MEASURING VOLATILITY SPILLOVERS BETWEEN DEVELOPED AND SOUTHEAST ASIAN EMERGING STOCK MARKETS: A MULTIVARIATE GARCH APPROACH

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Abstract

In this paper, we measure volatility spillovers among eleven stock markets, including five developed markets (the United States, Japan, Germany, the United Kingdom, Hong Kong) and six Southeast Asian developing markets (Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam) over the 25-year period from January 1, 1993 to December 31, 2017. Employing the GARCH-DCC model and non-parametric sign tests on the correlations between developed markets and emerging markets, we find that correlations between developed markets and the Southeast Asian markets have risen sharply during periods of crisis, indicating the existence of volatility spillover effects from the developed markets to emerging ones. Full sample analysis suggests that volatility spillover from Japanese and the UK markets to the Southeast Asian emerging markets is stronger and more apparent than those transmitted from the US and Germany markets. Sub-sample analysis is able to identify the markets transmitting shocks to others. Results also suggest that Vietnam market is not fully integrated to the regional and global markets.

Keywords: volatility spillovers, GARCH-DCC model, emerging market, financial crisis

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1. Introduction

The dynamic technology development, enhancement in capital flow between countries have contributed to the robust linkages of stock markets. International investors are, therefore, interested in investigating these linkages in order to optimally construct their investment strategy, not only to obtain high return but also to minimize risk through diversification. This shall be even of greater importance during the period of crises, when there are fierce changes in the economies. The shock of one market may have an impact on both return and volatility of stocks in other markets, or in other words, the level of linkages between markets shall determine the degree of the return and volatility spillovers among them.

The existing literature presents different approaches to international spillovers. Bekaert and Harvey (1997) study how emerging markets are affected by the world market and find that in fully integrated markets, volatilities are affected by the world shocks while in segmented markets, the local factors dominate. Ng (2000) extends her approach and consider an additional regional factor and suggests that the world shock (the United States) has significantly stronger volatility spillovers to Asian markets than the regional (Japan) one. In a similar approach, Miyakoshi (2003) finds that Japanese market volatility spillovers on Asian market are much stronger than that of the US market. Worthington and Higgs (2004) investigate the source and degree of returns and volatility spillovers among three Asian developed equity markets and six emerging markets, indicating the presence of the volatility spillovers effects. Incorprating the effects of the Global financial crisis, Karunanayake et al. (2010) examine on the stock market returns and volatility of the US, the United Kingdom, Australia and Singapore from 1992 to 2009. Using a multivariate GARCH model, they find no significant impact on returns but significantly increased volatilities across four markets during the crises.. With the same idea and asymmetric BEKK-GARCH approach, Li and Giles (2013) investigate the linkages between stock markets across the US, Japan and six Asian developing countries during the period of crises from January 1, 1993 to December 31, 2012.

Over the last decades, Southeast Asian economies and markets have played increasingly influential role in the global economic and financial market. Southeast Asian combined GDP of more than US$2.55 trillion in 2016 would make it the world's 6th largest economy if it were a nation. Its combined population of 635 million – 8.7% of the world's total – is the third largest after that of China and India[5]. Southeast Asian economies and markets is also a vibrant market, with a young and rising middle class. Besides attaining a growth rate well above the world average, the region has attracted huge capital flows to their markets. Southeast Asia remains a major destination of global foreign direct investment (FDI), receiving around 16 per cent of the world FDI among developing economies with total FDI flows of $120 billion in 2015. Southeast Asian markets have become more integrated into the global markets. Market integration typically involves both economic and financial links. In this regard, a shock in one market may

[1] The ASEAN Secretariat (2017), A Journey Towards Regional Economic Integration: 1967-2017

affect both returns and volatility in other markets. The spillover of the shock depends on the level of market integration. The higher the degree of integration, the more extensive the contagious effect.

The first decades of the new millennium have witnessed two of the most-devastating financial crises in history – the Global Financial Crisis 2007-2009 and the European Debt Crisis 2011-2012. The crises have badly hit major developed countries whose economies have strong ties with the rest of the world as they are interconnected in different ways. In this regard, a long lasting shock that spreads across developed economies will have long lasting direct and indirect effects in the global economy as a whole. It is, therefore, interesting to study how the region markets were affected during the recent global financial market turbulence. This paper examines to what extent stock returns volatility of Southeast Asian emerging markets are affected by the global and regional markets. In the spirit of Ng (2000), the innovations from the US may represent shocks from the world, while those from Japan and Hong Kong are regional shocks. We additionally consider shocks from European markets in the Debt Crisis and use the United Kingdom and Germany as proxies. We examine volatility spillovers as volatility is particularly sensitive to crisis. We collect data of five developed markets: the United States, the United Kingdom, Japan, Germany and Hong Kong and six emerging markets in Southeast Asia: Indonesia, Malaysia, the Phillipines, Singapore, Thailand and Vietnam. The data are gathered from January 1993 to December 2017, except for Vietnam beginning from March 2002 due to its late appearance. This sample covers the three important crises: The 1997 Asian financial crisis, the 2007-2009 global financial crisis and the 2010-2011 European Debt crisis. Our contribution to literature is twofold. First, apart from the global and regional markets, we also consider the spillover effects from the European markets to emerging countries in the context of the European debt crisis. Second, our sample spans 25 years, studying spillover effects through three major financial crises. We are also interested in examining the level of integration of Vietnam market to the global and regional markets. Following Forbes and Rigobon (2002), we measure spillover effects by looking at correlations among markets in tranquil and crisis time. The GARCH-Dynamic Conditional Correlation (DCC) model of Engle (2002) is applied to estimate conditional correlations among developed and Southeast Asia emerging markets. We report three findings. First, correlations between developed markets and the Southeast Asian markets have risen sharply during periods of crisis, indicating the existence of volatility spillover effects from the developed markets to emerging ones. Second, full sample analysis suggests that volatility spillover from Japanese and the UK markets to the Southeast Asian emerging markets is stronger and more apparent than those transmitted from the US and Germany markets. Third, in 1997 Asian financial crisis, most of the volatility spillover effects were originated from Asian markets, while in the 2007 global crisis, the US market is the main source of shocks transmitting to others. Results also suggest that Vietnam market is not fully integrated to the regional and global markets.

The remainder of this paper is organized as follows. Section 2 introduces a brief literature

review. Section 3 describes the methodology employed to examine the spillover effects in volatility. The data analysis is provided in Section 4. Section 5 discusses the empirical results. Finally, section 6 summarizes the findings and draws the conclusion.

