The Volatility Comovement among Stock Markets in East Asian Countries

Miss Weijie Yu

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Arts in International Economics and Finance
Field of Study of International Economics
Faculty of Economics
Chulalongkorn University
Academic Year 2018

ความเคลื่อนไหวไปด้วยกันของความผันผวนของตลาดหุ้นในกลุ่มประเทศเอเชียตะวันออก

น.ส.เหว่ยเจีย ยู

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาศิลปศาสตรมหาบัณฑิต
สาขาวิชาเศรษฐศาสตร์และการเงินระหว่างประเทศ สาขาวิชาเศรษฐศาสตร์ระหว่างประเทศ
คณะเศรษฐศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2561

Thesis Title	The Volatility Comovement among Stock Markets in East Asian Countries
By	Miss Weijie Yu
Field of Study	International Economics and Finance
Thesis Advisor	Assistant Professor Yong Yoon, Ph.D.

Accepted by the Faculty of Economics, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Arts

.... Dean of the Faculty of Economics
(Professor WORAWET SUWANRADA, Ph.D.)

THESIS COMMITTEE

.... Chairman
(Associate Professor SOTHITORN MALLIKAMAS, Ph.D.)

.... Thesis Advisor
(Assistant Professor Yong Yoon, Ph.D.)

.... Examiner
(Assistant Professor SAN SAMPATTAVANIJA, Ph.D.)

.... External Examiner
(Tientip Subhanij, Ph.D.)

เหว่ยเจีย ยู : ความเคลื่อนไหวไปด้วยกันของความผันผวนของตลาดหุ้นในกลุ่มประเทศเอเชียตะวันออก. (The Volatility Comovement among Stock Markets in East Asian Countries) อ.ที่ปรึกษาหลัก : ผศ.ยอง ยูนดร.

การวิจัยนี้ศึกษาความผันผวนที่เคลื่อนไหวไปด้วยกันของอัตราผลตอบแทนของตลาดหุ้นในเอเชียตะวันออกผ่านแบบจำลอง DCC-MGARCH ที่ความถี่รายวันตั้งแต่วันที่ 5 มกราคม พ.ศ. 2538 ถึง 31 ธันวาคม พ.ศ. 2561 ผลลัพธ์เชิงประจักษ์แสดงให้เห็นว่าความผันผวนที่เคลื่อนไหวไปด้วยกันที่เกิดขึ้นในตลาดหุ้นเอเชียตะวันออกนั้นเพิ่มขึ้นในช่วงไม่กี่ปีที่ผ่านมา นอกจากนี้ตลาดที่พัฒนาแล้ว (สิงคโปร์ ฮ่องกง จีน ญี่ปุ่นและสาธารณรัฐเกาหลี) มีความสัมพันธ์กันเป็นอย่างมาก ส่วนตลาดการเงินของประเทศเกิดใหม่ (จีน อินเดีย ไทย อินโดนีเซีย มาเลเซียและฟิลิปปินส์) ได้ค่อยๆปรับระดับความผันผวนที่เคลื่อนไหวไปพร้อมกันเข้ากับตลาดอื่นๆ การศึกษานี้ได้ตรวจสอบผลกระทบการรั่วไหลของความผันผวนในเอเชียตะวันออกในระดับต่างๆในช่วงวิกฤตการเงินโลกปี 2551 เราพบว่าวิกฤตการณ์ทางการเงินที่รุนแรงมีผลกระทบเชิงบวกและมีนัยสำคัญต่อทั้งความผันผวนที่เคลื่อนไหวไปด้วยกันและการรั่วไหลของความผันผวนของตลาดการเงินในเอเชียตะวันออก หลังจากวิกฤตสิ้นสุดลง ความสัมพันธ์ข้ามพรมแดนมีความเชื่อมโยงกันและซับซ้อนมากขึ้น ทว่าวิกฤติการเงินก่อให้เกิดการบูรณาการอย่างเป็นระบบในระดับที่สูงขึ้นและความหยุดนิ่งของข้อมูลในตลาดหุ้นเอเชียตะวันออก

สาขาวิชา	เศรษฐศาสตร์และการเงินระหว่างประเทศ	ลายมือชื่อนิสิต ....
ปีการศึกษา	2561	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

6085613429 : MAJOR INTERNATIONAL ECONOMICS AND FINANCE
KEYWORD: Volatility Comovement, Volatility Spillover, East Asian Stock Market, DCC-MGARCH, Impulse Response Function

Weijie Yu : The Volatility Comovement among Stock Markets in East Asian Countries. Advisor: Asst. Prof. Yong Yoon, Ph.D.

