Germany, French and Switzerland were strongly affected by their own past shocks and volatility effects and that there was a moderate-level of correlation between the selected markets from November 2007 to October 2011. Siriopoulos and Fassas (2013) analyzed the spillover effects of thirteen implied volatilities indices from 2004 to July 2009 and found that in periods of turbulence in the financial markets, the conditional correlations across implied volatility indices increased. Ding and Huang (2014) examined the U.S., European, German, Japanese, and Swiss implied volatility linkages from January 1999 to December 2009 and found a asymmetric two-way relation between the VIX and other market volatility indices, and VIX has a larger impact in both the tranquil and crisis times spanning. Thakolsri et al. (2016) examined the volatility transmission from the VIX to the Euro (Euro STOXX50) and Thai (SET50) stock markets from November 2010 to December 2013 and the study revealed that the U.S. stock market was the leading source of volatility transmission which was unidirectional and there was no impact of the subprime crisis in the U.S. Badshah (2018) examined the U.S. VIX with VXEFA (developed market) and VXEEM (emerging market) from March 16, 2011 to October 30, 2015 and reported that there was considerable spillover from VIX to VXEFA and VXEEM of about 57.07%, and 63.77%, respectively.

The studies on transmission across global stock market volatility indices reveal that the U.S. was the leading source of uncertainty to the Asian and European markets, however, these studies are predominantly carried out during the pre-crisis and during the crisis period. To the best of our knowledge, only very minimal studies have examined the presence of international stock market integration during the post crisis period. However, it is imperative to investigate whether the U.S. is still the leading source of uncertainty in its own market and in the other markets. In this context this study has chosen the U.S. and the key markets from America, Europe, Asia and Australia in the post global crisis period to examine the transmission of uncertainty and the proportion of implied volatility spillover from the own and external markets. The global implied volatility transmissions across the implied volatility indices are examined using techniques such as Granger causality, Impulse response function and Variance decomposition of the Vector Autoregressive (VAR) framework.

3. THEORETICAL FRAMEWORK

3.1. VIX Index

A volatility index is designed to reflect the expected short-term market volatility. Volatility Index (VIX) is an index, computed on a real-time basis throughout each trading day which measures volatility and not price. VIX was introduced in 1993 to provide an index upon which futures and options contracts on volatility could be written. VIX, is forward-looking, measuring volatility that the investors expect to see. The increase in VIX are feared as an increase in volatility means increase in uncertainty in market. VIX has been termed as the "investor fear gauge." due to the fact that the VIX spikes during periods of market turmoil. Hence, the relation between the rate of change in VIX should be inversely proportional to the rate of return on the S&P 500 index (Whaley, 2008).

The idea of the volatility index was first proposed by Gastineau (1977), but the seminal work of Whaley (1993) led to the introduction of a risk measure, and facilitated volatility trading in an efficient way. The original index was based on the prices of S&P 100 (ticker symbol "OEX"), not S&P 500 (ticker symbol "SPX"), index option prices. Subsequently, VIX was calculated as a weighted average of the implied volatilities derived from eight at-the-money, nearby and second-nearby options on S&P 100 index (known as the OEX option contract).

Implied volatility of an option is defined as the market's assessment of the underlying asset's volatility, as reflected in the options price (Mayhew, 1995). Implied volatility are not directly observable are computed from the market observable parameters of the Black Scholes model. The parameters comprise of the options price, strike price of the options, time to expiration of the option contracts, underlying stock price and risk-free interest rate. Options contract are purchased by the investor by paying a premium called the options price. The strike price or the

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exercise price is the price incurred when the options contract is executed. The time to maturity is the number of days at which the options contract is to be executed or exercised. Implied volatility, the unknown parameter is that volatility that makes the model price exactly identical to the observed market price (Jackwerth, 2004).

Prior to 2003, VIX was computed by using the implied volatilities calculated by inverting the Black-Scholes option pricing model and interpolated to represent the implied volatility of a hypothetical at-the-money OEX option with exactly 30 days to mature. In September 2003 Chicago Board Options Exchange (CBOE) introduced the new VIX, independent of any option pricing Model which was derived directly from the S&P 500 index option prices and captured the volatility skew by using option prices over a wide range of strike prices instead of using just at-the-money options (Kumar SSS, 2012).

The calculation is done based on the following formula given by Britten-Jones and Neuberger (2000):

$$\sigma^2 = \frac{2}{T}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i) - \frac{1}{T}\left[\frac{F}{K_0} - 1\right]^2 \qquad (1)$$

where σ is the VIX/100; F is the forward index level identified as the strike price where the difference between call and put prices is smallest; K_0 is the first strike below the forward index level, Q (K_i) is the mid-price of the bid/ask spread for the option with strike K_i. Δ K_i is the interval between strikes on either side of K_i, R is the risk-free interest rate to expiration and T is the time to maturity in minutes. VIX is quoted in percentage points similar to the standard deviation of rates of return (Kumar SSS, 2012).

3.2. Vector Autoregressive (VAR) framework

The simultaneity among the chosen indices to study the volatility transmission, makes all the variables to be treated in the same way and as endogenous variables. The Vector Autoregressive (VAR) framework, a simultaneous equations system with all endogenous variables developed by Sims (1980) is used in this study. In this model, the value of a variable is expressed as a linear function of the past or lagged values of that variables and all other variables included in the model.

A time series data is characterized as stationary if the mean, variance and auto-covariance remain constant over the sample time period and unit root tests are applied to determine the stationarity of the data series. The Pearson correlation among the select markets is carried out to ascertain the degree of correlation among the markets. The order of the VAR is determined based on the standard lag length criteria and vector autoregressive modeling is applied to ascertain the causal dynamics of the implied volatilities.

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The VAR (p) system following the works of Nikkinen and Sahlström (2004) and Äijö (2008) is used in the study

$US_t= a^{US}+ \sum_{1=1}^{n} b_t^{US}\ US_{t-1} +\sum_{1=1}^{n} c_t^{US}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{US}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{US}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{US}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{US}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{US}\ JAP_{t-1}+ \sum_{1=1}^{n} i_t^{US}\ IND_{t-1}+ €^{US}$

$CAN_t= a^{CAN}+ \sum_{1=1}^{n} b_t^{CAN}\ US_{t-1} +\sum_{1=1}^{n} c_t^{CAN}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{CAN}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{CAN}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{CAN}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{CAN}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{CAN}\ JAP_{t-1}+ i_t^{CAN}\ IND_{t-1}+ €^{CAN}$

$EU_t= a^{EU}+ \sum_{1=1}^{n} b_t^{EU}\ US_{t-1} + \sum_{1=1}^{n} c_t^{EU}\ CAN_{t-1}+ \sum_{1=1}^{n} d_t^{EU}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{EU}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{EU}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{EU}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{EU}\ JAP_{t-1}+ \sum_{1=1}^{n} i_t^{EU}\ IND_{t-1}+ €^{EU}$

$UK_t= a^{UK}+ \sum_{1=1}^{n} b_t^{UK}\ US_{t-1} + \sum_{1=1}^{n} c_t^{UK}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{UK}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{UK}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{UK}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{UK}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{UK}\ JAP_{t-1} +\sum_{1=1}^{n} i_t^{UK}\ IND_{t-1}+ €^{UK}$

$AUS_t= a^{AUS}+ \sum_{1=1}^{n} b_t^{AUS}\ US_{t-1} + \sum_{1=1}^{n} c_t^{AUS}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{AUS}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{AUS}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{AUS}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{AUS}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{AUS}\ JAP_{t-1}+ \sum_{1=1}^{n} i_t^{AUS}\ IND_{t-1}+€^{AUS}$

$HK_t= a^{HK}+ \sum_{1=1}^{n} b_t^{HK}\ US_{t-1} + \sum_{1=1}^{n} c_t^{HK}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{HK}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{HK}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{HK}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{HK}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{HK}\ JAP_{t-1}+ \sum_{1=1}^{n} i_t^{HK}\ IND_{t-1}+€^{HK}$

