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Return and volatility spillover across equity markets between China and Southeast Asian countries

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Abstract

Purpose – This paper aims to study the daily returns and volatility spillover effects in common stock prices between China and four countries in Southeast Asia (Vietnam, Thailand, Singapore and Malaysia).

Design/methodology/approach – The analysis uses a vector autoregression with a bivariate GARCH-BEKK model to capture return linkage and volatility transmission spanning the period including the pre- and post-2008 Global Financial Crisis.

Findings – The main empirical result is that the volatility of the Chinese market has had a significant impact on the other markets in the data sample. For the stock return, linkage between China and other markets seems to be remarkable during and after the Global Financial Crisis. Notably, the findings also indicate that the stock markets are more substantially integrated into the crisis.

Practical implications – The results have considerable implications for portfolio managers and institutional investors in the evaluation of investment and asset allocation decisions. The market participants should pay more attention to assess the worth of across linkages among the markets and their volatility transmissions. Additionally, international portfolio managers and hedgers may be better able to understand how the volatility linkage between stock markets interrelated overtime; this situation might provide them benefit in forecasting the behavior of this market by capturing the other market information.

Originality/value – This paper would complement the emerging body of existing literature by examining how China stock market impacts on their neighboring countries including Vietnam, Thailand, Singapore and Malaysia. Furthermore, this is the first investigation capturing return linkage and volatility spill over between China market and the four Southeast Asian markets by using bivariate VAR-GARCH-BEKK model. The authors believe that the results of this research's empirical analysis would amplify the systematic understanding of spillover activities between China stock market and other stock markets.

Keywords Financial crisis, Emerging market, Stock markets, Volatility spillover, GARCH-BEKK

Paper type Research paper

1. Introduction

The increasingly improving role of Chinese financial market in the world economy, especially in Asia, has recently attracted great attention to the problem of volatility

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spillovers (Wang and Wang, 2010; Yarovaya *et al.*, 2016). The globalization and financial liberalization become an evident trend worldwide and more correlated and connected than ever before. Therefore, to systematically understand the connectedness and correlation among different financial markets is significant for investors, financial institutions and governments (Zhou *et al.*, 2012). Moreover, emerging markets have been popular destination for international portfolio investors looking for obtaining diversification benefits (Xuan Vinh and Ellis, 2018). Specifically, the process of increased financial integration has been followed by a growing trend of international and regional trade agreements among countries (Balli *et al.*, 2015).

It is true that in the context of the literature, the volatility spillover can be divided into three fundamental points: first, a bidirectional volatility spillover among stock markets; second, a unidirectional flow of volatility from a stock market to another stock market and vice versa; third, non-persistence of the volatility spillover among them (Ngo Thai Hung, 2018). Early studies predominantly centered on the connectedness among the financial markets of developed countries. For example, Hamao *et al.* (1990) pointed out price volatility transmissions from New York to London and Tokyo, London to Tokyo. In a same vein, Koutmos and Booth (1995) demonstrated that negative innovations in three developed markets (New York, Tokyo and London) increase volatility in the next market to trade more than positive innovations do.

In the past 20 years, with ever-increased importance of emerging markets, the interaction between emerging and developed markets has been attracted by financial economists because of its meaning to global integration and financial liberalization. Many papers have empirically studied the co-movement of stock prices across international financial markets, for instance, Bekaert and Harvey (1997), Ng (2000), Jebran *et al.* (2017), Joshi (2011), Jin and An (2016), Gupta and Guidi (2012), Al Nasser and Hajilee (2016) and Balli *et al.* (2015).

Acknowledging the growing impact of China stock market on the region, Mohammadi and Tan (2015) examined the dynamics of daily returns and volatility in stock markets of the USA, Hong Kong and mainland China over January 2001 to February 2013 employing specifications of multivariate GARCH-types model (CCC-DCC-VAR-GARCH-BEKK). Their results confirmed that there existed the unidirectional spillover in returns and volatility from the US to the other three markets, while correlations between mainland China and other markets were relatively significant. At the same time, Li and Giles (2015) conducted an examination of the linkages of stock markets across the USA, Japan and six Asian developing countries: China, India, Indonesia, Malaysia, the Philippines and Thailand over the period January 1993 to December 2012. The methodology of this paper was like Mohammadi and Tan (2015). The findings also revealed that significant unidirectional shock and volatility spillovers from the US market to both the Japanese and the Asian emerging markets. More importantly, the authors pointed out that the influence of China stock market on the Japanese Stock Market was more apparent.