Using daily indices for several East Asian and Asian emerging stock markets from 5 January 1995 to 31 December 2018, this study investigates the volatility comovement of the stock market returns in using the DCC-MGARCH model. The empirical results depict that the volatility comovement among East Asian stock markets have increased in recent years. Moreover, this correlation is stronger in the developed markets of Singapore, Hong Kong, Japan and Korea. Volatility comovement across emerging countries, namely, China, India, Thailand, Indonesia, Malaysia and Philippines, has also increased. This study also examines the volatility spillover effects in East Asia at different stages including the periods before and after the 2008 global financial crisis. We find that severe financial crises have positive and significant impacts on both volatility comovement and volatility spillover in East Asian financial markets. And after the crisis periods the cross-border correlations have become even more interconnected and complex, despite the fact that financial crisis tends to trigger higher degree of systematic integration and risk in East Asian stock markets.

Field of Study:	International Economics and Finance	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....

ACKNOWLEDGEMENTS

I would like to express my very profound appreciation and gratitude to Asst. Prof. Dr. Yong Yoon, my thesis advisor, for his patient guidance, enthusiastic encouragement, and valuable and constructive suggestions throughout the planning and development of this research work. Special thanks should also be given to the thesis committee chairman, Assoc. Prof. Dr. Sothitorn Mallikamas, and members of thesis committee, Asst. Prof. San Sampattavanija and Dr. Tientip Subhanij. Their professional comments and recommendations have substantially improved this study.

I cannot forget my close friends who have gave me sincere and unconditional friendship along the way. They cared for me, cheered me up, and went through hard times together with me.

Finally, last but by no means least, I wish to thank my beloved family, my parents Hui Yu and Rongmei Zhang and my brother Weiye Yu, for their selfless love and unfailing support both spiritually and financially throughout my years of study. I would not have come this far without them.

Weijie Yu

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1
INTRODUCTION

1.1 Background

As the enhancing degree of globalization and the increasing openness of capital markets across the world, less barriers exist for international trade and foreign direct investment, the world economy is getting more and more integrated, and the cross-border linkages among countries or regions are becoming much closer to each other and more sensitively-interdependent, including the financial markets. At the same time, the advancement of science and technology has accelerated the speed of information transmission, even the bad news moving rather faster. This has dramatically shortened reaction time and enhanced response speed of investors when something happens. Especially when the issue is rather significantly related to the financial market, people would modify a lot on their investment strategies and investment behaviors, basically due to the nature of risk aversion. Consequently, the stock markets volatile to a great scale. The global financial crises again and again reflect the strong indication of the worldwide financial risk contagion, implying that there exists high possibility for a specific financial disturbance in one country to spread to other countries with great rapidity and that the stock markets are essentially connected.

Apart from that, an increasing number of empirical evidences has been found to show the comovement of stock markets among different country groups or country pairs either in small range or large range, possibly due to the increasing interaction and interdependence among these countries. In other words, they have tendency to move together to some extent, although the degree of effects differ from each country pair. Besides, there are three dimensions related to the stock market comovement phenomenon, namely the index comovement, return comovement and volatility comovement. For now, most of the existing studies paid attention to the stock market comovement in terms of the stock market returns instead of the volatility of returns.

By studying the volatility comovement and spillover, we could know the market correlation degree between country pairs. With obtaining and understanding this comovement relationship, namely risk transmission mechanism behind the market, we could identify which markets are more stable and which markets could be affected by others easily. We could also predict how one market would react and how great the potential financial risk is for itself when other markets are in front of unexpected information and issues. For international investors, if they could tell which international assets are less correlated, they get more opportunity to reduce the risk exposure of their international asset portfolio by diversification. Studying the correlation of different markets would also give some hints for policy makers with financial stability concerns. They could have more evidence to recognize and assess the financial systematic risk to decide when and to what extent to tighten or loosen the financial regulations reacting to turbulence in other financial systems, and to make good policy and regulations for improving the ability to resist financial risk and to maintain a stable financial market. What's more, for both investors and policy makers, it provides certain reference significance to take early-warning actions in advance to prevent huge harm and large-range financial crisis from the risk transmission.