$JAP_t= a^{JAP}+ \sum_{1=1}^{n} b_t^{JAP}\ US_{t-1} +\sum_{1=1}^{n} c_t^{JAP}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{JAP}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{JAP}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{JAP}\ AUS_{t-1} + \sum_{1=1}^{n} g_t^{JAP}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{JAP}\ JAP_{t-1}+ \sum_{1=1}^{n} i_t^{JAP}\ IND_{t-1}+€^{JAP}$

$IND_t= a^{IND}+ \sum_{1=1}^{n} b_t^{IND}\ US_{t-1} +\sum_{1=1}^{n} c_t^{IND}\ CAN_{t-1} + \sum_{1=1}^{n} d_t^{IND}\ EU_{t-1} + \sum_{1=1}^{n} e_t^{IND}\ UK_{t-1}+ \sum_{1=1}^{n} f_t^{IND}\ AUS_{t-1}+ \sum_{1=1}^{n} g_t^{IND}\ HK_{t-1}+ \sum_{1=1}^{n} h_t^{IND}\ JAP_{t-1}+ \sum_{1=1}^{n} i_t^{IND}\ IND_{t-1}+ €^{IND}$ (2)

where US_t, CAN_t, EU_t, UK_t, AUS_t, HK_t, JAP_t and IND_t are the respective implied volatility index measures of the U.S., Canada, Eurex, the U.K., Australia, Hong Kong, Japan and India stock markets at day t. a^{US}, a^{CAN}, a^{EU}, a^{UK}, a^{AUS}, a^{HK}, a^{JAP} and a^{IND} are intercepts and n indicates the lag length, i.e. order of the VAR model.

The interpretation of the VAR framework analysis is carried done by applying Granger causality, impulse response analysis and variance decomposition analysis. Granger causality tests are used to identify potential lead-lag relationships between the implied volatilities and the direction of causalities. In the impulse response analysis the response of the one variable to an impulse in another variable can be investigated. Variance decomposition is used to detect fraction of the variation in one variable explained by a variation in another variable and hence it can investigated how important other markets are in explaining uncertainty changes in another markets.

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4. METHODOLOGY

4.1. Data description

This paper aims to investigate the implied volatility spillover phenomenon between the U.S. implied volatility index and the other global markets and considers the VIX indices of the eight markets namely the U.S., Canada, Eurex, the U.K., Australia, Hong Kong, Indian and Japan. Table 1 summarizes the list of the volatility indices, their underlying indices and the corresponding markets. The data of the U.S., Canada, Eurex, U.K., India and Japan volatility indices used for the study has been taken from the official stock exchange websites of the respective countries and the data of the Hong Kong and Australian volatility indices are taken from the Bloomberg database. Considering the post global crisis period and the launch of the Hong Kong Volatility index on February 21, 2011, the sample period considered for the study is from February 21, 2011 to June 30, 2018 and the daily closing values of the volatility indices have been used in this study.

Table 1: List of volatility indices and their underlying indices used in the study

Volatility Index	Underlying Stock Index	Market
CBOE Volatility Index (VIX)	S&P 500	U.S.
Volatility Index of Canada (VIXC)	S&P/TSX 60	Canada
Volatility Index of UK (VFTSE)	FTSE 100	U.K.
Dow Jones EURO STOXX 50 Volatility Index (V2TX)	DJ Euro STOXX 50	Major markets in 12 Eurozone countries*
Volatility Index of Australia(AVIX)	S&P/ASX 200	Australia
Volatility Index of Hong Kong (VHSI)	Hang Seng	Hong Kong
Volatility Index of Japan (VXJ)	NIKKEI 225	Japan
Indian Volatility Index (IVIX)	S&P CNX Nifty	India

Note: *Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain.

Chicago Board Options Exchange (CBOE), the first volatility index was introduced by CBOE. The CBOE volatility index (the VIX index) measures near-term volatility as indicated by index option prices in the S&P 500 index. The index was introduced in 1993 and is considered a benchmark barometer of market volatility. The volatility index for the Canadian stock market,

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was originally launched in December 2002 by the Montreal exchange, a model-based implied volatility index, termed as the MVX. In 2010 the Montreal Exchange replaced the MVX with the VIXC, which is based on model-free method and uses the S&P/TSX 60 stock index options prices for the calculation of implied volatility.

The FTSE 100 volatility index (VFTSE) represents the implied volatility embedded in the options prices of the UK benchmark equity index, the FTSE 100, that trade in the London International Financial Futures and Options Exchange (LIFFE). VFTSE follow the CBOE VIX methodology which is independent of any model and have become the investor fear gauge in the UK market. The VFTSE became operational, on a real time basis, from 23 June 2008.The volatility index of Eurex is VSTOXX or V2TX. The indices are based on EURO STOXX 50 options prices, which represent 12 major markets in the Eurozone countries. Eurex offers both futures and options contract on VSTOXX. VSTOXX futures were originally launched in September 2005 and then relaunched in 2009 as Mini VSTOXX. The volatility index options launched from March 2010.

The Australian Volatility index S&P/ASX 200 VIX (A-VIX) tracks S&P/ASX 200 index option prices as a means of monitoring anticipated levels of near-term volatility in the Australian equity market. The A-VIX reflects expected equity market volatility over the next 30 days by using mid prices for S&P/ASX 200 put and call options to calculate a weighted average of the implied volatility of the options.

The Volatility Index of Hong Kong, the HSI Volatility Index (VHSI) was launched on February 21, 2011 and measures 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 traded on the Hong Kong Exchanges and Clearing Limited's derivatives market. India VIX (IVIX), the Volatility Index of India launched on 2nd March 2009 is computed on NIFTY Options. 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. India VIX uses the computation methodology of CBOE, with suitable amendments to adapt to the NIFTY options. The Volatility Index of Japan (VXJ), a benchmark of future volatility in the Japanese stock market is based on Nikkei 225 index options, and provides a measure of how volatile the Japanese stock market will be over the next month. 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 and was launched in the year 2011.

4.2. Descriptive Statistics

Figure 1 shows the time-series plots of the eight volatility indices movements for the sample period February 21, 2011 till June 30, 2018. Table 2 presents the descriptive statistics of the level