In the context of Asian equity markets, Yilmaz (2010) applied the spillover index methodology proposed by (Diebold and Yilmaz, 2009) to measure returns and volatility spillovers in East Asia. This paper reported that there was a substantial difference between the behavior of the East Asian return and volatility spillover indices over time during the crisis and non-crisis episodes. This work also found that the burst in volatility spillovers across markets outweighed the return spillovers. Engle *et al.* (2012) modeled the interrelations of equity market volatility in eight East Asian countries before, during, and after the Asian currency crisis by applying a new class of asymmetric volatility multiplicative error models based on the daily data. The paper documented that dynamic propagation of volatility innovations occurred through a network of interdependencies. Furthermore, Jebran *et al.* (2017) investigated the volatility transmission among Asian emerging markets in pre- and post-2007 financial crisis period for five selected countries, namely, China, Pakistan, Hong Kong, Srilanka and India. Based on multivariate EGARCH model, the results showed bidirectional volatility spillover between stock markets of India and Sri Lanka in both sub-periods. Importantly, there was unidirectional volatility spillover from China to the rest of other countries in the post-crisis period. Moreover, this paper also highlighted the asymmetric volatility spillover among the stock markets. Similarly, Nath and Mishra (2010) used GARCH model to study stock market integration and volatility spillover between India and its major Asian counterparts and found that contemporaneous intraday return spillovers between India and its Asian counterparts were positively significant and bi-directional. The four Asian markets of Hong Kong, Korea, Singapore and Thailand were where there was a significant flow of market information to India. Xuan Vinh and Ellis (2018) carried out the investigation of the interdependence between Vietnamese stock market and advanced equity stock markets in terms of return linkage and volatility spillover spanning the pre and post the 2008 global financial crisis. The returns and volatility spillovers between Vietnam and developed countries were statistically significant by using VAR-GARCH-BEKK models.

According to Kim *et al.* (2015), China was one of the most influential economies among Asian countries, so the issue of stock market co-movement between China and other international stock markets has attracted the attention from academic researchers and practitioners in recent years. Nishimura and Men (2010) studied volatility spillover effects in common stock prices between China and G5 countries using EGARCH model. As per Wang and Wang (2010), their research concentrated on return and volatility spillover effects between Greater China and the US and Japan by using the daily opening and closing stock prices of stock indices from July 1992 to May 2004. The volatility transmission was estimated based on the frameworks of GIR-BEKK-GARCH model. Regarding volatility spillovers, significantly strong effects were reported between the Greater China markets and the developed markets of the US and Japan, while the dominance effect of developed markets over developing markets was not significant. At the same time, Moon and Yu (2010) estimated volatility spillovers between the U.S and China stock market using Structural Break Test. In another study, Zhou *et al.* (2012) measured the directional volatility spillovers between Chinese and world equity markets based on volatility index proposed by Diebold and Yilmaz's (2011).

Given this background, the primary objective of the paper is to estimate the nature of returns and volatility transmissions between China stock market and the four stock markets in Southeast Asia namely, Vietnam, Thailand, Singapore and Malaysia. In financial literature, there are many various kinds of methodologies to capture volatility spillovers across countries. However, this is the first study using VAR framework and GARCH-BEKK model to examine the return and volatility spillover between China stock market and the four stock markets in Southeast Asia. To capture volatility transmissions, exponential GARCH model is employed because it is capable of explicitly capturing asymmetries (Kumar, 2013). Apart from spillover index proposed by Diebold and Yilmaz (2009), multivariate GARCH model has been applied in many papers concerned about the estimates of volatility spillover in recent years. For example, Erten *et al.* (2012) analyzed the presence and magnitude of the volatility transmissions in emerging markets, Liu (2016) examined volatility effects in major equity markets, Li and Giles (2015) modeled volatility spillover effects between developed stock market and Asian emerging stock markets. MacDonald *et al.* (2018) explored volatility co-movements and spillover Effects within Eurozone Economies. Moreover, GARCH-BEKK model has the capability to analyze the return, volatility linkage and volatility spillover effects (Kumar, 2013). Therefore, this paper would complement the emerging body of existing literature by examining how China stock market impacts on their neighboring countries. We believe that the results of this research's empirical analysis would amplify the systematic understanding of spillover activities between China stock market and other stock markets.