Furthermore, the volatility comovement among financial markets in East Asia is even little estimated in the literature. Despite these stock markets are not as mature as the markets in many developed countries, it has illustrated that the Asian emerging economies should be kept an eye on and they are showing more and more power in impacting the global financial market since the Asian financial crisis. Specifically, Table 1 shows that from 2005 to 2017 countries in East Asia got quite rapid prosperity in terms of both GDP and stock market capitalization. Furthermore, the market capitalization has accounted for about one third of the global stock market at the end of 2017. The growing power of East Asia has made this region significant enough to pay attention to.

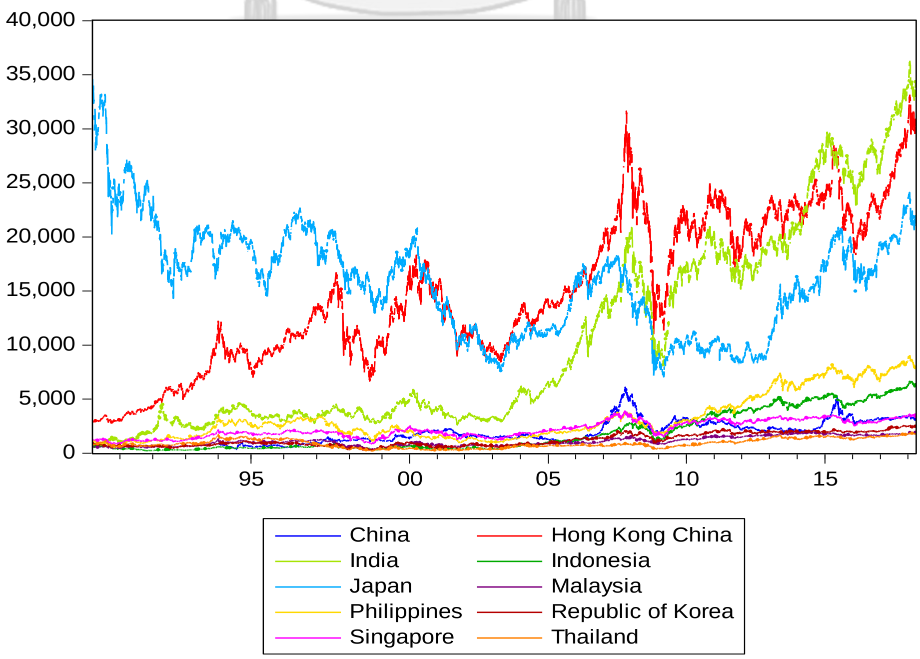
Table 1: GDP and market capitalization of countries in East Asia, 2005 and 2017

Country	GDP (Billion US$)		Market capitalization (Billion US$)		Market capitalization (% of GDP)		GDP growth rate (2005-2017)	Market capitalization growth rate (2005-2017)	Market capitalization (% of world)	
	2005	2017	2005	2017	2005	2017			2005	2017
China	3569.85	10161.01	401.85	8711.27	18%	71%	185%	2068%	1%	11%
Japan	5672.31	6156.33	4572.90	6222.83	96%	128%	9%	36%	11%	8%
Hong Kong, China	188.65	280.35	1055.00	4350.51	581%	1274%	49%	312%	3%	5%
India	1111.20	2629.54	553.07	2331.57	68%	90%	137%	322%	1%	3%
Republic of Korea	894.71	1345.95	718.01	1771.77	80%	116%	50%	147%	2%	2%
Singapore	170.72	310.00	257.34	787.26	202%	243%	82%	206%	1%	1%
Thailand	283.77	422.90	123.88	548.80	65%	121%	49%	343%	0%	1%
Indonesia	571.20	1090.46	81.43	520.69	28%	51%	91%	539%	0%	1%
Malaysia	204.86	364.36	180.52	455.77	126%	145%	78%	152%	0%	1%
Philippines	156.87	303.36	39.80	290.40	39%	93%	93%	630%	0%	0%

Source: author's calculation, based on CEIC database

Figure 1 shows the top 10 stock market indices in East Asia ranking by market capitalization (based on data in 2017) for the period 1995 to 2018. To some extent, the East Asian stock index comovement phenomenon is illustrated, especially when it comes to the financial crisis.