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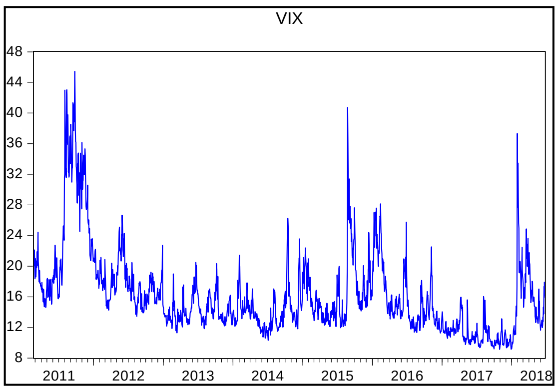
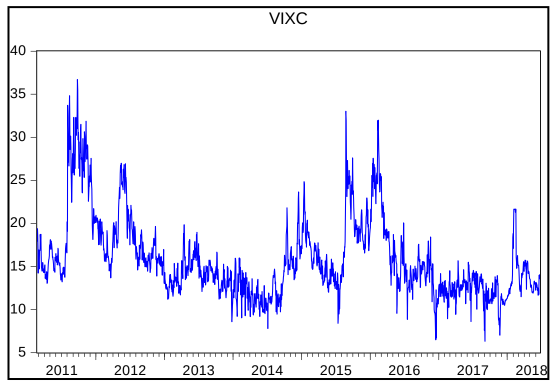
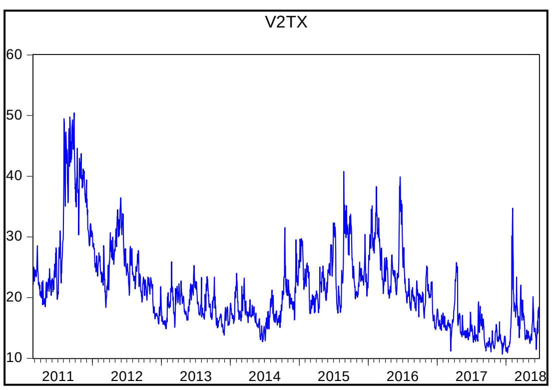
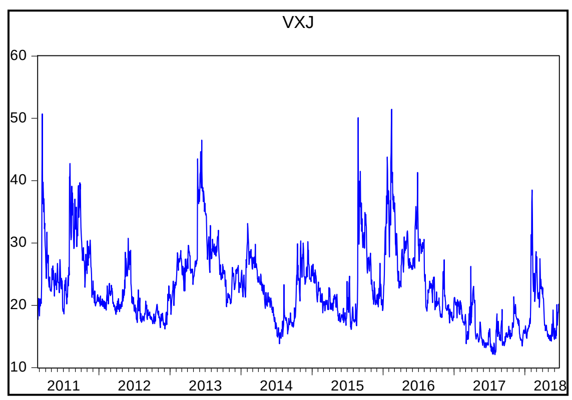
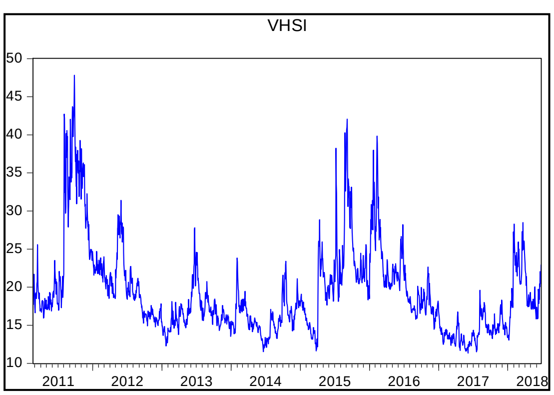
and first differences of the eight implied volatility indices. It can be noted that on an average values of volatility indices was ranging from 15 to 17 however the average values of Eurex (V2TX) and Japan (VXJ) was higher with values of 21.53 and 22.76 respectively. Among the eight indices the maximum value was 51.45 for VXJ and minimum value was 6.19 for the VFTSE index. The average of the first difference of the eight volatility indices is not statistically different from zero indicating the absence of any trend in the data. From the measures of skewness and kurtosis it can be observed that the indices are not normal in nature.

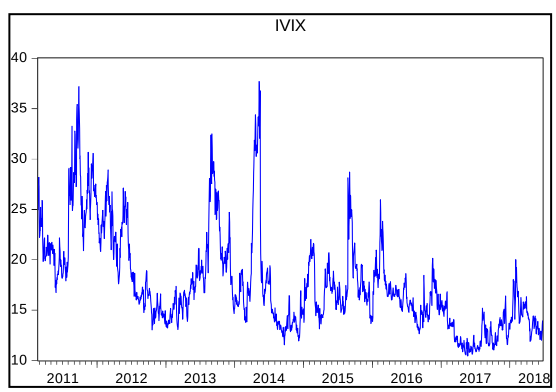












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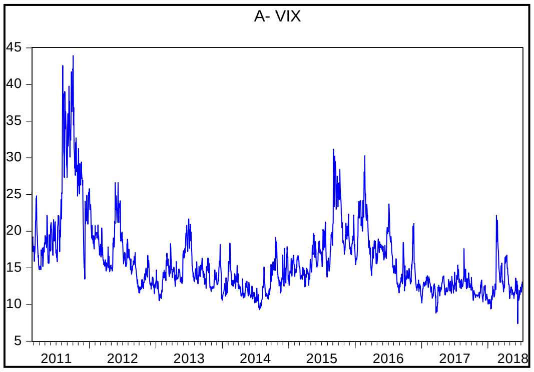

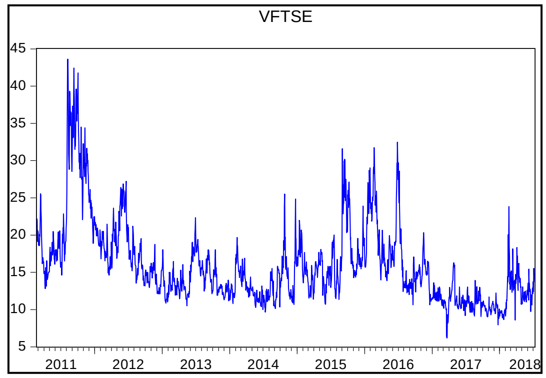

Figure 1: Time series plot of volatility indices from February 2011 to June 2018

Table 2: Descriptive Statistics of volatility indices from February 2011 to June 2018

	Index (At Level)							
	VIX	*VIXC*	*V2TX*	*VFTSE*	*A-VIX*	*VHSI*	*VXJ*	*IVIX*
Mean	16.23	15.89	21.53	15.95	15.97	19.34	22.76	17.72
Median	14.77	14.69	20.33	14.75	14.70	17.81	21.51	16.51
Maximum	45.45	36.71	50.44	43.61	43.93	47.82	51.45	37.71
Minimum	9.14	6.32	10.68	6.19	7.39	11.36	12.09	10.45
Std. Dev.	5.49	4.66	6.86	5.41	4.91	5.79	6.05	4.85
Skewness	2.00	1.37	1.34	1.73	1.93	1.67	1.02	1.19
Kurtosis	8.03	4.93	5.23	6.69	7.92	6.24	4.35	4.24
	Index (First Difference)							
	D(VIX)	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
Mean	-0.002	-0.002	-0.003	-0.003	-0.002	0.003	0.001	-0.006
Median	-0.050	-0.030	-0.027	-0.016	-0.058	-0.090	-0.070	-0.020
Maximum	20.01	14.62	12.13	11.05	10.45	14.10	17.14	11.02
Minimum	-7.34	-5.74	-8.85	-7.26	-9.44	-6.93	-13.89	-12.47
Std. Dev.	1.51	1.31	1.60	1.42	1.21	1.35	1.78	1.01
Skewness	2.29	0.92	0.75	0.57	0.87	2.19	1.60	-0.02

Kurtosis	27.87	13.74	11.47	9.87	14.51	22.54	23.82	27.27

* First difference of Volatility index (VIX) is D (VIX) = $VIX_t - VIX_{t-1}$

The Pearson Correlation coefficient analysis on the volatility indices are presented in Table 3. It can be observed from Table 3 that high degree correlation existed between the European markets, highest value of 0.96 between Eurex and the U.K. The correlation between the American, European and Australian markets were high with values ranging from 0.91 to 0.84. Among the Asian markets high degree of correlation between the Hong Kong index with the American, European and Australian markets was present. However the correlation of India and Japan with the other markets was found to be comparatively lower. The correlation between the Indian and the Japanese markets was the lowest.

Table 3: Pearson's Coefficient of Correlation of volatility indices

	VIX	*VIXC*	*V2TX*	*VFTSE*	*A-VIX*	*VHSI*	*VXJ*	*IVIX*
VIX	1							
	(0.000)							
VIXC	0.88	1						
	(0.000)	(0.000)						
V2TX	0.89	0.87	1					
	(0.000)	(0.000)	(0.000)					
VFTSE	0.91	0.87	0.96	1				
	(0.000)	(0.000)	(0.000)	(0.000)				
A-VIX	0.87	0.84	0.89	0.91	1			
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
VHSI	0.86	0.83	0.85	0.88	0.88	1		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
VXJ	0.57	0.54	0.59	0.63	0.63	0.59	1	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
IVIX	0.62	0.55	0.61	0.63	0.61	0.57	0.48	1

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(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

**Correlation is significant at the 0.01 level (2-tailed).

The unit root tests, the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are applied to determine the stationarity of the eight volatility indices. The unit root tests without time trend is used for testing since the time series plot did not exhibit any particular trend (Figure 1). Table 4 presents the results of the unit root tests of the eight volatility indices and its first differences and the results indicate that the volatility indices are not stationary at level and stationary at first difference. Therefore, first differences of implied volatility series are used in the analysis, similar to the works of Nikkinen and Sahlstrom (2004), Äijö (2008), Padhi (2011), Kumar SSS, (2012) and Thakolsri et al. (2016).