The rest of the paper is organized as follows: Sections 2 and 3 specify the model used in this study and the descriptive analysis of the data. In Section 4, we present our empirical results. Finally, Section 5 concludes and brings out the implications.

2. Methodology

2.1 Vector autoregressive model

To examine the possibility of spillovers in returns over time and across different markets, we use the VAR models to find out the strength and sign of cross-correlation between returns. In this paper, bivariate VAR models with two lags are used to estimate interrelationships between the returns of the China market and other indices. These VAR equations can be written as:

$$r_{china,t} = a + b_1 r_{china,t-1} + b_2 r_{china,t-2} + c_1 r_{vietnam,t} + \varepsilon_t \quad (1)$$

$$r_{china,t} = a + b_1 r_{china,t-1} + b_2 r_{china,t-2} + c_1 r_{thailand,t} + \varepsilon_t \quad (2)$$

$$r_{china,t} = a + b_1 r_{china,t-1} + b_2 r_{china,t-2} + c_1 r_{singapore,t} + \varepsilon_t \quad (3)$$

$$r_{china,t} = a + b_1 r_{china,t-1} + b_2 r_{china,t-2} + c_1 r_{malaysia,t} + \varepsilon_t \quad (4)$$

where $r_{china,t}$, $r_{thailand,t}$, $r_{singapore,t}$, $r_{malaysia,t}$ and $r_{vietnam,t}$ are the stock index returns of China, Thailand, Singapore, Malaysia and Vietnam respectively.

2.2 BEKK-GARCH model

The study of volatility interdependence between the China stock market and the four Southeast Asian stock markets is carried out by employing the BEKK-GARCH model proposed by Engle and Kroner (1995). For the model allows the interaction among conditional variances and covariance, the positive conditional covariance matrix is generated, and it renders significant parameter reduction in the estimation.

$$R_t = \alpha \Gamma R_{t-1} + u_t \quad (5)$$

$$u_t|\Omega_{t-1} \sim N(0, H_t) \quad (6)$$

Where the return vector for the stock market variables is given by $R_t = [R_{1,t}, R_{2,t}]$, the vector of the constant is α which presents 5×1 vector. The residual vector, $u_t = [\varepsilon_{1,t}, \varepsilon_{2,t}]$, is bivariate and a conditional normal distribution. Ω_{t-1} is the market information set available at time t − 1. H_t represents the conditional covariance matrix and is a function of lagged cross products of errors.

Suppose for bivariate GARCH model, the covariance matrix $H_{ij,t} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$, its BEKK model as follows:

$$H_t = C'C + A'\varepsilon\varepsilon' A_{11} + B'H_{t-1}B \tag{7}$$

$$\begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} = \begin{bmatrix} c_{11,t} & c_{12,t} \\ c_{21,t} & c_{22,t} \end{bmatrix}' \begin{bmatrix} c_{11,t} & c_{12,t} \\ c_{21,t} & c_{22,t} \end{bmatrix} + \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon^2_{1,t-1} & \varepsilon_{1,t-1}, \varepsilon_{2,t-1} \\ \varepsilon_{2,t-1}, \varepsilon_{1,t-1} & \varepsilon^2_{2,t-1} \end{bmatrix} \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} + \begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix}' \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix} \tag{8}$$

where C is the 2 × 2 upper triangular matrices. Matrix A reflects ARCH effect of volatility, the element of α_{ij} indicates the impact of market i volatility on market j. On the other hand, matrix B is related to GARCH effect of volatility, the elements of β_{ij} shows the persistence of volatility spillover between market i and market j.

To estimate the BEKK-GARCH parameters under the assumption of normally distributed random errors, Quasi Maximum Likelihood is applied. The Quasi Maximum Likelihood function of Bollerslev and Wooldridge (1992) has the following form:

$$L(\theta) = -Tn/2 + \ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\left(\ln|H_t| + \varepsilon'|\frac{1}{H_t}|\varepsilon_t\right) \tag{9}$$

where T is the number of observations, n is the number of markets, and θ is the vector of estimated parameters.