Figure 1: Stock indices of 10 stock markets in East Asia



Source: CEIC database

1.2 Objectives

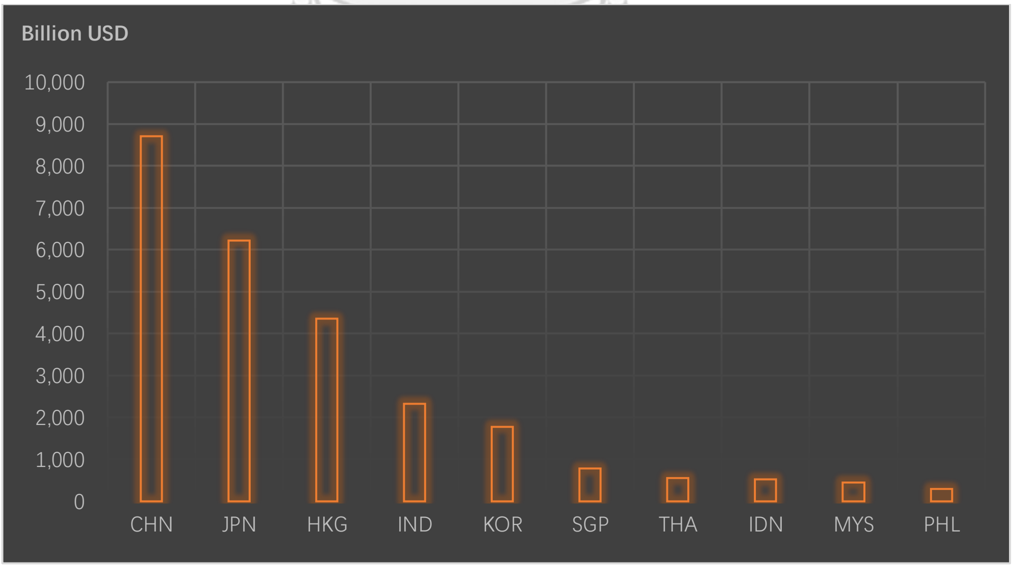
- To measure short-run dynamic linkage across different stock markets in terms of volatility comovement in East Asia, through the dynamic conditional correlation between each country pair obtaining from the DCC-Multivariate GARCH approach.

- To observe the time-varying property of the comovement correlations over the period of 1995-2018, and to analyze how the volatility comovement relationships perform when they meet with financial crisis.

- To investigate how these stock markets in East Asia respond to the internal and external disturbance, namely the volatility spillover effects, during the different stages of the 2008 financial crisis, through impulse response function from VAR approach. Furthermore, to explore how the financial crisis has affected financial system in East Asia.

1.3 Scope

Figure 2: Top 10 regions in East Asia ranking by market capitalization in 2017, billion USD



Source: World Federation of Exchanges database.

This study focuses on 10 regions with the largest market capitalization in East Asia based on 2017 dataset, to investigate the volatility comovement relationship between each pair of nations.

Regions: China, Hong Kong China (Hong Kong), India, Indonesia, Japan, Republic of Korea (Korea), Malaysia, Philippines, Singapore and Thailand.

Time period: 1995:1-2018:12 (Including 1997 Asian financial crisis and 2008 Financial crisis)

CHAPTER 2
LITERATURE REVIEW

2.1 Conceptual Literature

Volatility of returns in one stock market reflects the risk of the market, namely the uncertainty of the market. Hence, the volatility comovement implies the risk transmission across national stock markets. It could be spread via both economic linkage and financial linkage.

2.1.1 Economic linkage

An essential aspect is that shocks in one market can be transmitted to other markets through cross-country bilateral trade, which triggers these economies to have more interaction with each other. Research of Aamir and Ali Shah (2018) mentions the theories of non-contingent crisis, stating that "economies as well as stock markets of two countries are anticipated to be highly integrated due to their strong bilateral trade relationship". In other words, when two nations have high degree of bilateral trade interdependence and trade intensity, they might have high degree of stock market comovement. Therefore, the trade interdependence relationship between two different nations is expected to be a key factor to explain their stock market comovement. To some extent, factors that lead to more bilateral trade intensity of two economies are likely to lead to higher cross-country stock market comovement.

In the perspective of Gravity Theory (Anderson, 2011), when two markets are geographically closer, the volume of trade between them is relatively high because of less information asymmetry, low information costs, and low transaction costs, implying that these two markets are interacting and interdependent at a higher degree and they have more power to affect each other. Thus, the countries in East Asia could have high probability to be affected by the same disturbance, showing stock market volatility move together.