2. Literature review

It is well documented that markets have become more integrated and a shock in one country may both affect returns and volatility in other markets. The spillover of the shock depends on the level of market integration. The higher the degree of integration, the more extensive the spillover effects. The existing literature presents different approaches to international spillovers. Early researches provide insight into the interdependence among developed stock markets. Eun and Shim (1989) study the universal transmission of stock market movements in a VAR system in nine developed markets (Hong Kong, Japan, Australia, Switzerland, Canada, France, Germany, the United States, and the United Kingdom) and demonstrate statistically significant interconnection among them. While an innovation in the US market quickly transmits to others, none of the remaining countries have strong impact on the US market movements. Allowing for heteroscedasticity in volatilities, Theodossious and Lee (1993) study return and volatility spillover effects of five developed markets (the United States, Japan, the United Kingdom, Canada, and Germany) using a multivariate GARCH-M model. Despite the weak return spillovers, the results of volatility spillovers are quite robust, suggesting significant volatility spillovers from the US stock market to all four stock markets, from the UK stock market to the Canadian stock market, and from the German stock market to the Japanese stock market. Applying the MARMA (Multivariate Autoregressive Moving Average) model, Dedi et al. (2017) examine the transmission of volatilities of developed markets (the US and European countries) in 3 periods: before, during and after global crisis 2007-08. The results are quite similar throughout 3 periods, reinforcing the importance of the US market, which transmits the volatilities to all other developed markets. They also suggest that the market with high foreign ownership rates will receive high spillovers effects from the market where shocks occur and investors have to sell assets in other markets to cover losses.

Researchers are also interested in the spillover effects from developed to emerging markets, especially after the 1997 Asian crisis. Bekaert and Harvey (1997) study how emerging markets are affected by the world market and find that in fully integrated markets, volatilities are affected by the world innovations while in segmented markets, the local factors dominate. Ng (2000) extends her approach and consider an additional regional factor. Given the assumption that the three sources of local, regional and world shocks are all significant to the unexpected return of any specific Pacific-Basin market, Ng constructs a volatility spillover model to analyze the dynamics of the cross-market volatility spillovers and suggests that the world shock (the US) has significantly stronger volatility spillovers to Asian markets than the regional (Japan) one. They also highlight the importance of liberalization to the extent of the spillover effects from the US and Japan markets to markets of Pacific-Basin countries. In a similar approach, Miyakoshi (2003) examines the effects of

return and volatility spillovers from Japan and US stock markets to seven Asian equity markets (Korea, Taiwan, Singapore, Thailand, Indonesia, Malaysia and Hong Kong) using a bivariate EGARCH model for Japan and Asian markets with an exogenous variable being US shock. They suggest that only US market return influenced significantly on Asian market return while that influence of Japanese market is not significant. However, in terms of volatility, Japanese market spillovers on Asian market are much stronger than that of US market. Using a multivariate GARCH model, Worthington and Higgs (2004) investigate the source and degree of returns and volatility spillovers among three Asian developed equity markets (Hong Kong, Japan and Singapore) and six emerging markets (Indonesia, Korea, Malaysia, the Philippines, Taiwan and Thailand). Indicating the presence of the volatility spillovers effects, the results also point out that the volatility for all markets, especially for the emerging markets, is largely determined by its own-volatility than the cross-volatility spillovers.

The 2007-2009 global financial crisis, again, triggers interests in spillover effects. Karunanayake et al. (2010) examine on the stock market returns and volatility of the US, the UK, Australia and Singapore from 1992 to 2009. Using a multivariate GARCH model, they find no significant impact on returns but significantly increased volatilities across four markets during the crises. Their result also suggests that a high degree of time-varying co-volatility among these markets will not enable investors to benefit from diversifying their portfolio by holding stocks within these four countries only. With the same idea and asymmetric BEKK-GARCH approach, Li and Giles (2013) investigate the linkages between stock markets across the US, Japan and six Asian developing countries during the period of crises from January 1, 1993 to December 31, 2012. They find significant unidirectional shock and volatility spillover from the US market to Japanese market, noticeably strong bidirectional spillovers between the US market to Asian emerging markets (China, India, Indonesia, Malaysia, the Philippines and Thailand) during 1997 crisis, and from Japanese to Asian market recently.

Other studies look at the cointegration among markets. Masih and Masih (1999) examine the long run and short run dynamic linkages in the Asian crisis-affected markets using the cointegration and vector-error correction methods. They suggest that in addition to Japan, Hong Kong plays a regional leader role in Asia. Allowing for time variations in stock market integration, Awokuse et al. (2009) explore the contemporaneous information flow among emerging markets and between emerging markets and major developed markets using rolling cointegration analysis and identify the time-varying cointegration relationship among the markets. They also suggest that Asian markets are affected by global (the US) and regional (Japan and Hong Kong) shocks, however, they are not much influenced by shocks from the UK. In another approach, Favero and Giavazzi (2002) employ a VAR approach to study financial interdependence in devaluation expectations among the currencies that belonged to the Exchange Rate Mechanism (ERM) of the European Monetary System. Ewing (2002) uses generalized forecast error variance decomposition technique within a VAR framework to analyze the interrelationship among five major sectors in the US. He finds

that unanticipated 'news' or shocks in one sector have significant impact on other sector returns.

Spillover effects may also be identified by looking at correlations among markets. Following GARCH model, Hamao et al. (1990) use conditional variance to examine the correlation between market movements for the 1987 crisis and find out the bidirectional spillovers between United States, UK and Japan stocks market. King and Wadhwani (1990) study the Black Monday (October 19, 1987) phenomenon for a significant decline in the US Dow Jones, resulting in the similar downfall in other markets such as the UK, Japan by focusing on the cross-market return correlation. The empirical results show that the correlation coefficients increase significantly, similar to the results of Lee and Kim (1993). Solnik et al. (1996) also investigate the correlation among the US stock, bond and other markets, indicating that spillover effects exist as evidenced by sharply increasing correlations during shock period. By applying DCC-GARCH model, Savva (2009) measures the magnitude of return volatility spillovers between the US and European countries (UK, Germany, France). Cho and Parhizgari (2008) conduct research about 14 East Asian stock markets with a view to Thailand and Hong Kong as the countries where the shock originates and conclude that there is evidence of spillover effects. Bouaziz et al. (2012) examine the US crisis 2007-2008 and find out that the post-crisis correlations increase significantly between the US and developed markets. With a closer look to another object of forex markets, Celık (2012) has also apply DCC-GARCH model and conclude spillover effects in the US crisis period 2007-2008 to several stock markets, which emerging markets are more influenced by the shock spillovers than developed countries are. Similar results have also been reported by Hwang et al. (2010) with a sample of 38 countries including developed and emerging countries. Studies generally suggest that during crisis, there is higher conditional correlations between markets compared to the tranquil time (see, e.g., Alper et al.,2004, Huang, 2011, Akhtaruzzaman et al., 2014, Tan et al., 2009).

3. Methodology

In this paper, we examine volatility spillover effects from developed to emerging markets by looking cross-country correlations. We focus on volatility spillovers because we are interested in crises and volatility is particularly crisis-sensitive. It is a well-established fact that the covariance matrix of financial asset returns is both time-varying and highly persistent, hence, we adopt a multivariate conditional volatility model to capture these features. Motivated by the balance in specification between the parsimony and the flexibility, we use the GARCH-DCC model of Engle (2002) to measure conditional correlations among markets. The DCC model not only provides a higher parsimonious level than DVECH model and BEKK model, but also a more flexible degree than CCC model. In addition, the DCC model facilitates the modelling and estimation of conditional volatility and conditional correlation (Lee, 2006), hence simplifying the calculation of correlation matrix. Another main benefit of GARCH-DCC model is that it considers heteroskedasticity to eliminate any volatility bias, on account of the continuous adjustment of volatility in the estimation (Chiang et al., 2007). Furthermore, Cho and Parhizgari

(2008) regards GARCH-DCC as a preferable measure of correlation since the model continuously adjusts the correlation for time-varying volatility.