Our aim of the investigation is to estimate the above models to study the nature of volatility spillover between stock market returns. Therefore, α and β parameters are our interest.

3. Data

Our sample comprises the daily closing price of the Chinese, Vietnamese, Singapore, Thailand and Malaysian indices, abbreviated as SSE (the Shanghai Stock Exchange Composite Index), VNI (Vietnam Ho Chi Minh Stock Index), STI (the Straits Times Index), SET (Thai composite stock market index), KLCI (Kuala Lumpur Composite Index), respectively. All the time series data have been obtained from Bloomberg. The five stock indices span 28 July 2000 to 31 July 2018. The sample is divided into two groups. The first covers the pre-global finance crisis period from 28 July 2000 to 29 August 2008 and the second period is the post-global finance crisis period from 3 September 2008 to 31 July 2018. The whole period in the present study divides into pre and post global financial crisis period on the basics of certain justifications. Because the countries have different trading days, we synchronized the data by omitting non-overlapping trading days. The reason for choosing daily data is to capture more the precise information content of changes in stock prices than doing with weekly or monthly data (Jebran and Iqbal, 2016; Ngo Thai Hung, 2018), and better able to capture the dynamics between variables (Agrawal *et al.*, 2010). These indices were matched in pairs of two with a total of four pairs: China–Vietnam, China–Thailand, China–Singapore, China–Malaysia. In addition, we concentrate on Southeast Asian markets only because they are Asian emerging stock markets (Li and Giles, 2015) except for Singapore known as developed stock market (Yarovaya *et al.*, 2016), and with their rapidly developing financial markets, these nations started to play an increasingly influential role in the global financial system (Yilmaz, 2010).

Table I presents the results of the descriptive statistics, unit root test and ARCH test for the pre- and post-crisis periods, respectively. The analyses show that sample means of stock return are positive and significantly different from zero in these countries for both sub-periods. The daily returns of Thailand and Singapore in the post-crisis period are smaller than in the pre-crisis period, while Vietnam, China and Malaysia are the opposite. The unconditional variance, as measured by standard deviations, indicates that the volatility in selected countries decreases in the post-crisis period. Before the crisis, Vietnam has the highest standard deviation. All return

	Thailand	Malaysia	China	Singapore	Vietnam
Panel A. Pre-crisis period					
Mean	0.0531	0.0199	0.0109	0.0176	0.1050
Median	0.0396	0.0502	0.0649	0.0616	0.0126
Maximum	10.5770	5.2615	12.2045	7.0487	13.8823
Minimum	−16.0632	−9.9785	−9.2560	−8.4188	−13.5265
Std. Dev	1.5745	1.0619	1.8293	1.3334	1.9549
Skewness	−0.9496	−1.2733	0.0496	−0.0973	−0.1323
Kurtosis	16.3235	16.5741	7.2779	7.3775	10.3587
Jarque–Bera	12,105.1*	12,747.9*	1,223.7*	1,283.2*	3623.8*
PP test	−38.4577*	−34.8895*	−40.5730*	−39.6738*	−31.2176*
ADF test	−38.4460*	−20.6234*	−40.5711*	−39.6728*	−13.5825*
ARCH test	112.6754*	93.3924*	20.398*	40.4978*	63.5786*
Observations	1,604	1,604	1,604	1,604	1,604
Panel B. Post-crisis period					
Mean	0.0453	0.0234	0.0110	0.0096	0.0256
Median	0.0846	0.0395	0.0716	0.0260	0.0955
Maximum	7.5487	4.7227	9.0344	9.2451	9.8187
Minimum	−10.0994	−5.1242	−8.9058	−12.9278	−8.2822
Std. Dev	1.2623	0.7198	1.6317	1.1738	1.5030
Skewness	−0.5944	0.0074	−0.5349	−0.2422	−0.2460
Kurtosis	10.3381	10.2238	7.7807	18.3086	6.000
Jarque–Bera	4,890.6*	4,618.2*	2,124.0*	20,761.0*	818.2*
PP test	−42.691*	−40.029*	−44.214*	−43.884*	−39.124*
ADF test	−42.664*	−40.179*	−44.216*	−43.887*	−38.954*
ARCH test	220.8008*	39.8115*	104.4249*	180.475*	141.078*
Observations	2,124	2,124	2,124	2,124	2124