Table 4: Unit root tests

	Index (At Level)							
	VIX	*VIXC*	*VFTSE*	*V2TX*	*A-VIX*	*VHSI*	*VXJ*	*IVIX*
ADF	-1.435	-1.478	-1.495	-1.620	-1.306	-0.953	-1.333	-1.459
	0.1412	0.1307	0.1265	0.0994	0.1774	0.3041	0.1694	0.1352
PP	-1.318	-1.171	-1.443	-1.130	-1.201	-0.894	-1.024	-1.365
	0.1737	0.2211	0.1393	0.2356	0.2107	0.3290	0.2755	0.1600
	Index (First Difference)							
	D(VIX)	*D(VIXC)*	*D(VFTSE)*	*D(V2TX)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
ADF	-24.01	-36.46	-26.40	-45.00	-25.87	-22.49	-29.37	-33.67
	0.000	0.000	0.000	0.0001	0.000	0.000	0.000	0.000
PP	-52.82	-58.97	-48.90	-49.88	-51.36	-45.72	-52.34	-43.82
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

*, ** The ADF and Philips-Perron test statistics are computed without time trend. At the 1% level the critical value of ADF and PP, the t statistic are compared with the table of critical values computed by Dickey and Fuller .The t value is found to be outside the confidence interval the null hypothesis of unit root is rejected

4.3. Vector Auto Regressive (VAR) Analysis

Vector autoregressive modeling is applied to ascertain the causal dynamics of the implied volatilities. In the vector auto regressive framework, the order of the VAR is determined based

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on the standard lag length criteria. The lag length is ascertained using four different criteria, FPE (Final prediction error), AIC (Akaike information criterion), SC (Schwarz information criterion) and HQ (Hannan-Quinn information criterion) and the results are reported in Table 5. Lag length of six is selected on the basis of both FPE and AIC criteria for the study.

Table 5: Lag Selection Criteria

Lag	LogL	FPE	AIC	SC	HQ
0	-23806.9	9.711231	24.9763	24.9996	24.98487
1	-22789.4	3.572477	23.97628	24.18594*	24.05345
2	-22595.8	3.118583	23.84039	24.23643	23.98616*
3	-22509.5	3.046469	23.81699	24.3994	24.03135
4	-22443.5	3.040267	23.81493	24.58372	24.0979
5	-22368.3	3.004646	23.80312	24.75828	24.15468
6	-22288.2	2.954566*	23.78628*	24.9278	24.20643
7	-22228.6	2.968264	23.79085	25.11875	24.2796
8	-22177	3.007441	23.80389	25.31816	24.36124

* indicates lag order selected by the criterion
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion
FPE: Final prediction error

Granger causality tests are used to identify potential lead-lag relationships between the implied volatilities and the direction of causalities. The results of the Granger causality performed on the differences of the implied volatility indices are presented in Table 6. It is evident from the results that the U.S. market granger causes all the select America, European, Australian and Asian markets and still remains the dominant index. Canada was also found to granger causes all the markets except the U.S., Hong Kong granger caused all the markets including the U.S. The Asian markets were found to granger cause the U.S. market. The European markets granger caused each other and the other markets. The Australian market granger caused the U.K. Hong Kong and Japan markets. Among the Asian markets Japan granger caused all markets except Eurex, Hong Kong and India. In sum, Table 6 clearly shows that the U.S. is the leading source of

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volatility transmission to all select global markets and Hong Kong is the next leading source among the all the global markets.

Table 6: Granger Causality

Null Hypothesis	F-Statistic	Prob.
D(VIX) does not Granger Cause D(VIXC)	17.2071	0.000
D(VIXC) does not Granger Cause D(VIX)	0.80133	0.569
D(VIX) does not Granger Cause D(V2TX)	44.6683	0.000
D(V2TX) does not Granger Cause D(VIX)	1.50691	0.172
D(VIX) does not Granger Cause D(VFSTE)	54.5344	0.000
D(VFTSE) does not Granger Cause D(VIX)	0.89557	0.497
D(VIX) does not Granger Cause D(A-VIX)	139.899	0.000
D(A-VIX) does not Granger Cause D(VIX)	1.01157	0.416
D(VIX) does not Granger Cause D(VHSI)	14.4717	0.000
D(VHSI) does not Granger Cause D(VIX)	21.0826	0.000
D(VIX) does not Granger Cause D(VXJ)	89.6464	0.000
D(VXJ) does not Granger Cause D(VIX)	3.4869	0.002
D(VIX) does not Granger Cause D(IVIX)	24.0255	0.000
D(IVIX) does not Granger Cause D(VIX)	2.13603	0.047
D(VIXC) does not Granger Cause D(V2TX)	7.37033	0.000
D(V2TX) does not Granger Cause D(VIXC)	7.77039	0.000
D(VIXC) does not Granger Cause D(VFSTE)	13.1467	0.000
D(VFTSE) does not Granger Cause D(VIXC)	8.57935	0.000
D(VIXC) does not Granger Cause D(A-VIX)	55.864	0.000
D(A-VIX) does not Granger Cause D(VIXC)	1.71031	0.115
D(VIXC) does not Granger Cause D(VHSI)	5.38051	0.000
D(VHSI) does not Granger Cause D(VIXC)	26.314	0.000
D(VIXC) does not Granger Cause D(VXJ)	30.4237	0.000
D(VXJ) does not Granger Cause D(VIXC)	2.39682	0.026

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D(VIXC) does not Granger Cause D(IVIX)	7.35919	0.000
D(IVIX) does not Granger Cause D(VIXC)	3.68009	0.001
D(V2TX) does not Granger Cause D(VFSTE)	5.62962	0.000
D(VFTSE) does not Granger Cause D(V2TX)	0.5958	0.734
D(V2TX) does not Granger Cause D(A-VIX)	77.7198	0.000
D(A-VIX) does not Granger Cause D(V2TX)	0.74525	0.613
D(V2TX) does not Granger Cause D(VHSI)	6.98082	0.000
D(VHSI) does not Granger Cause D(V2TX)	37.0443	0.000
D(V2TX) does not Granger Cause D(VXJ)	53.3474	0.000
D(VXJ) does not Granger Cause D(V2TX)	1.89949	0.078
D(V2TX) does not Granger Cause D(IVIX)	6.91126	0.000
D(IVIX) does not Granger Cause D(V2TX)	3.19616	0.004
D(VFTSE) does not Granger Cause D(A-VIX)	69.506	0.000
D(A-VIX) does not Granger Cause D(VFSTE)	2.60669	0.016
D(VFTSE) does not Granger Cause D(VHSI)	8.80863	0.000
D(VHSI) does not Granger Cause D(VFSTE)	42.9063	0.000
D(VFTSE) does not Granger Cause D(VXJ)	42.0415	0.000
D(VXJ) does not Granger Cause D(VFSTE)	2.12369	0.048
D(VFTSE) does not Granger Cause D(IVIX)	3.39132	0.003
D(IVIX) does not Granger Cause D(VFSTE)	1.71532	0.114
D(A-VIX) does not Granger Cause D(VHSI)	2.30932	0.032
D(VHSI) does not Granger Cause D(A-VIX)	64.6475	0.000
D(A-VIX) does not Granger Cause D(VXJ)	2.78979	0.011
D(VXJ) does not Granger Cause D(A-VIX)	4.47376	0.000
D(A-VIX) does not Granger Cause D(IVIX)	0.72746	0.628
D(IVIX) does not Granger Cause D(A-VIX)	20.4005	0.000
D(VHSI) does not Granger Cause D(VXJ)	65.0002	0.000
D(VXJ) does not Granger Cause D(VHSI)	1.03987	0.397
D(VHSI) does not Granger Cause D(IVIX)	31.2864	0.000

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D(IVIX) does not Granger Cause D(VHSI)	1.15567	0.328
D(IVIX) does not Granger Cause D(VXJ)	9.69347	0.000
D(VXJ) does not Granger Cause D(IVIX)	1.1711	0.319

The VAR (6) system given by Equation (2) is used to ascertain possible lead-lag relationships between the volatility indices, to examine the transmission of shocks in the implied volatility of one index on the other implied volatilities in the system and linkages among the eight volatility indices. The VAR (6) results are summarized in Table 7. The significance of the VAR (6) model is established by the F statistics results, the adequacy of lag selection is established by the absence of residual serial correlation using the Ljung-Box statistic for 8 lags. The adjusted R-square value was found to be between 0.083 for Hong Kong and 0.311 for Japan indices.