Following Forbes and Rigobon (2002), we compare the spillover effects between developed markets and developing markets in pre-crisis, during crisis and after crisis periods. We want to examine whether correlations increase during crisis time. And if that is the case, investors would not be able to benefit from risk diversification when they need it the most. In this section, we will give details of the GARCH-DCC model and the Forbes and Rigobon framework.

3.1. The GARCH-DCC model

The GARCH-DCC is introduced by Engle (2002). They provide a convenient framework to estimate and forecast the conditional covariance matrix in large systems.

Consider an n-dimensional vector of returns $r_t = (r_{1t}, r_{2t},...r_{nt})'$. The return is decomposed into an expected conditional mean $\mu_t = E(r_t|F_{t-1})$ based on the information set F_{t-1} available at time t-1 and an innovation ε_t

$$r_t = \mu_t + \varepsilon_t$$

$$\varepsilon_t = H^{1/2} z_t$$

where z_t is a n×1 white noise process with zero mean and unit variance and H_t is an n×n matrix of conditional covariance of ε_t at time t. The conditional covariance matrix can be separated into two matrices of conditional standard deviation and a correlation matrix:

$$\mathbf{H_t = D_t R_t D_t}$$

$$\mathbf{R_t = diag(Q_t)^{-1/2} Q_t diag(Q_t)^{-1/2}}$$

$$\mathbf{Q_t = (1- \lambda_1 - \lambda_2)\bar{R} + \lambda_1 \tilde{\varepsilon}_{t-1} \tilde{\varepsilon}'_{t-1} + \lambda_2 Q_{t-1}}$$

where $\mathbf{R_t}$ is the conditional correlation matrix, $\mathbf{D_t}$ is a diagonal matrix with the time varying standard deviations $\sqrt{h_{i,t}}$ on the main diagonal, i.e., $\mathbf{D}_t = diag\left\{\sqrt{h_{i,t}}\right\}$, $\mathbf{Q}_t$ is the approximation of the conditional correlation matrix $\mathbf{R_t}$, and $\bar{\mathbf{R}}$ is the unconditional average correlation $\bar{\mathbf{R}} = \frac{1}{T}\sum_{t=1}^{T} \boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}'_t$. The positive semi-definiteness of $\mathbf{Q_t}$ is guaranteed if $\boldsymbol{\lambda_1}$ and $\boldsymbol{\lambda_2}$ are positive with $\boldsymbol{\lambda_1}+\boldsymbol{\lambda_2} \leq 1$ and the initial matrix $\mathbf{Q_t}$ is positive definite.

In this paper, we employ the GARCH (1,1) process to estimate the time varying standard deviations h_it.

3.2. Measuring spillover effects

We apply the framework of Forbes and Rigobon (2002) to measure volatility spillover effects. Forbes and Rigobon suggests that correlations among markets may increase in crisis, suggesting cross-market linkages. The GARCH-DCC model is employed to estimate conditional correlation among markets.

We then compare cross-market correlations between prior-crisis and post-crisis. Suppose we examine the spillover effect from market i to market j, where market i represents the country where the shock occurs and market j is the market affected by the shock. Therefore, in this research, market i represents a developed market and market j is an emerging one. To examine the significant increase in market correlation, the null hypothesis is H_0: $\rho_2 = \rho_1$ and the alternative hypothesis is H_1: $\rho_2 > \rho_1$, where ρ_2 and ρ_1 are the correlations between the two markets during crisis period and pre-crisis period respectively. The non-parametric sign test is applied to test the hypothesis with H_0: "There is no significant increase in the correlation among markets during the crisis period". If the correlation coefficient increases significantly, the mechanism of

transmission between markets is enhanced during the shock period, thus suggesting that there exists the volatility spillover effect.

4. Data analysis and the estimation process

In this paper, we examine the correlations between the stock markets of 11 selected countries, thus, we test for the existence of volatility spillovers not only from developed markets to emerging markets but also across the Southeast Asian stock markets.

Daily nominal local-currency stock market indices are collected from Datastream. The data covers the period from 01 January 1993 to 31 December 2017 for five developed markets including the US (S&P500), Japan (Nikkei 225), Germany (DAX), the United Kingdom (FTSE100) and Hong Kong (Hang Seng) and six emerging Asian stock markets, which are Singapore (STI), Malaysia (KLCI), the Philippines (PSE), Thailand (SET), Indonesia (JKSE) and Vietnam (VNI). Due to data limitation, data for Vietnam market is only from 01 March 2002. Weekly returns are calculated as log differences using Friday to Friday closing index prices to avoid non-synchronous trading and any potential day-of-the-week problems. When price data for Friday are not available due to a holiday, we use data of the closest previous trading day. The dataset comprises 15 years of weekly returns, yielding total of 1303 observations for 10 international indices and 826 observations for VNINDEX. Table 1 reports the descriptive statistics for the international dataset.

As observed from Table 1, mean returns of 11 indices are all positive. Indonesia market has the highest annualized return (13.4%), followed by Vietnam (10.6%). Emerging markets such as Philippines, Indonesia, Viet Nam have significantly higher than those of developed markets like the US, the UK, Germany. Especially, the Japanese stock market has the worst performance with the lowest average annualised return (1.21%). However, high returns are associated with high levels of risk. The risks of emerging markets are relatively higher than those of developed markets. Vietnam and Indonesia are also the most risky market to invest with high annualized standard deviation of 26.81% and 25.52% respectively. The US market performs quite well with high returns (7.41%) and very low risk.

Returns are non-normal (based on the Jarque-Bera tests), leptokurtic and, in most cases, negatively skewed. Negative returns are likely to appear more densely than positive returns. From the Table 1, we also reject the null hypothesis of the ARCH (1) test and conclude that variance of error term is varying and conditionally autoregressive, thus, proving for the rational application of DCC-GARCH in studying the volatility spillovers between stock markets.

Table 1: Summary statistic for 11 international stock markets - Full sample

Return series	Mean (%)	Std. Deviation (%)	Skewness	Kurtoris	Min (%)	Max (%)	JB	ARCH (1)
USA	7.41	16.43	-0.73	9.9	-20.084	11.356	2610***	0.36***
JP	1.21	21.66	-0.79	9.42	-27.884	11.45	2269***	0.26***
UK	4.09	16.64	-0.98	13.76	-23.632	12.585	6341***	0.41***

Return series	Mean (%)	Std. Deviation (%)	Skewness	Kurtoris	Min (%)	Max (%)	JB	ARCH (1)
GER	8.97	22.16	-0.64	8.05	-24.347	14.942	1406***	0.41***
HK	6.74	24.29	-0.27	6.35	-19.922	17.052	614***	0.25***
IND	13.43	25.52	-0.18	8.31	-17.854	20.594	1533***	0.45***
MAL	4.42	19.64	-0.03	12.84	-19.027	22.757	5252***	0.66***
PHIL	6.46	24.22	-1.03	13.02	-31.005	16.185	5507***	0.27***
SIN	3.29	20.19	-0.65	12.33	-25.507	15.321	4745***	0.48***
THAI	3.69	25.49	-0.22	8.11	-26.661	21.838	1430***	0.34***
VIET	10.6	26.81	-0.26	7.02	-18.311	16.709	558***	0.65***