Notes: *Denotes significance at the 1% level. All returns are expected in percentages. ADF and PP test represent the augmented Dickey and Fuller test and Phillips Perron test of stationarity respectively. ARCH test is employed to test the presence of ARCH effect in data sets

Table I.
Descriptive statistics of index returns

series are highly leptokurtic with respect to the normal distribution during both periods, this is formally confirmed by The Jarque–Bera test statistics, which rejects the null hypothesis of normal distribution for all series. For stationarity of the data, we attempt to confirm that the return series are found to be stationary at level (i.e. I(0)) at the 1 per cent significance level according to the PP and ADF statistics for both sub-periods. Similarly, the null hypothesis of no ARCH effect is rejected. The existence of ARCH effect indicates that GARCH-BEKK models can be perfectly captured the price volatility interaction between financial markets.

The raw series are plotted in Figure 1 where stock market returns in five countries fluctuate before and after crisis period. We can see that all five stock markets follow the same movements over the study period.

We report the sample correlations for all markets in Table II. The highest correlation is between Thailand and Singapore in the post-crisis period (0.5903), while between Vietnam and Singapore is the lowest (0.0013) in the pre-crisis period. Overall, we observe that the correlation coefficients between financial markets are higher during the post-crisis period in

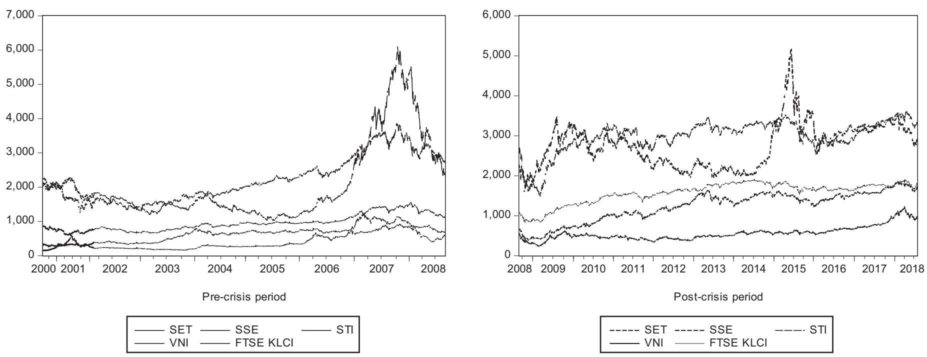

Figure 1. Plots of daily stock prices. SSE, Shanghai Stock Exchange; SET, Stock Exchange of Thailand; STI, Singapore index; FTSE KLCI, Kuala Lumpur Composite Index; VNI, Vietnam Index

Source: The author

Table II. Correlation matrix between index returns

	China	Thailand	Malaysia	Singapore	Vietnam
Pre-crisis					
China	1				
Thailand	0.1118	1			
Malaysia	0.1584	0.3705	1		
Singapore	0.1487	0.4190	0.4559	1	
Vietnam	0.0605	0.0123	0.0217	0.0013	1
Post-crisis					
China	1				
Thailand	0.2763	1			
Malaysia	0.2846	0.5017	1		
Singapore	0.3457	0.5903	0.5853	1	
Vietnam	0.1570	0.2041	0.2593	0.2140	1

Source: The author

comparison with the pre-crisis period. This means that the financial stock markets become more integrated after crisis period.

4. Results

4.1 Return spillovers between China and other stock markets

The return transmissions are analyzed using a VAR(2) model, where the lag length of two is selected by the Schwarz information criterion. Parameters estimate for the bivariate-VAR in the pre- and post-crisis respectively are presented in Table III. Overall, we find that the China stock market has a substantial impact on the four of Southeast Asian Countries in our data sample. Mostly, return spillovers from China to the four countries have a reverse effect when we make a comparison between the pre- and post-crisis period. Specifically, we observe that the stock return linkage between China and other stock markets seems to be negative after the global financial crisis. The result of return transmissions between China and other stock markets is consistent with Moon and Yu (2010).

Figure 2 plots the impulse response functions of returns from the China market to shocks in other markets along with their 95 per cent confidence bounds. Considering the signs of responses, in the pre-crisis period, innovations to China market have a positive impact on the four financial markets, while in the post-crisis period, shocks to financial stock exchange in China have a negative influence on the rest of the stock markets in the short run, and the effect of the shock equals zero in the long run periods. Briefly, the impulse response functions reveal a similar trend of price information across stock markets, which is consistent with the efficient operation of the market.