Table 7: VAR (6) Results

	D(VIX)	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
Adj. R-squared	0.092	0.139	0.211	0.233	0.391	0.083	0.311	0.134
F-statistic	5.044	7.391	11.622	13.079	26.487	4.605	18.932	7.134
P value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Q(8)	6.575	9.910	6.343	12.930	7.580	1.846	8.026	0.298
P value	0.583	0.271	0.609	0.114	0.371	0.985	0.431	1.000

The residual correlations of the eight volatility indices are presented in Table 8. It can be seen that all residual correlations are positive and statistically significant. The highest residual correlation was found between the U.K. and Eurex residuals with the correlation coefficient of 0.81 and lowest correlation was between Canada Kong and Japan residuals correlation coefficient being 0.08. The residual correlations results are consistent with the results of Granger Causality Test, which suggest that the U.S. is influential in transmitting implied volatilities to the other markets with higher correlation when compared with the residuals of other markets.

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Table 8: Residual correlation

Residual	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
D(VIX)	1							
	0.000							
D(VIXC)	0.58	1						
	0.000	0.000						
D(V2TX)	0.57	0.44	1					
	0.000	0.000	0.000					
D(VFTSE)	0.50	0.42	0.81	1				
	0.000	0.000	0.000	0.000				
D(A-VIX)	0.17	0.17	0.19	0.21	1			
	0.000	0.000	0.000	0.000	0.000			
D(VHSI)	0.37	0.25	0.28	0.30	0.15	1		
	0.000	0.000	0.000	0.000	0.000	0.000		
D(VXJ)	0.16	0.08	0.17	0.17	0.32	0.11	1	
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
D(IVIX)	0.23	0.22	0.30	0.30	0.16	0.21	0.16	1
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The speed at which the volatility movements are transmitted from one market to another 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 shock of one index to itself and to the other indices and also the persistence of these shocks. The dynamics of volatility transmission is examined using the impulse response analysis. The shock observed in day 1 is the contemporaneous effect and the subsequent days are the lagged effect. The impulse response analysis is performed using generalized one standard deviation shocks on the implied volatilities. The impulse response functions with the Monte Carlo simulated 95 percent confidence bounds (dashed lines) are presented in Figure 2. It can be observed that the shock of the U.S. index, has impact on all the other markets on Day 2 and the impact gradually subsides on the fourth day. The shock of Hong Kong market impact creates impact on all the markets including the U.S. but the impact subsides immediately on the next day. The shock of Eurex creates significant impact on the U.K. market and the shock of Australian market causes impact on the Japanese market. However the shock on Canada, U.K. India and Japan does not create impact on the other markets.

The variance decomposition analysis is carried out to study the fraction of variation in one volatility index caused by innovations in the other volatility indices in the system and to examine their relative importance. The variance decompositions of the eight volatility indices are presented in Figure 3. It can be observed, that the forecast variance of the U.S. index is primarily

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caused by innovations in itself, marginally by the Hong Kong Index and not affected by other indices. Similarly the Hong Kong index is caused by its own innovations and marginally from the U.S. The forecast variance of U.K. is due its own innovations and from the U.S. and marginally from Hong Kong and Eurex. It can be observed that the forecast variance in all markets is caused by its own innovations, from the U.S. and marginally from Hong Kong. Table 9 presents the detailed numerical illustration of variance decomposition of each of the indices comprising of the number of days ahead error variances and the standard errors and the percentage forecast error variances due to specific innovations, each row adding up to 100 percent. The standard error is the forecast error of the variable at a particular forecast horizon. The forecast error is the variation in the current and future expected values of the innovations to each variable in the dynamic VAR system. The 10- day ahead forecast error variance of the U.S. is predominantly explained by its own innovations and marginally by Hong Kong. In case of Canada, India, Eurex and Australia 10- day ahead forecast error variance is explained by its own innovations and from U.S. and marginally from Hong Kong. However. 10- day ahead forecast error variance of the U.K. is explained by U.S., Eurex and marginally by Hong Kong. The 10-day ahead forecast error variance of Japan is influenced by its own innovations and from U.S. Hong Kong and Australia. The findings clearly shows that the U.S. is the influential transmitter of uncertainty to all the global markets and Hong Kong is the next influential market in the global context.

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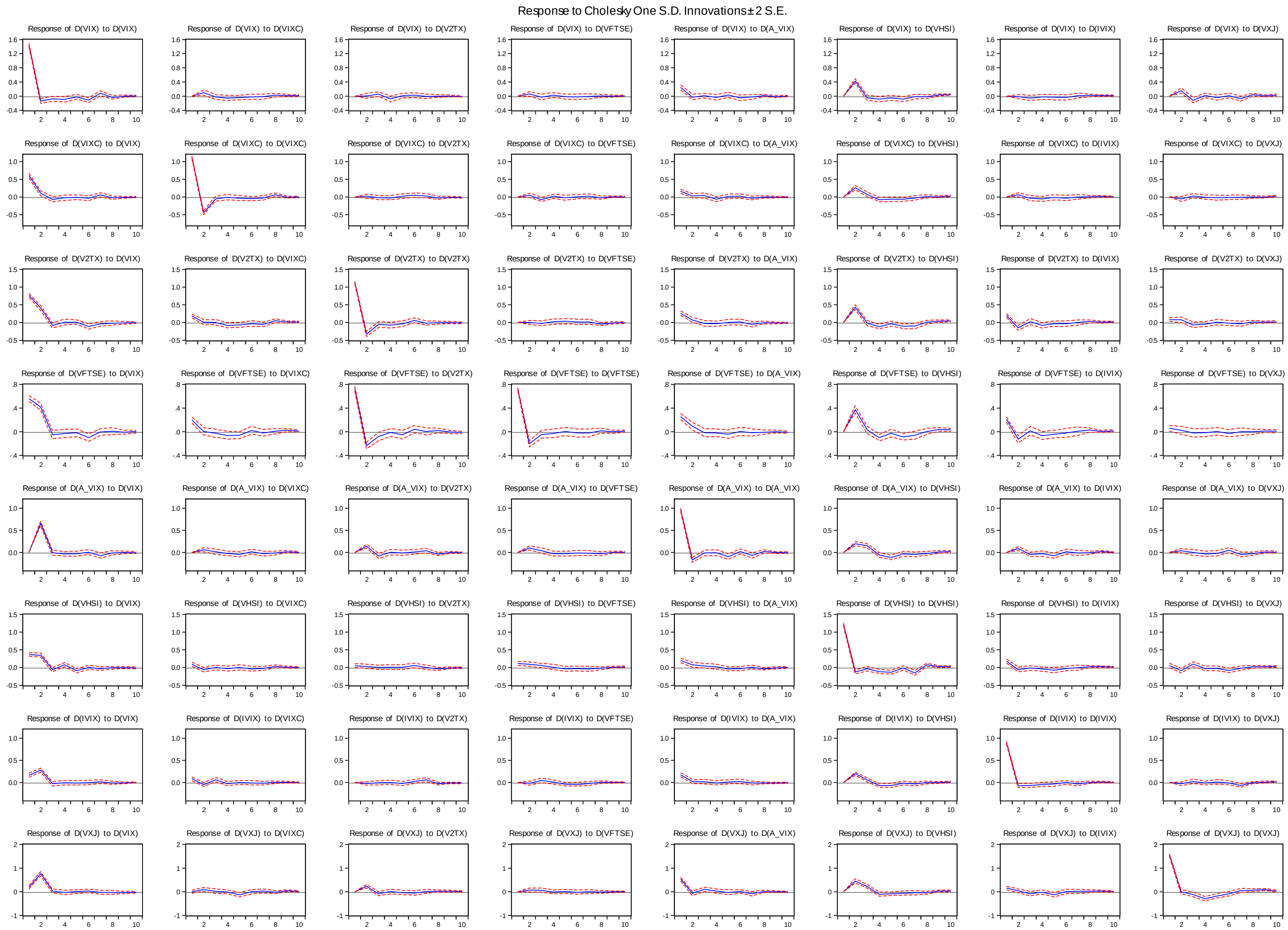