*This tables report the descriptive statistics of return series for 11 stock market indices. The returns are measured weekly, using Friday to Friday closing price index prices. The sample size covers the period from January 1, 1993 to December 31, 2017. The statistics include annualized means (Mean), annualized standard deviations (Std. Deviation), skewness (Skewness) and kurtosis (Kurtosis), maximum value (Max), minimum value (Min). Jarque-Bera test are the empirical statistics test for normality based on skewness and kurtosis. ARCH (1) effect refers to the empirical statistics of the statistical test for conditional heteroscedasticity of order 1. *, **, *** indicate the rejection of the null hypothesis of associated statistical test at the 10%, 5% and 1% levels respectively.*

With regard to the estimation process, in order to test spillover effects among markets, we divide the whole sample into two subsamples. These two periods are considered owing to their inclusion of some serious crises, namely the Asian financial crisis (1997), the Global financial crisis (2007) and the European Sovereign Debt Crisis (2010). Since changes in market correlations might arise as a consequence of major financial events, these aforementioned crises could have a decisive impact on volatility spillovers across stock markets. Therefore, sub-sample analysis facilitates the investigation in the influence of each crisis on the correlation between markets before, during and after crisis period, as well as the test for volatility spillover effects. Specifically, this study includes two subsample periods: the first period is from 01 January 1993 to 07 March 2002 and the second one is from 08 March 2002 to 31 December 2017.

In order to identify crisis points, also known as structural breakpoints to divide each subsample into pre-crisis, during crisis and post-crisis periods, we implement the Chow Test for each stock index. Results obtained show that all observed markets are affected by three major breakpoints including August 29, 1997; October 15, 2007, and December 31, 2012. This result will be exploited in investigating volatility spillovers on the reliability of the Sign Test. The aim of this paper is not only to explore volatility spillovers from one country to another through testing for changes in correlations between nations before and after the crisis under the Sign Test, but also to examine which selected

country has a prominent influence on others within the crisis episode.

The first subsample is characterized by the nature of Asian financial crisis (1997). The Asian financial crisis originated in Thailand, then widely spread to many Asia countries, especially Hong Kong and Japan through affecting various financial asset markets. Accordingly, we test for volatility spillovers among Asian countries, specifically from Thailand, Japan and Hong Kong to the rest of Asia.

The second subsample includes the Global financial crisis (2007) and the European Sovereign Debt Crisis (2010). The former crisis stemming from the financial crisis in the United States was one of the most serious crises with an universal impact, whereas the latter crisis arose in Greece and profoundly affected the European Union countries including Germany and the UK. As the global economy increasingly becomes interdependent, those severe financial shocks in one country will, in some cases, have a negative impact on other countries such as those in Southeast Asia. Thus, this study examines the volatility spillover effect from the United States (related to the global crisis) and Germany, UK (related to the debt crisis in Europe) respectively to developing countries namely Indonesia, Philippines, Malaysia, Singapore, Thailand and Vietnam.

Then, based on test results from each subsample, we draw a conclusion about the existence of volatility spillover from one country to another and compare the level of impact of shocks in those nations on other selected nations. Furthermore, we conduct a volatility spillover test on the entire sample to provide an overview of the long-run volatility spillover effects among markets, thus contributing to the completeness of this study.

5. Empirical Results

5.1. Full sample analysis

From the GARCH-DCC model, we obtain the results of the cross-market conditional correlation coefficients. Developed markets are highly correlated with each other and have low correlations with the emerging markets over the period. This result supports investment strategy to put capital resources in emerging markets for risk consideration. With regard to the correlation coefficients among developed stock markets, Germany and England have the highest correlation coefficient (0.875), followed by the US and the UK (0.856), representing pairs of developing markets in different regions. The lowest correlation is between the developed stock market German and the emerging one Malaysia, which is relatively low correlated at 0.331.

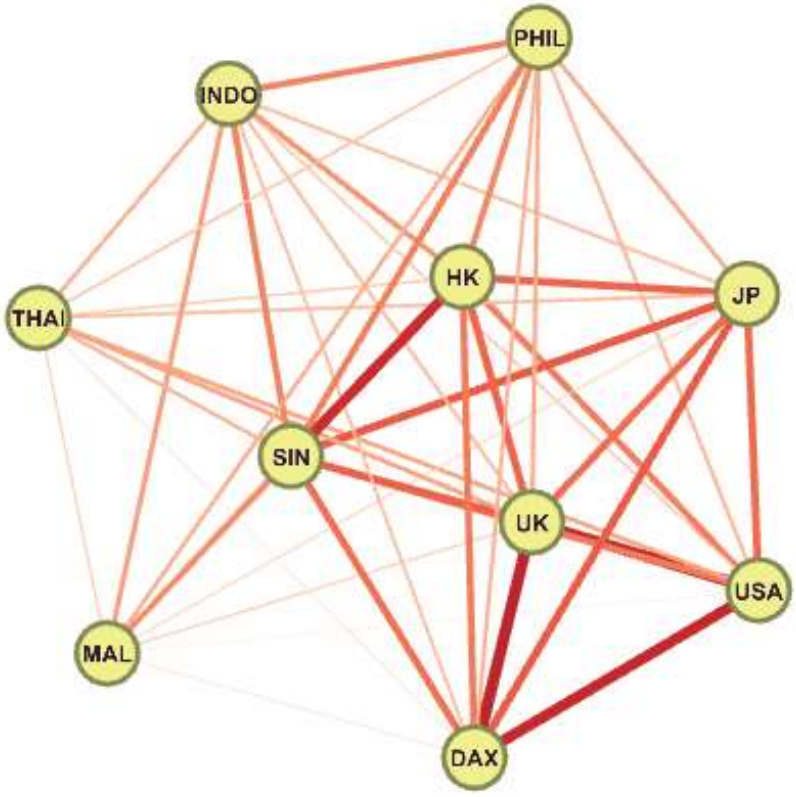
Table 2: Conditional correlation among markets for the whole sample period (1 Jan 1993 to 29 Dec 2017)

	USA	JP	UK	GER	HK	INDO	MAL	PHIL	SIN	THAI
USA	**1**									
JP	0.695	**1**								
UK	0.856	0.688	**1**							
GER	0.843	0.720	0.875	**1**						

	USA	JP	UK	GER	HK	INDO	MAL	PHIL	SIN	THAI
HK	0.655	0.703	0.703	0.662	**1**					
INDO	0.468	0.499	0.503	0.495	0.604	**1**				
MAL	0.381	0.431	0.445	0.402	0.587	0.580	**1**			
PHIL	0.512	0.546	0.543	0.523	0.635	0.645	0.535	**1**		
SIN	0.666	0.724	0.709	0.683	0.826	0.645	0.622	0.652	**1**	
THAI	0.553	0.500	0.559	0.401	0.462	0.533	0.447	0.475	0.522	**1**

Graphical illustrations would be better to understand the structure of the correlation matrix in Table 2. Figure 1 provides a display of pairwise correlations among the ten countries. Edge thickness indicates the size of average pairwise correlations. Node location also shows average pairwise spillovers – closer nodes have higher spillovers. It can be seen from Figure 1 that the 10 countries form two groups of developed and emerging markets. Looking at the node location, developed markets are closely linked together, indicating a higher spillover effects among those markets in full sample period. The five Southeast Asian markets form another group, which are scattered from the center. Hong Kong and Japan are closer to Southeast Asian markets than other developed countries, suggesting higher spillover effects from these countries.