4.2 Volatility spillovers between China and other stock markets

Volatility spillover between China and other selected equity markets are examined employed the dynamic conditional GARCH-BEKK model. The estimation results for the BEKK model are reported in Table IV. Here, $\alpha(\mathrm{i},\mathrm{i})$ and $\beta(\mathrm{i},\mathrm{i})$ are the corresponding ARCH and GARCH parameters associated with market i. The squared ARCH parameters $[\alpha(\mathrm{i},\mathrm{i})]^2$captures the responses of volatility in market i to squared standardized innovations in pairs of China and the four countries. Similarly, the squared GARCH parameters $\beta(\mathrm{i},\mathrm{i})$ capture the responses of volatility in market i to past volatility in pairs of China and the four countries (Mohammadi and Tan, 2015). According to Xuan Vinh and Ellis (2018), it is crucial to pay attention to the conditional variances and conditional covariances when representing the diagonal elements of the GARCH-BEKK model.

The ARCH effects illustrate that all diagonal elements $\alpha(1,1)$, $\alpha(2,2)$ are statistically significant for both sub-periods, suggesting that each conditional variance depends on its own squared lagged innovations, this means that the volatility of China stock market is strongly dependent on past its own innovations (ARCH effects). Additionally, the small size of ARCH coefficient estimates reveals that conditional volatility has not been able to change dramatically under the impulsions of returns innovation (Xuan Vinh and Ellis, 2018). The findings show that the parameter estimates of α_{12} are statistically significant for Thailand, Singapore and Malaysia. The past shocks of the China stock market affect the present volatility of stock returns in Thailand, Singapore before and after the global crisis. For Malaysia, the past shocks of the China stock market have a significant impact only during the post period. This implies that the increase in the innovation of the China

Table III.
Bivariate VAR model

Parameter	Pre-crisis			
	Vietnam	Singapore	Thailand	Malaysia
China (−1)	0.0533* (0.0255) [2.0916]	−0.0084* (0.0184) [−0.4580]	−0.0064* (0.0215) [−0.2991]	0.0064* (0.0145) [0.4415]
China (−2)	−0.015460 (0.02556) [−0.60485]	−0.0177 (0.0184) [−0.9642]	−0.0110 (0.0215) [−0.5142]	0.0117 (0.0145) [0.8079]
Constant	0.074764 (0.04670) [1.60086]	0.0166 (0.0333) [0.5002]	0.0481 (0.0392) [1.2277]	0.01808 (0.0263) [0.6871]

Note: *Denotes significance at the 0.05 level

(*continued*)

Parameter			Post-crisis	
	Vietnam	Singapore	Thailand	Malaysia
China (−1)	0.0343* (0.0199) [1.7194]	−0.0470* (0.0166) [−2.8339]	−0.0433* (0.0174) [−2.4878]	−0.0103* (0.0099) [−1.0389]
China (−2)	−0.0091 (0.0199) [−0.4568]	0.0646 (0.0166) [0.3890]	0.0249 (0.0174) [1.4302]	−0.0001 (0.0099) [−0.01645]
Constant	0.0225 (0.0321) [0.7008]	0.01145 (0.0253) [0.4515]	0.0409 (0.0273) [1.4995]	0.0208 (0.0155) [1.3479]

Table III.