Figure 2: Impulse response of volatility indices*

* Impulse response functions with the Monte Carlo simulated 95 percent confidence bounds (dotted lines)

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Figure 3: Variance decomposition of volatility indices*

* The dotted lines around each variance decomposition present 95 percent confidence bounds obtained via Monte Carlo simulation.

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Table 9: Variance decomposition of volatility indices*

Table 9.1: Variance Decomposition of U.S.

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	1.4354	100	0	0	0	0	0	0	0
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.4814	94.10	0.00	0.02	0.06	0.02	5.29	0.02	0.49
		(1.0717)	(0.0615)	(0.0665)	(0.1307)	(0.0881)	(1.0177)	(0.1071)	(0.2948)
3	1.4952	93.35	0.10	0.12	0.12	0.04	5.20	0.54	0.54
		(1.1766)	(0.1371)	(0.1842)	(0.1963)	(0.1403)	(0.9934)	(0.3673)	(0.3080)
4	1.5072	92.09	0.21	0.48	0.11	0.14	5.87	0.55	0.55
		(1.3486)	(0.2253)	(0.3297)	(0.2224)	(0.2252)	(1.1652)	(0.3606)	(0.3115)
5	1.5100	91.91	0.22	0.48	0.11	0.28	5.85	0.60	0.56
		(1.3488)	(0.2383)	(0.3371)	(0.2400)	(0.2789)	(1.1492)	(0.3828)	(0.3165)
6	1.5175	91.51	0.27	0.48	0.14	0.39	6.04	0.59	0.59
		(1.3861)	(0.2566)	(0.3461)	(0.2509)	(0.2821)	(1.1670)	(0.3897)	(0.3170)
7	1.5239	91.07	0.32	0.47	0.17	0.38	6.10	0.72	0.76
		(1.3447)	(0.2790)	(0.3472)	(0.2764)	(0.2824)	(1.1803)	(0.3990)	(0.3635)
8	1.5249	90.95	0.32	0.48	0.17	0.41	6.10	0.81	0.76
		(1.3763)	(0.2821)	(0.3489)	(0.2900)	(0.2893)	(1.1736)	(0.4425)	(0.3626)
9	1.5253	90.92	0.34	0.48	0.17	0.41	6.11	0.81	0.76
		(1.3803)	(0.2843)	(0.3474)	(0.2897)	(0.2895)	(1.1745)	(0.4426)	(0.3619)
10	1.5255	90.89	0.34	0.48	0.17	0.41	6.12	0.82	0.76
		(1.3839)	(0.2848)	(0.3474)	(0.2889)	(0.2919)	(1.1740)	(0.4434)	(0.3624)

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Table 9.2: Variance Decomposition of Canada

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	1.2159	33.53	66.47	0	0	0	0	0	0
		(1.8998)	(1.8998)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.2938	30.06	65.44	0.10	0.18	0.02	4.19	0.00	0.00
		(1.6893)	(1.7747)	(0.1277)	(0.1905)	(0.0654)	(0.8359)	(0.0924)	(0.0658)
3	1.3038	29.80	64.64	0.16	1.04	0.04	4.15	0.10	0.07
		(1.6675)	(1.7986)	(0.1895)	(0.4436)	(0.0913)	(0.8227)	(0.1910)	(0.1376)
4	1.3112	29.98	63.94	0.23	1.05	0.15	4.33	0.10	0.21
		(1.6144)	(1.7881)	(0.2295)	(0.4528)	(0.2170)	(0.9054)	(0.2156)	(0.1912)
5	1.3146	29.84	63.81	0.32	1.07	0.18	4.40	0.14	0.24
		(1.6035)	(1.7633)	(0.2677)	(0.4423)	(0.2497)	(0.8918)	(0.2297)	(0.2106)
6	1.3211	29.70	63.24	0.38	1.07	0.18	4.96	0.14	0.33
		(1.6173)	(1.7520)	(0.2961)	(0.4353)	(0.2477)	(0.9226)	(0.2624)	(0.2495)
7	1.3250	29.75	62.90	0.39	1.07	0.20	5.12	0.18	0.40
		(1.6426)	(1.7450)	(0.3027)	(0.4425)	(0.2528)	(0.9142)	(0.2869)	(0.2731)
8	1.3257	29.72	62.90	0.40	1.07	0.21	5.12	0.19	0.40
		(1.6383)	(1.7495)	(0.3203)	(0.4460)	(0.2595)	(0.9109)	(0.2929)	(0.2772)
9	1.3259	29.72	62.89	0.40	1.08	0.21	5.12	0.19	0.40
		(1.6395)	(1.7486)	(0.3210)	(0.4467)	(0.2617)	(0.9109)	(0.2952)	(0.2780)
10	1.3263	29.70	62.86	0.42	1.08	0.21	5.13	0.20	0.40
		(1.6384)	(1.7472)	(0.3231)	(0.4487)	(0.2617)	(0.9154)	(0.2966)	(0.2773)

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Table 9.3: Variance Decomposition of Eurex

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	1.4246	32.66	1.64	65.69	0	0	0	0	0
		(1.7512)	(0.4588)	(1.8485)	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.5859	33.90	1.52	57.99	0.02	0.02	5.53	0.00	1.02
		(1.6067)	(0.4506)	(1.7354)	(0.1261)	(0.1024)	(0.8274)	(0.0762)	(0.3619)
3	1.5936	34.04	1.57	57.55	0.05	0.03	5.48	0.20	1.08
		(1.6552)	(0.4625)	(1.7214)	(0.1648)	(0.1094)	(0.8249)	(0.1981)	(0.3775)
4	1.6048	33.58	1.68	57.06	0.05	0.04	6.10	0.27	1.23
		(1.6409)	(0.4769)	(1.7428)	(0.1898)	(0.1653)	(0.9696)	(0.2147)	(0.4019)
5	1.6070	33.50	1.82	56.95	0.07	0.04	6.11	0.27	1.24
		(1.6383)	(0.5090)	(1.7429)	(0.2232)	(0.1734)	(0.9731)	(0.2215)	(0.4058)
6	1.6179	33.74	1.82	56.20	0.07	0.06	6.46	0.35	1.29
		(1.6635)	(0.4903)	(1.7597)	(0.2394)	(0.1866)	(0.9761)	(0.2385)	(0.4100)
7	1.6214	33.63	1.81	55.98	0.19	0.07	6.43	0.42	1.46
		(1.6538)	(0.4986)	(1.7577)	(0.2836)	(0.1876)	(0.9655)	(0.2461)	(0.4679)
8	1.6229	33.60	1.83	55.91	0.22	0.07	6.43	0.44	1.50
		(1.6596)	(0.4973)	(1.7669)	(0.2936)	(0.1930)	(0.9773)	(0.2535)	(0.4619)
9	1.6234	33.58	1.83	55.87	0.22	0.07	6.46	0.47	1.50
		(1.6547)	(0.4985)	(1.7709)	(0.2967)	(0.1949)	(0.9832)	(0.2602)	(0.4612)
10	1.6240	33.56	1.83	55.83	0.22	0.07	6.51	0.47	1.50
		(1.6538)	(0.4995)	(1.7713)	(0.2965)	(0.1961)	(0.9887)	(0.2604)	(0.4609)

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Table 9.4: Variance Decomposition of U.K.