Figure 1. Pairwise Correlations among the 10 International Stock Markets – Full Sample from 1 January 1993 to 31 December 2017



Focusing on the thickness of the edge size, developed markets like the US, UK and Germany have noticeable high pairwise correlations, thus proving the interconnectedness and linkages between these countries. Among the emerging markets, Singapore has the strongest directional spillovers to others, expressed in the close location to developed markets.

We also apply the non-parametric sign test to examine the spillover effects of each pair of a developed market and an emerging market. Our null hypothesis for the test over the whole dataset is to investigate if two developed stock markets have the same effect on the volatility spillovers to the emerging markets. As a result of the test, the Japanese and the UK markets have higher spillovers impact on the Southeast Asian emerging markets than those from the US and Germany across the sample. This confirms the visual presentation in Figure 1. The similar result was also announced by Tatsuyoshi Miyakoshi (2002) of the volatility spillover effects which Japanese market– the Asian regional influence is much stronger than the effect from the US market – a global factor.

The full-sample analysis shows correlations among markets in 25 years' time and hence may fail to capture the time-varying behavior of stock volatilities and missing important movements in spillovers. The global financial markets have become more integrated. This period also witnesses some of the most dramatic financial crisis ever (e.g., the Asian financial crisis 1997 - 1998, the Global Financial crisis 2007 - 2009, the European Debt crisis 2010 - 2011). In the following section, we will study the spillover effects in these crises.

5.2. The evidence of spillover effects from the Asian financial crisis period

In July 1997, the Asian financial crisis started with the devaluation of Thai baht, then rapidly spread to other Southeast Asian economies. Following Forbes and Rigobon (2002), we study the conditional correlations among markets before and after the crisis with the structural break of August 29, 1997. Results are reported in Table 3.

It is necessary to pay close attention to the effect of Asian stock markets on other economies in this crisis period. Firstly, we consider Thailand linkages with other markets to examine the spillovers from this country where shock originates to others. Before crisis, the conditional correlation coefficients of Thailand with developed countries (USA, Japan, UK and Germany, except Hong Kong) are relatively low and almost only statistically significant at 10%. However, after the crisis, these correlations increase significantly and are statistically significant at 1%. The non-parametric sign-test model shows that the spillover effects from Thailand to the developed countries are statistically significant at 5% after the crisis. The linkages between Thailand and other emerging markets, on the contrary, are quite high and significant in both periods.

Japan also plays an important role in investing capital in Southeast Asian developing markets. This developed country in the pre-crisis period has relatively low and insignificant coefficients of conditional correlations with the Southeast Asian markets. Nevertheless, in post-crisis, the correlation coefficients between Japan and all other countries increase and are significant at 1%. From the sign-test result, the shock

Table 3: Conditional correlation among markets in the Asian financial crisis (1997)

	USA	JP	UK	DAX	HK	INDO	MAL	PHIL	SIN	THAI
Panel A	*Before the 1997 Asian financial crisis (1 Jan 1993 to 28 Aug 1997)*									
USA	**1**									
JP	0.2390***	**1**								
UK	0.4061***	0.2234***	**1**							
DAX	0.3690***	0.1760***	0.5418***	**1**						
HK	0.2782***	0.1720**	0.3909***	0.3168***	**1**					
INDO	0.2139**	0.1319	0.2004*	0.3326***	0.4850***	**1**				
MAL	0.1754*	0.1568**	0.2584***	0.2193***	0.4660***	0.5579***	**1**			
PHIL	0.1117	0.1332	0.2200*	0.3212*	0.5364***	0.6828***	0.4921***	**1**		
SIN	0.2055*	0.1981	0.2289*	0.3074***	0.5427***	0.5411***	0.5815***	0.5127***	**1**	
THAI	0.1483**	0.0851	0.2238*	0.2171*	0.4866***	0.5078***	0.4871***	0.4757***	0.5774***	**1**
Panel B	*After the 1997 Asian financial crisis (29 Aug 1997 to 7 Mar 2002)*									
USA	**1**									
JP	0.4886***	**1**								
UK	0.7639***	0.4511***	1 **1**							
DAX	0.7691***	0.4348***	0.8192***	**1**						
HK	0.5878***	0.4640***	0.7341***	0.6672***	**1**					
INDO	0.2069***	0.2245***	0.1711**	0.2076***	0.3268***	**1**				
MAL	0.2534**	0.2855***	0.2476*	0.3463***	0 .2929**	0.2233**	**1**			
PHIL	0.2085	0.1479	0.3642***	0.2629***	0.3279	0.3481***	0.2584***	**1**		
SIN	0.4749***	0.5651***	0.6179***	0.3828***	0.6755***	0.4281***	0.3552***	0.5107***	**1**	
THAI	0.3866***	0.4450***	0.4951***	0.2934***	0.6005***	0.4505***	0.3867***	0.6379***	0.7869***	**1**

Note: This table shows cross-market correlation results obtained from employing GARCH-DCC model with weekly stock return data (Friday-to-Friday) from 1 January 1993 to 7 March 2002. (***), (**) and (*) indicate significance at the 1%, 5% and 10% level , respectively.

volatility of the Japanese market influences the volatility of all stock markets in sub-sample period, developed and emerging countries at a statistically significant level of 1%, 10% and 5%, respectively.

The correlations between Hong Kong and other markets are statistically significant at high level of confidence, especially, Hong Kong and the emerging markets in Southeast Asia are relatively correlated. However, although the prior-crisis correlations between Hong Kong and other developed markets are lower, they witness considerable increase during crisis and even higher compared to its linkages with the emerging markets. The sign-test also supports the existence of spillover effects from Hong Kong stock market to other developed markets at a 10% level of confidence. Moreover, Hong Kong is the Asian developed market highly interconnected with other developed markets like the US, UK and Germany than Japanese stock market is.

With regard to the global factor, the US market is the important and central market to be considered if there is spillover effect of global shocks to emerging economies. Interestingly, during this Asian crisis period, there is no spillover effect from the US market to emerging markets as the sign-test result cannot reject the null hypothesis of statistically almost the same magnitude of correlation. However, it can be seen from the illustration of Figure 2 that Singapore is the developing markets among other emerging ones has the highest correlation with the US market after crisis with a high correlation coefficient of 0.475.

To sum up, in the first sub-sample considering the effect of Asian financial crisis 1997, only Japan is a developed market spreading return volatility spillover effect to the developing markets in Southeast Asia. Most of the volatility spillover effects originated from Asian markets, to others. We also apply the sign-test method to compare the spillover effect from three markets Thailand, Japan and Hong Kong to explore which market transmit the most significant spillover effects to the developed markets. From the result, we cannot reject the null hypothesis and conclude that during crisis, the spillover effects from these three markets towards the developed countries expressed in the correlation coefficients are nearly the same.