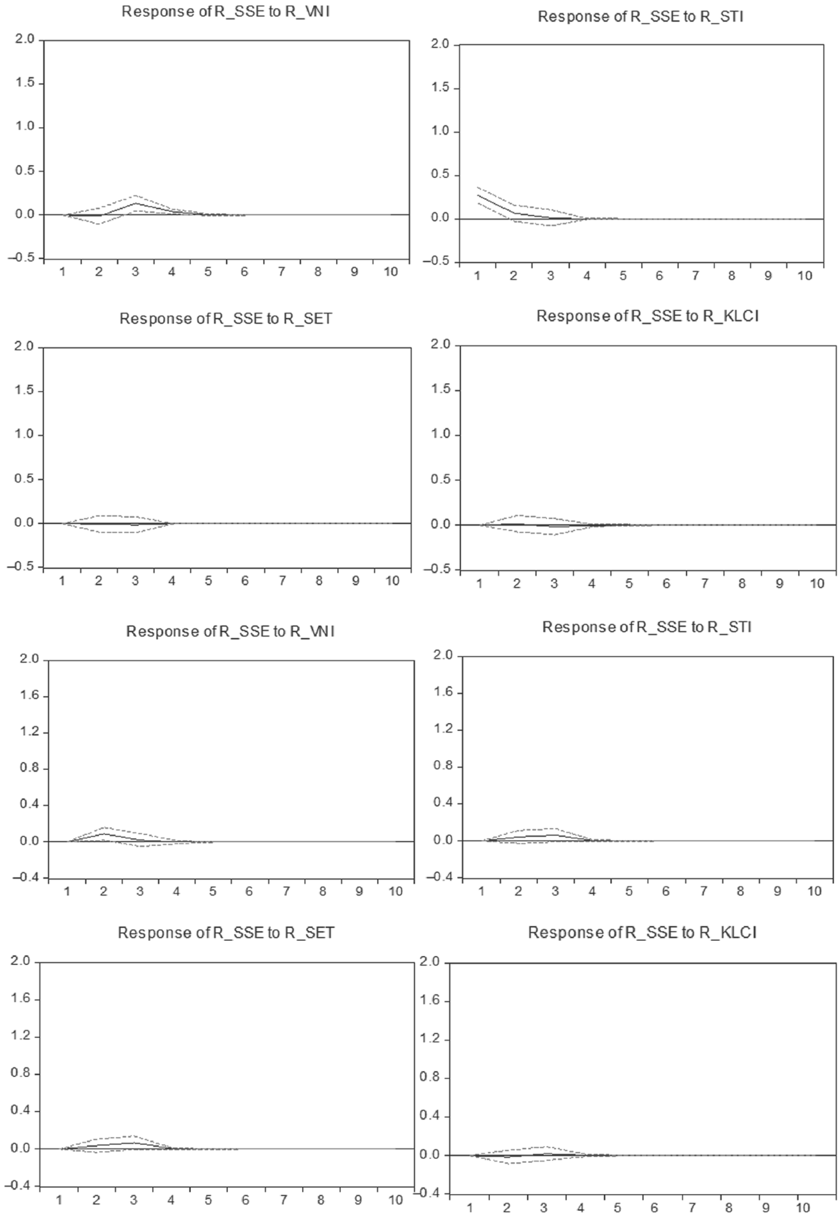

Figure 2.
Impulse response functions

Source: The author. Response to Cholesky One S.D. innovation ± 2 S.E. Pre-crisis period. Post-crisis period

Table IV. Parameters estimates of diagonal BEKK model

	China-Vietnam		China-Thailand		China-Singapore		China-Malaysia	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Conditional Mean								
μ_1	0.015	0.012	0.026	0.011	0.007	0.008	0.023	−0.010
μ_2	−0.016	0.053**	0.110**	0.073*	0.059**	0.033***	0.036**	0.041*
Conditional Variance								
c_{11}	0.156*	0.096*	0.217*	0.082*	0.303*	0.086*	0.312*	−0.009
c_{21}	0.158	0.125*	−0.011	0.008	−0.016	−0.004	0.005	0.136*
c_{22}	−0.170	0.144*	0.749*	0.121*	0.166*	0.095*	0.071*	0.0004
α_{11}	0.192*	0.191*	0.291*	0.198*	0.380*	0.204*	0.371*	0.166*
α_{12}	−0.018	−0.021	−0.105*	−0.030**	−0.035**	−0.022***	−0.023	−0.067*
α_{21}	−0.003	0.052*	0.007	0.023	−0.011	0.005	−0.042	0.155*
α_{22}	0.607*	0.339*	0.392*	0.316*	0.268	0.258*	0.216*	0.395*
β_{11}	0.976*	0.980*	0.952*	0.980*	0.918*	0.977*	0.919*	0.987*
β_{12}	−0.019***	0.006	0.044*	0.010*	0.016**	0.007**	0.009***	0.018*
β_{21}	0.021**	−0.022*	−0.005	−0.010	0.003	−0.001	0.008	−0.057*
β_{22}	0.837***	0.935*	0.781*	0.944*	0.953*	0.959*	0.973*	0.895*
Diagnostic test								
Q(20)	72.278 (0.000)	15.650 (0.738)	29.265 (0.082)	19.562 (0.485)	29.974 (0.070)	14.99 (0.776)	29.453 (0.079)	12.372 (0.902)
QS(45)	68.37 (0.013)	57.33 (0.102)	81.46 (0.0001)	41.02 (0.641)	62.87 (0.040)	65.73 (0.023)	45.30 (0.459)	38.38 (0.746)