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	1.2391	24.53	2.80	38.54	34.13	0	0	0	0
		(1.8109)	(0.6670)	(1.4015)	(1.3086)	0.0000	0.0000	0.0000	0.0000
2	1.4023	28.15	2.26	33.32	29.50	0.13	5.91	0.00	0.73
		(1.6104)	(0.5744)	(1.4442)	(1.1952)	(0.1822)	(0.9173)	(0.0597)	(0.3644)
3	1.4109	28.10	2.24	33.39	29.42	0.15	5.84	0.12	0.74
		(1.6732)	(0.5682)	(1.4250)	(1.2162)	(0.1955)	(0.9143)	(0.1798)	(0.3560)
4	1.4192	28.02	2.28	33.06	29.16	0.15	6.29	0.18	0.85
		(1.6547)	(0.5745)	(1.4236)	(1.1818)	(0.2300)	(1.0121)	(0.2058)	(0.3839)
5	1.4221	27.95	2.44	33.04	29.04	0.20	6.27	0.19	0.86
		(1.6564)	(0.5956)	(1.3979)	(1.1723)	(0.2514)	(1.0165)	(0.2104)	(0.3767)
6	1.4291	28.14	2.43	32.75	28.78	0.20	6.57	0.26	0.88
		(1.6618)	(0.5870)	(1.4130)	(1.1753)	(0.2555)	(1.0652)	(0.2177)	(0.3799)
7	1.4305	28.09	2.43	32.69	28.72	0.23	6.58	0.26	1.01
		(1.6559)	(0.5927)	(1.4194)	(1.1801)	(0.2689)	(1.0596)	(0.2241)	(0.4284)
8	1.4322	28.09	2.42	32.68	28.70	0.23	6.57	0.26	1.05
		(1.6685)	(0.5904)	(1.4258)	(1.1919)	(0.2705)	(1.0621)	(0.2234)	(0.4227)
9	1.4326	28.07	2.43	32.66	28.68	0.24	6.59	0.27	1.06
		(1.6638)	(0.5948)	(1.4275)	(1.1926)	(0.2731)	(1.0692)	(0.2261)	(0.4229)
10	1.4329	28.06	2.43	32.65	28.68	0.24	6.60	0.28	1.05
		(1.6627)	(0.5943)	(1.4290)	(1.1914)	(0.2742)	(1.0730)	(0.2263)	(0.4229)

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Table 9.5: Variance Decomposition of Australia

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	0.9418	2.82	0.74	1.16	0.67	94.61	0	0	0
		(0.6850)	(0.4565)	(0.4921)	(0.3742)	(0.9267)	0.0000	0.0000	0.0000
2	1.1840	26.99	0.79	1.73	0.77	65.92	3.62	0.02	0.17
		(1.5877)	(0.3189)	(0.4654)	(0.2792)	(1.4233)	(0.6760)	(0.0500)	(0.1497)
3	1.1952	26.55	0.98	2.31	0.80	64.72	4.06	0.09	0.50
		(1.5602)	(0.4040)	(0.5819)	(0.3003)	(1.4366)	(0.6753)	(0.1503)	(0.2520)
4	1.1987	26.78	1.00	2.29	0.88	64.34	4.08	0.10	0.53
		(1.5381)	(0.4034)	(0.5894)	(0.3614)	(1.4845)	(0.6793)	(0.1800)	(0.2812)
5	1.2109	26.38	1.04	2.30	1.06	63.55	4.86	0.20	0.62
		(1.5267)	(0.4161)	(0.5916)	(0.4048)	(1.4637)	(0.8159)	(0.2556)	(0.3119)
6	1.2130	26.30	1.03	2.32	1.06	63.37	4.95	0.34	0.62
		(1.5425)	(0.4132)	(0.6083)	(0.4045)	(1.4518)	(0.8546)	(0.3197)	(0.3169)
7	1.2189	26.46	1.03	2.35	1.05	62.96	4.91	0.63	0.62
		(1.5161)	(0.4102)	(0.6019)	(0.4072)	(1.4306)	(0.8370)	(0.3934)	(0.3279)
8	1.2205	26.40	1.04	2.38	1.05	62.95	4.90	0.65	0.65
		(1.5084)	(0.4111)	(0.5981)	(0.4126)	(1.4389)	(0.8289)	(0.3922)	(0.3309)
9	1.2213	26.38	1.04	2.38	1.06	62.87	4.90	0.69	0.67
		(1.5072)	(0.4172)	(0.5982)	(0.4164)	(1.4395)	(0.8333)	(0.3981)	(0.3327)
10	1.2216	26.37247	1.04438	2.376974	1.069842	62.84243	4.920515	0.700969	0.672419
		(1.5061)	(0.4175)	(0.5974)	(0.4209)	(1.4445)	(0.8412)	(0.3993)	(0.3333)

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Table 9.6: Variance Decomposition of Hong Kong

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	1.2950	13.85	0.15	0.63	0.94	0.49	83.95	0	0
		(1.5421)	(0.1351)	(0.3447)	(0.3507)	(0.2965)	(1.5197)	0.0000	0.0000
2	1.3283	16.87	0.15	0.65	1.32	0.49	80.25	0.16	0.11
		(1.6802)	(0.1375)	(0.3476)	(0.4494)	(0.3119)	(1.7074)	(0.1947)	(0.1504)
3	1.3370	16.69	0.16	0.71	1.32	0.60	80.11	0.18	0.22
		(1.6734)	(0.1636)	(0.4011)	(0.4442)	(0.3462)	(1.7318)	(0.2127)	(0.2276)
4	1.3407	16.60	0.22	0.71	1.32	0.60	80.11	0.21	0.24
		(1.6754)	(0.2423)	(0.3935)	(0.4541)	(0.3565)	(1.7544)	(0.2155)	(0.2484)
5	1.3521	16.47	0.32	0.71	1.48	0.61	79.75	0.33	0.33
		(1.6919)	(0.3325)	(0.3925)	(0.5274)	(0.3625)	(1.7508)	(0.2686)	(0.2702)
6	1.3579	16.34	0.53	0.84	1.50	0.68	79.10	0.60	0.40
		(1.6728)	(0.3876)	(0.4371)	(0.5331)	(0.4092)	(1.7304)	(0.3344)	(0.2948)
7	1.3633	16.24	0.54	0.87	1.52	0.77	78.98	0.60	0.49
		(1.6528)	(0.3939)	(0.4355)	(0.5521)	(0.4289)	(1.7275)	(0.3457)	(0.3250)
8	1.3677	16.14	0.63	0.88	1.51	0.78	78.85	0.69	0.53
		(1.6450)	(0.4189)	(0.4387)	(0.5487)	(0.4282)	(1.7512)	(0.3844)	(0.3404)
9	1.3686	16.12	0.62	0.88	1.52	0.79	78.84	0.70	0.53
		(1.6441)	(0.4198)	(0.4423)	(0.5595)	(0.4327)	(1.7619)	(0.3930)	(0.3413)
10	1.3689	16.12	0.63	0.88	1.54	0.79	78.81	0.70	0.53
		(1.6439)	(0.4233)	(0.4442)	(0.5649)	(0.4361)	(1.7615)	(0.3965)	(0.3416)