5.3. The evidence of spillover effects from The Global Crisis (2007) and European Debt Crisis (2010)

The sample is divided into three periods: prior – crisis (8 March 2002 – 14 October 2007), during crisis (15 October 2007 – 31 December 2012) and post crisis (1 January 2013 – 31 December 2017). The structural points are identified based on Chow test. We include Vietnam market in this sample. Table 4 reports the conditional correlations among markets in this sample.

Prior-crisis and during crisis periods

Panel A and B of Table 4 shows that most of correlations between developed markets including UK, Japan, Germany, UK and the Southeast Asian emerging markets before and during crisis are significant at 1%, which means that there is interdependence between volatility of stock return in Southeast markets and developed markets mentioned. Sok-Gee et al (2010) reach the similar conclusion. All the sign test results between correlations of each developed market including US,

Table 4: Conditional correlations among markets in the Global financial crisis (2007) crisis and the European Debt Crisis (2010)

	USA	JP	UK	DAX	HK	INDO	MAL	PHIL	SIN	THAI	VIET
Panel A	*Before the 2007 Global financial crisis and 2010 European Debt crisis (8 Mar 2002 to 14 Oct 2007)*										
USA	**1**										
JP	0.4769***	**1**									
UK	0.7512***	0.6594***	**1**								
DAX	0.7950***	0.6940***	0.8758***	**1**							
HK	0.4686***	0.5702***	0.5355***	0.5134***	**1**						
INDO	0.4136***	0.5193***	0.3997***	0.4309***	0.6119***	**1**					
MAL	0.2596***	0.5662***	0.4116***	0.4014***	0.6610***	0.6207***	**1**				
PHIL	0.3272***	0.4112***	0.4465***	0.4507***	0.3950***	0.4624***	0.4277***	**1**			
SIN	0.5696***	0.6856***	0.6225***	0.6342***	0.7198***	0.6772***	0.7587***	0.4968***	**1**		
THAI	0.2444***	0.4785***	0.4129***	0.4097***	0.4064***	0.4699***	0.4387***	0.3827***	0.4304***	**1**	
VIET	0.1017	0.1141	-0.062	0.1375	0.265	0.0039	-0.0374	-0.0469	0.02223	-0.0535	**1**
Panel B	*During the 2007 Global financial crisis and 2010 European Debt crisis (15 Oct 2007 to 31 Dec 2012)*										
USA	**1**										
JP	0.7819***	**1**									
UK	0.9420***	0.7917***	**1**								
DAX	0.9268***	0.7963***	0.9378***	**1**							
HK	0.8046***	0.8161***	0.8337***	0.7886***	**1**						
INDO	0.7599***	0.7485***	0.7894***	0.7284***	0.8597***	**1**					
MAL	0.6104***	0.6539***	0.6585***	0.6060***	0.7387***	0.7838***	**1**				
PHIL	0.7000***	0.7052***	0.7304***	0.6675***	0.8188***	0.8738***	0.7673***	**1**			
SIN	0.7919***	0.7924***	0.8318***	0.7939***	0.9085***	0.8553***	0.7459***	0.7973***	**1**		
THAI	0.7259***	0.6597***	0.7178***	0.6573***	0.8312***	0.8419***	0.7629***	0.7994***	0.8305***	**1**	
VIET	0.4586***	0.4991***	0.4477***	0.4256***	0.4990***	0.4946***	0.5575***	0.5228***	0.4765***	0.4638***	1

	USA	JP	UK	DAX	HK	INDO	MAL	PHIL	SIN	THAI	VIET
Panel B	*After the 2007 Global financial crisis and 2010 European Debt crisis (1 Jan 2013 to 31 Dec 2017)*										
USA	**1**										
JP	0.5378***	**1**									
UK	0.7411***	0.4719***	**1**								
DAX	0.6583***	0.5424***	0.7211***	**1**							
HK	0.5413***	0.4312***	0.5652***	0.4172***	**1**						
INDO	0.1539**	0.1688***	0.3266***	0.2662***	0.3355***	**1**					
MAL	0.4069***	0.2674***	0.4091***	0.4511***	0.6353***	0.4829***	**1**				
PHIL	0.2971***	0.2698***	0.3515***	0.2999***	0.4311***	0.5092***	0.4157***	**1**			
SIN	0.4562***	0.4960***	0.8445***	0.4072***	0.6579***	0.4070***	0.5161***	0.4843***	**1**		
THAI	0.4499***	0.2739***	0.4753***	0.3890***	0.4384***	0.4490***	0.4428***	0.4521***	0.4161***	**1**	
VIET	0.1784***	0.1053*	0.1718***	0.1225*	0.2259***	0.1175*	0.1288*	0.2867***	0.2132***	0.2667***	**1**

Note: This table shows cross-market correlation results obtained from employing GARCH-DCC model with weekly stock return data (Friday-to-Friday) for the period prior to the 2007 crisis and the 2010 crisis, which is from 8 March 2002 to 29 December 2017. The structural breaks for the prior-crisis, during crisis and post-crisis are 15 October 2007 and 31 December 2012.

(***), (**) and (*) indicate significance at the 1%, 5% and 10% level , respectively.

Japan, Germany, UK, respectively, with all the remaining markets, with the remaining developed markets, and with the emerging markets show that we are able to reject the null hypothesis H0 in one-sided test: correlations before and during crisis are equal, thus accepting the hypothesis H1: the correlations between the markets during crisis are significantly higher than that before crisis.

Again, we illustrate the parwise correlations to better observe correlations and spillovers between markets (see Figures 2 and 3). Looking at the node location, although they spread out and indicate an independent relationship in the prior-crisis period, the nodes become closer together during crisis. This behaviour indicates stronger presence of the spillovers effects during crisis compared to the previous period. Especially, the node of Vietnamese infant stock market is located considerably far from others during the first crisis period, but then move closer during crisis. Turning to the thickness of edges connecting each market, we can easily witness that the edges are significantly thicker during crisis period compared to those before crisis. More interestingly, the trend of the pairwise correlations of developed markets in connection with developing market is nearly the same to the full sample analysis, however, indicates clearly thicker edges during the crisis than in the long-run.

The sign test of increase in correlations $\Delta\rho$ before and during crisis between developed markets and the emerging markets shows that the increase in correlations between US market (presenting global factor) and emerging markets is higher than the increase in correlation between Japan and emerging markets, proving that spillover effects from global market are superior in comparison with those effects from Asian market. Although this result may sound contradictory to the full sample analysis which we conclude the regional factor has a stronger impact on the emerging markets, this period is in the Global crisis and may emphasize the greater influence of global factor on other markets. Volatility spillover effects from European markets to emerging markets are also not as strong as those from the US. It is not able to reject H0 hypothesis (increase in correlations, $\Delta\rho$, between each of two developed markets to emerging markets are equal) when we conduct the sign test on before-during crisis $\Delta\rho$ between Germany/UK/Japanese markets and the emerging markets, which means that there is no significant difference among the volatility spillovers from the European market and Asian market to the emerging markets. The result arouses an interesting point because in the European debt crisis, the volatility spillovers from the European markets are not even higher than those effects originated from the Japanese markets. The effects are also reflected in the Figure 4 with the same width of edge pairwise correlations between the UK and emerging markets as well as Germany or Japan to those.