Notes: *, ** and *** represent the levels of significance of 1%, 5% and 10% respectively. Q(20) denotes the 20th order Ljung Box test and QS(45) denotes the 45th order McLeod-Li test. Numbers in parentheses are probability stock market changes the volatility of stock returns in Thailand, Singapore and Malaysia. As the opposite direction, the past shocks of Vietnam and Malaysia have a significant impact on the conditional volatility of China stock market returns.

Furthermore, the results point out strong GARCH effects. The GARCH effects illustrate three patterns: First, all conditional variances depend on their own history during study periods, namely β_{11}, β_{22} GARCH parameters, which are all statistically significant at 5 per cent level. The China stock market reveals a sharp increase in the coefficients of own volatility during the post period. The results imply that own transmissions are always much larger than the cross-market spillovers (Mohammadi and Tan, 2015). Second, we find a unidirectional volatility spillover from China to Thailand, Singapore and Malaysia in both periods, to Vietnam in the pre-crisis period. Third, there is a volatility spillover from Vietnam to China in both periods and from Malaysia to China in the post-crisis period.

In summary, we find that there is strong evidence of volatility spillovers from China to the four Southeast Asian Countries for both sub-periods. Likewise, the GARCH and ARCH effects are strong in the Vietnam, Thailand, Singapore and Malaysia equity market indices.

Our finding of return spillovers between China and other stock markets is consistent with Wang and Wang (2010) who finds that volatility spillovers are stronger than price spillovers between China markets and the developed markets of the US and Japan. Similarly, this finding shares with Li and Giles (2015).

The last rows of Table IV report diagnostic tests. Namely, the Ljung-Box and the McLeod-Li statistics are used to test the null hypothesis of no serial correlation and the conditional heteroscedasticity ARCH effects on the standardized residuals respectively. Q(20) is the Liung-Box test of the serial interdependence of 20th order. We fail to reject the null hypothesis in all cases in the post-crisis period. Similarly, QS (45) is the McLeod-Li test of serial interdependence in the squares of standardized residuals. We fail to reject the null hypothesis in most cases except China-Thailand in the pre-crisis period. This means that there is strong evidence of no ARCH effect in the model. These results provide some indications of good specification in the VAR-GARCH-BEKK model.

5. Conclusion

This paper investigates the returns and volatility spillovers between China and four Southeast Asian stock markets using bivariate GARCH-BEKK model for the pre- and post-global financial crisis periods.

Overall, the findings regarding the volatility spillover posit that China stock market has strong impact on the four Southeast Asian stock markets in our data sample. For the stock return, linkage between China and other markets seems to be remarkable during and after global financial crisis. This result tallies with Jebran *et al.* (2017). Moreover, the results present that in comparison with pre-crisis period, the volatility spillover is less apparent during the sub-prime crisis. The findings suggest that there exists significant unidirectional volatility spillover from China stock market to Vietnam, Thailand, Singapore and Malaysia during the sub-prime crisis, which supports Zhou *et al.* (2012).

Our results have considerable implications for portfolio managers and institutional investors in the evaluation of investment and asset allocation decisions. The market participants should pay more attention to assess the worth of across linkages among the markets as well as their volatility transmissions. Investors will increase in the level of anxiety owning to a high level of volatility in stock market, so they might become more risk-adverse. More importantly, Singhal and Ghosh (2016) suggest that investors tend to diversify their investment portfolio and hedging to maximize returns and minimize risks.

The findings also have relevant implications for policymakers in the context of the stock market in China and the neighboring countries. Particularly, international portfolio managers and hedgers may be better able to understand how the volatility linkage between stock markets interrelated overtime; this situation might provide them benefit in forecasting the behavior of this market by capturing the other market information. Moreover, globalization and financial integration is the outgoing trend to promote further international connectedness (Xuan Vinh and Ellis, 2018).

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