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Table 9.7: Variance Decomposition of Japan

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	1.4777	2.67	0.02	1.05	0.16	8.44	0.04	87.61	0
		(0.6830)	(0.0865)	(0.4512)	(0.1973)	(1.2332)	(0.0831)	(1.3894)	0.0000
2	1.7492	19.06	0.05	1.55	0.16	7.76	5.74	65.64	0.03
		(1.3409)	(0.1087)	(0.4528)	(0.1577)	(1.0881)	(0.9519)	(1.5820)	(0.0819)
3	1.7807	18.56	0.13	1.96	0.17	7.54	6.21	64.99	0.44
		(1.3006)	(0.1603)	(0.5631)	(0.1621)	(1.0402)	(0.9159)	(1.5900)	(0.2556)
4	1.7867	18.53	0.14	1.95	0.24	7.49	6.33	64.88	0.45
		(1.2899)	(0.1701)	(0.5521)	(0.1976)	(1.0443)	(0.9511)	(1.5633)	(0.2755)
5	1.7959	18.37	0.57	1.97	0.24	7.44	6.48	64.22	0.71
		(1.2655)	(0.3455)	(0.5799)	(0.1994)	(1.0188)	(0.9827)	(1.5743)	(0.3592)
6	1.7985	18.32	0.57	2.03	0.24	7.47	6.49	64.11	0.77
		(1.2519)	(0.3535)	(0.5938)	(0.2267)	(1.0131)	(0.9890)	(1.5678)	(0.4155)
7	1.8005	18.31	0.58	2.03	0.24	7.61	6.49	63.98	0.77
		(1.2386)	(0.3662)	(0.5990)	(0.2402)	(1.0055)	(0.9827)	(1.5623)	(0.4165)
8	1.8017	18.30	0.58	2.05	0.25	7.64	6.51	63.90	0.78
		(1.2349)	(0.3653)	(0.6109)	(0.2536)	(1.0078)	(0.9832)	(1.5553)	(0.4222)
9	1.8021	18.29	0.59	2.05	0.25	7.64	6.52	63.88	0.78
		(1.2343)	(0.3703)	(0.6121)	(0.2552)	(1.0076)	(0.9826)	(1.5569)	(0.4224)
10	1.8024	18.29	0.59	2.05	0.25	7.64	6.52	63.87	0.78
		(1.2327)	(0.3707)	(0.6113)	(0.2555)	(1.0079)	(0.9862)	(1.5579)	(0.4224)

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Table 9.8: Variance Decomposition of India

Period	*S.E.*	*D(VIX)*	*D(VIXC)*	*D(V2TX)*	*D(VFTSE)*	*D(A-VIX)*	*D(VHSI)*	*D(VXJ)*	*D(IVIX)*
1	0.9318	5.51	1.09	3.34	0.86	0.81	0.96	0.66	86.77
		(1.0836)	(0.5150)	(0.7570)	(0.4285)	(0.3882)	(0.3972)	(0.3744)	(1.4694)
2	0.9930	11.14	0.98	3.03	0.84	0.80	5.48	0.66	77.05
		(1.4311)	(0.4850)	(0.6814)	(0.4253)	(0.3556)	(0.9556)	(0.3622)	(1.7224)
3	1.0000	10.99	1.25	3.12	0.93	0.80	5.41	0.76	76.72
		(1.4166)	(0.5112)	(0.7194)	(0.4332)	(0.3667)	(0.9484)	(0.4204)	(1.7251)
4	1.0028	11.11	1.26	3.12	0.96	0.80	5.52	0.88	76.35
		(1.4553)	(0.5191)	(0.7223)	(0.4486)	(0.3753)	(0.9649)	(0.4492)	(1.7833)
5	1.0077	11.05	1.26	3.16	1.13	0.83	6.06	0.89	75.63
		(1.4593)	(0.5189)	(0.7267)	(0.4985)	(0.3887)	(0.9994)	(0.4660)	(1.7982)
6	1.0094	11.01	1.27	3.23	1.30	0.86	6.05	0.90	75.38
		(1.4501)	(0.5230)	(0.7509)	(0.5731)	(0.4024)	(0.9968)	(0.4853)	(1.8656)
7	1.0126	11.01	1.27	3.42	1.33	0.85	6.03	1.15	74.94
		(1.4447)	(0.5249)	(0.7674)	(0.5745)	(0.4089)	(0.9870)	(0.5289)	(1.8779)
8	1.0131	11.00	1.28	3.43	1.38	0.85	6.03	1.15	74.88
		(1.4335)	(0.5282)	(0.7680)	(0.5884)	(0.4104)	(0.9934)	(0.5289)	(1.8866)
9	1.0134	10.99	1.28	3.43	1.37	0.85	6.05	1.18	74.84
		(1.4323)	(0.5264)	(0.7703)	(0.5892)	(0.4104)	(1.0041)	(0.5332)	(1.8913)
10	1.0136	10.99	1.28	3.44	1.38	0.85	6.05	1.19	74.82
		(1.4325)	(0.5264)	(0.7711)	(0.5898)	(0.4108)	(1.0044)	(0.5340)	(1.8947)

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In the global context, the findings from the study reveal that the U.S. is the leading source of uncertainty among the global markets in the post global crisis period, similar to the findings of the previous studies conducted during the pre-crisis and crisis period by Aboura (2003), Nikkinen and Sahlström (2004), Jiang et al. (2012), Padhi (2011), Kumar SSS (2012), Ding and Huang (2014) and Thakolsri et al. (2016) who have established U.S. as the influential index. Another key finding from this stidy is that Hong Kong is the influential volatility index next to the U.S. across the global markets which also influences the U.S. market.

CONCLUSIONS

The advent of globalization and financial liberalization has led to the interconnectedness of financial markets across the globe. The uncertainty or turmoil in one market is reflected in other markets in short span of time and the global crisis stands as an exemplar for this. Several studies has documented that the U.S. financial market is the dominant market and influences the other markets during the pre-crisis and crisis period. The global financial crisis which lasted from 2007 to 2011 had a severe impact on global markets. In this context, this paper was set to examine the transmission of market uncertainty across global markets and the influence of the U.S. market on these global markets during the post crisis period. Eight key American, European, Australian and Asian markets namely were chosen for the study and transmission of market uncertainty from the U.S. and among these markets were analyzed using the volatility indices.

The study revealed several interesting facts. First, the Pearson correlation analysis revealed the existence of strong relationship between the American and the European markets and also with Hong Kong from the Asian market and weak relationship between India and Japanese markets. Second, in the VAR framework, granger causality tests revealed that the U.S. was the leading source of volatility transmission among the select global markets and Hong Kong was the next leading source of volatility transmission in the global scenario. The impulse response analysis showed that the shock in innovations in the U.S. market had impact in its own market and other global markets and the shock in innovations in Hong Kong market had marginal impact on all the global markets. The shock in Hong Kong market had impact on the U.S. market. Finally, the variance decomposition analysis revealed that forecast variance of the U.S. market was solely caused by innovations from its own source and from Hong Kong market. Similarly the forecast variance of the Hong Kong index was caused by its own innovations and marginally from the U.S. However, in case of other global markets the forecast variance was due to its own innovations and marginally from the U.S. and Hong Kong markets. The results from this study corroborate that the U.S. market is main source of market uncertainty to the global markets. An interesting finding from the study is that Hong Kong market is found to be the next influential market in the global scenario.

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The financial markets have expanded from the domestic to the global dimension. Many countries are now showing keen interests in the financial markets of other countries and are also making investments on a global scale. Along with multinational organizations, other business enterprises are also being the part of global economic competition. The global crisis has also generated a lot of fear and anxiety among a growing number of international investors. Along these lines, this paper provides contribution to international investors, portfolio managers and business enterprises by investigating the transmission of financial market uncertainty across key global markets for taking decisions on investments and diversification.

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