As mentioned before based on the illustration, Vietnam market is quite insulated. Correlations between Vietnam and other markets are low and insignificant. Hence, Vietnamese market hardly has any interdependence with other markets in before-crisis period. During crisis period, correlations between this market with the developed ones are still the lowest among emerging markets, nevertheless, increasing nearly four times comparing with itself before

Figure 2. Pairwise Correlations before the Global crisis (2007) crisis and the European Debt Crisis (2010) from 8 March 2002 to 14 October 20

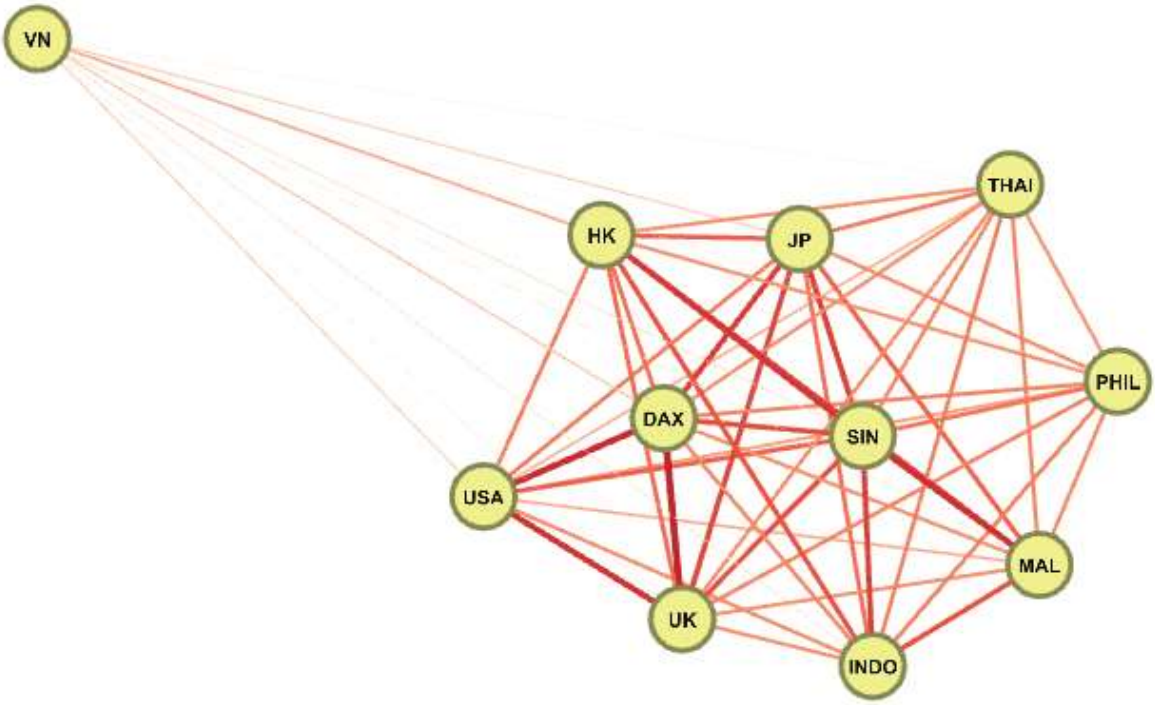
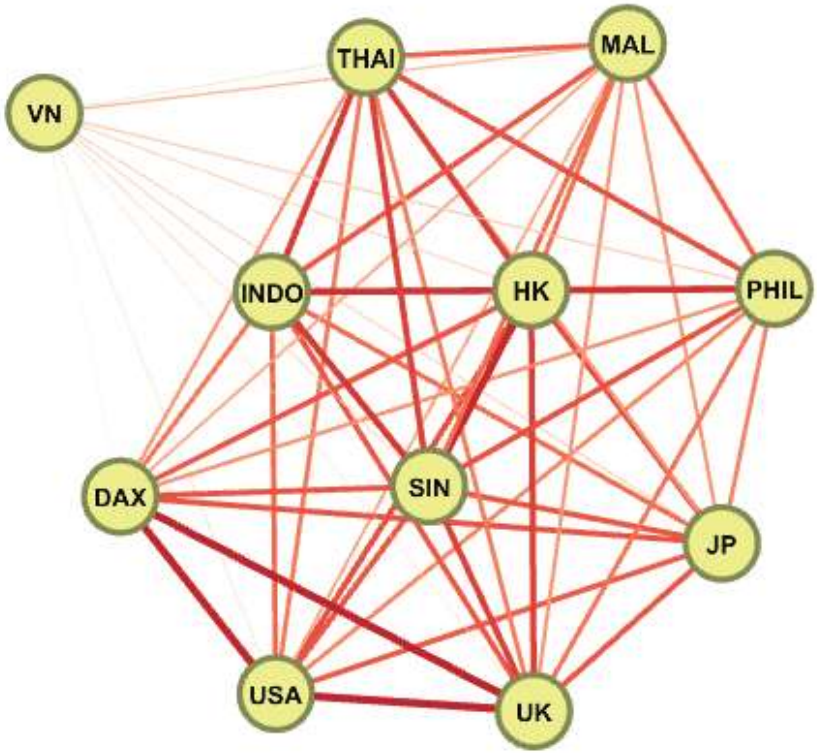


Figure 3. Pairwise Correlations during the Global crisis (2007) crisis and the European Debt Crisis (2010) from 15 October 2007 to 31 December 2012Debt



crisis and all become statistically significant. This shows that the correlation of this country is stronger during crisis, in other words, there is the clearer sign of volatility spillovers from developed markets to Vietnamese market.