Meanwhile, the macroeconomic harmonization and stability of one economy is another key factor to defend against financial shocks, so as to ensure financial stability (Aamir & Ali Shah, 2018). That is to say, the degree of the economic stability in one country is anticipated to negatively affect the extent of volatility comovement. Basically, an economy with a large scale tends to be more stable and to possess more market power, such as higher liquidity, more information, lower transaction costs etc., enhancing its ability to withstand market risks and maintain stable, in other words, it is not easily to be influenced by the shocks from other stock markets. Hence, lower volatility comovement. Instead, low stabilities tend to combine with high degree of volatility comovement between country pairs.

2.1.2 Financial linkage

In the perspective of financial theory, two dimensions could be considered to explain the comovement phenomenon. The behaviors and strategies of participants in the international investment market directly impact the correlation among separate markets. Moreover, the decisions of investors are based on the available information. Hence, the information transmission across markets could be the immanent cause.

2.1.2.1 Information transmission

Based on the different properties of information, Fleming, Kirby, and Ostdiek (1998) classified information into two categories which create volatility linkages between stock markets in two ways. One is common information, which simultaneously impacts expectations of investors in different stock markets. Therefore, it might simultaneously impact the returns and return volatility in multiple markets. The other one is information spillover through cross-market hedging. In this scenario, the information affects investors' expectations in just one market, then the investors would adjust their holding assets across markets. With these investors trading cross border, the information spills to other markets.

For instance, the international macroeconomic uncertainty is the systematic risk, namely the common information. This kind of unexpected international shocks can be spread rapidly to a quite large scale leading to common turbulence in the international financial markets. The country-specific changes are idiosyncratic risk of each stock market, which could be spread to other markets through investors' cross-border transactions. Specifically, Investors who hold international assets spill the specific information internationally when they rebalance their financial assets portfolios holdings across countries in response to losses or gains, hence volatility comovement will follow. Therefore, the volatility comovement across stock markets depends both on global fundamental disturbance and on the specific information spillover among these markets.

2.1.2.2 Herd behavior theory

On the other hand, the behavior of participants might directly contribute to the price of international assets, rate of returns as well as the volatility comovement phenomenon, especially the herd behavior due to the information asymmetries.

The herding behavior theory provides a dimension to understand the stock market volatility comovement. Herding is the phenomenon that investors copy other investors' behavior. The international herding behavior may lead to inefficiency in the international financial market and it is usually distinguished by fragility and idiosyncrasy, which could cause the excess volatility and systematic risk. Bikhchandani and Sharma (2000) discussed some potential reasons of this herding behavior in financial markets. It arises mainly from the imperfect information, concern for reputation, and compensation structures.

In detail, the imperfect-information-based herd behavior may arise when the accuracy, or lack thereof, of the information with market participants is not common knowledge. Investors may imitate the decisions of the initial group of traders in the erroneous belief that this group knows something. This kind of herding behavior can lead to stock market price bubbles and mispricing.

As to the reputation-based herding, it is based on the reputational concerns of investment professionals, such as fund managers and analysts. As the research mentioned, in the scenario with several managers to make decision, the action of the managers who decide early may be crucial in determining which way the majority will go eventually. Taking care of their reputation, the professionals prefer mimic the strategies of initial investors. As a result, even everyone would imitate the first managers' decisions. Thus, the herding result would be inefficient and fragile, because it is based on very little information. This leads to larger deviation from the fair value, and higher degree of simultaneous volatility.

The compensation-based herding behavior occur when an investment manager's compensation depends of how his or her performance compares with other similar managers. In this case, the manager's incentives are distorted, resulting to inefficient portfolios by just following the behavior of his or her benchmark instead of following profit-maximizing criteria.

Because there is always information asymmetry and principle-agent problem in global investment market, there will always be the possibility for these different types of herding behaviors. What's more, in emerging markets "one is likely to find a greater tendency to herd". The financial investment environment in these markets is relatively less transparent due to weak reporting requirements, lower accounting standards, lax enforcement of regulations, and costly information acquisition. (Bikhchandani & Sharma, 2000)

2.2 Empirical Literature

Many researchers have been interested in the phenomenon of financial contagion in stock markets in the world. While there are a growing number of studies that investigates the international stock market return comovement, the volatility comovement relationship among these markets are relatively unexplored, let alone the volatility comovement in East Asian equity markets.