During crisis and Post-crisis periods

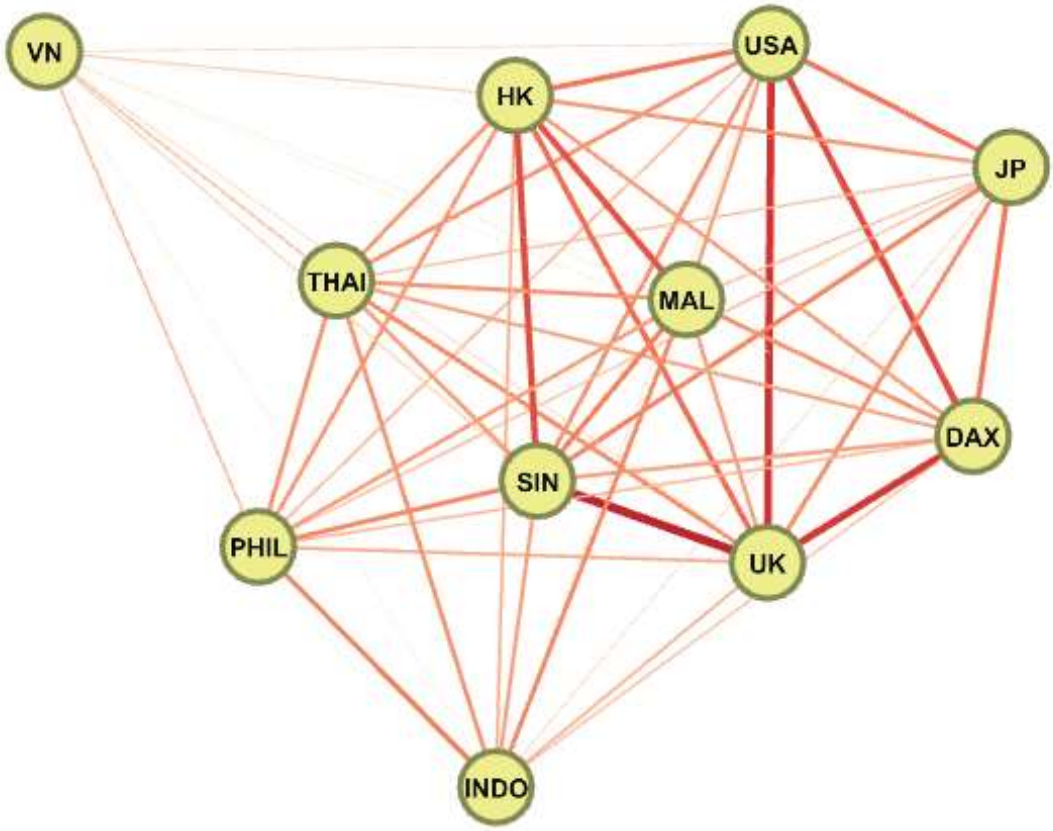
This study employed one-sided Sign Test with H_0: "*Correlation ρ among countries during the crisis and in post-crisis period are equal*" and H_1: "*Correlation ρ among countries in post-crisis period is significantly lower than that during the crisis*". The test on correlation between the US, Japan, the UK, Germany respectively and other countries, shows that ρ among countries in post-crisis period are all significantly lower than that during crisis. Specifically, being consistent with the results from previous correlation tests over pre-crisis versus during crisis period, the correlation coefficients between the US, UK, Japan, Germany, in turn with the rest of the stock markets during the crisis tends to be significantly higher than that in post-crisis episode. The results obtained from testing on correlation between each of the four above-mentioned markets respectively and other developed markets as well as Asian emerging markets have rejected H0 at a 5% significance level. Therefore, there is evidence of volatility spillover effects of return in this study. However, the correlation between the UK and most emerging markets, except for Singapore, in the post-crisis period, albeit decreasing compared to that during crisis period, is not statistically significant. This could partly be explained by the lasting impact of the European debt crisis (2010), hence the influence of volatility in the UK market on other Southeast Asian markets is still quite strong. Subsequentlly, the correlations between UK and those Asian nations in the post-crisis period, although falling, are not statistically significant.

As can be seen from Table 4, Singapore shows the strongest correlation with the US, UK, Japan, Germany stock markets respectively during the crisis period in comparison with any other Southeast Asia markets, thus highlighting the close linkages between Singapore and those four developed countries, which aligns with the full sample analysis.

In the case of Vietnam, regarding the market correlation between Vietnam and each developed country in the crisis period, ρVN-Japan coefficient has the largest value of 0.4991 whereas the smallest coefficient value is of ρVN-Germany (0.4256). Furthermore, the correlation coefficients between Vietnam in post-crisis period and the US, Japan, Germany, UK markets still show the lowest value when compared to the correlation between these four markets and the rest of Southeast Asia. This implies that the linkage between Vietnam and developed countries is still relatively loose compared to other Southeast Asian countries. Focusing on the graph, we can clearly observe the significant differences between Figure 3 and Figure 4. The Figure 4 shows large changes where the node position is scattered accompanied by the thin edges, especially Vietnam is isolated from group of markets.

Looking at the correlations among developed countries themselves including the US, UK, Germany, Japan and Hong Kong during the crisis, the coefficients also demonstrate a strong correlation among these five developed markets. Particularly, in this paper, ρUS-UK during the crisis period reached the highest value at 0.942 while ρHK-Japan has the lowest coefficient of 0.8161.

Figure 4. Pairwise Correlations after the Global crisis (2007) crisis and the European Debt Crisis (2010) from 1 January 2013 to 31 December 2017



In overall, the results from the sub-sample periods in the pre-crisis and post-crisis are not very different from the full sample based on the long-run aspects. For example, the strong correlations between the US, the UK and Germany are recorded throughout the period as well as high correlation of Singapore or loose interconnectedness of Vietnamese markets towards others. However, during times of crisis, we can clearly observe that the correlations increase from markets to markets depending on the regional or global factors that triggered the crisis, and therefore the nodes become closer as well as the thickness of the edges have also increased, proving the robust volatility spillover effects across markets.

6. Conclusion

In this paper, we measure the volatility spillover effects from the major global and regional markets (the US, the UK, Germany, Japan and Hong Kong) to Southeast Asian stock markets from 1993 to 2017. Full sample analysis shows that the volatility spillover from the UK markets and Japanese markets to the Southeast Asian emerging markets is stronger and more apparent than those transmitted from the US and Germany markets. We then study volatility spillover effects in different crisis time from the 1997 Asian financial crisis to the 2007-2009 global financial crisis and 2010-2011 European debt crisis. Results suggest that in the 1997 Asian financial crisis, Asian markets like Thailand,

Japanese and Hong Kong transmitted shocks to other countries. Only Japanese market clearly produces spillover effects to those in Southeast Asia. In the global financial and European debt crisis, however, the correlation between the developed markets and emerging markets in Southeast Asia increase considerably, thus, confirming the presence of volatility spillover effects from the US, the UK and Germany markets to emerging markets. Moreover, the spillover effect from global factor (the US) to emerging markets is stronger than those from the European or Japanese markets. It is interesting to see that given the European debt crisis, there is no significant difference between the impact of spillover from the European markets (in the UK and German) and the effect from Asian developed markets in Japan and Hong Kong to the Southeast Asian emerging stock market. However, after crisis, the correlations between UK and emerging markets are not likely to decrease, proving the persistent impact of the European debt crisis in 2010 on the volatility of emerging markets. Among the emerging stock markets, Singapore is the most strongly correlated with all the developed markets, especially during crisis, whereas the correlation between Vietnam and developed markets are always the lowest among emerging ones, even though the level of correlations of Vietnam with these markets has considerably increased.

In conclusions, the correlations between developed markets and emerging markets in Southeast Asia have risen sharply during the periods of crisis, reflecting a strong existence of volatility spillover effects between these developed markets including United States, Japan, Germany, Hong Kong and the emerging markets. Thus, investors are unlikely to be able to diversify their portfolio by constructing their portfolio from stocks of both developed and emerging markets to achieve their dual target of seeking for high return while reducing risk.

In this paper, we examine the volatility spillover effects between the developed markets and Southeast Asian emerging markets by comparing the conditional correlations obtained from the DCC multivariate GARCH model in prior-, during- and post-crisis period. It would be interesting to examine the dynamics of spillovers over time using a rolling window analysis. Also, using cross-market correlations allows us to study the linkage or spillovers among markets, but fails to identify the directional spillovers. This remains an idea for further research.

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