Up to now, lots of evidence has been found to show the cross-country stock market return correlation. Among equity markets in Americas, Johnson and Soenen (2003) found evidence of a high degree of contemporaneous integration between Argentina, Brazil, Chile, Mexico, Canada, Colombia, Peru, Venezuela and United States in terms of index returns comovement. They also found it is quite information efficient in Americas markets, due to few intermarket arbitrage opportunities beyond 24 hours. In Asia-Pacific Area, Johnson and Soenen (2002) found evidence that stock market of Australia, China, Hong Kong China, Malaysia, New Zealand and Singapore are highly integrated with the Japanese stock market. From another perspective, based on the data from 1973 to 2004, Morana and Beltratti (2008) found the linkages hold between some developed countries, US, the UK, Germany and Japan. By analyzing daily return data of 1997-2010 in some developed European stock markets, United Kingdom, Germany, France and Austria, Dajcman, Festic, and Kavkler (2012) found the return comovement between stock market pair is time-varying and scale dependent. Though the empirical evidence mentioned above implies the comovement between stock market returns, it still reveals the close relationship and strong interdependent among international stock markets. Horvath and Poldauf (2012) found the degree of return comovement somewhat increased during the financial crisis.

As to the volatility comovement, the existing evidence regarding to the return volatility comovement are mainly about the developed economies in the world. R. F. Engle and Susmel (1993) proposed an approach based on the framework of ARCH to investigate the volatility comovement in international equity markets, finding two groups of countries being suspected of having similar volatility behavior, one group composing Hong Kong China, Singapore/Malaysia and Australia, the other composing Belgium, Germany, Norway, Sweden and Spain. Both two groups of countries locate in the same time zone and share the same information within the group. Chen, Kobayashi, and McAleer (2017) investigated the volatility comovement of stock market returns based on the framework of multivariate stochastic volatility model, finding that the United Kingdom, Singapore and Australia share a common time-varying volatility factor consistently. Diebold and Yilmaz (2009) proposed another approach to measure the financial asset volatility spillover, *the spillover index*. After analysis of 19 global equity markets from early 1990s to 2007, found striking evidence of volatility spillovers displaying no trend, but clear bursts associated with crisis events. Following this spillover index method, Yilmaz (2010) found the time-varying volatility spillover among East Asian stock markets and the volatility spillover index experiences significant bursts during major market crises, including the East Asian crisis. In the same framework, Chow (2017) found the increasing overall volatility spillover is not a temporary surge but persisted after the crisis. He also mentioned the relative dominance of the US over the Japanese and

Chinese stock markets, as well as the level of influence on Asian stock markets from Chinese stock market rising to that of Japan. Morana and Beltratti (2008) not only find the increasing comovement in returns among the largest world stock markets, America, United Kingdom, Germany and Japan, but also the increasing comovement in volatilities, particularly strong for America and Europe. Statistically significant volatility spillover and comovement between America, United Kingdom and Japan are found by Balasubramanyan (2004) as well.

As to the methodologies, there exist several approaches to analyze the volatility comovement issues. Based on the approach of Variance Decomposition from VAR model, Diebold and Yilmaz (2009) calculated the volatility spillover index between each pair of equity markets which refers to the extent to which shocks in one stock market affect other stock market volatility of returns, thereby to see whether the markets exhibit comovement or not. Subsequently, rolling window estimations are used to get the volatility spillovers over time.

Multivariate generalized autoregressive conditional heteroscedasticity (MGARCH) model is widely used to investigate volatility comovement effects across markets. This model assumes that the conditional variance of disturbance term relies on the lagged disturbance. However, it is a problem to estimate the model. Especially, the number of parameters would increase dramatically when the number of time series are increased. Although VEC and BEKK approach provide alternative ways to estimate the model to get the parameter matrices, and the time-varying variances of returns and covariances between stock market return series can be obtained, with which the degree of volatility comovement could be measured by calculating the correlations, it still faces the problem of huge number of parameters. According to Bauwens, Laurent, and Rombouts (2006) these models are rarely applied when the number of series is larger than 3 or 4.

R. F. Engle and Sheppard (2001) developed a 2-step approach to simplify the estimating process to estimate the DCC-MGARCH to investigate and observe the dynamic volatility comovement phenomenon directly. This methodology allows more time series and reduces the amount of calculation to a large scale at the same time.

There is another widely-used methodology, namely Stochastic volatility (SV) model, to detect the volatility series (Chen et al., 2017). This model consists of an assumption that the time-varying variance behavior follows an unobserved stochastic process, besides relying on the previous observation. This property distinguishes the SV model from GARCH model. Since the existence of unpredicted shock to the volatility, there is not a certain likelihood function, hence it is not able to obtain the estimators through maximum likelihood estimation method. The Bayesian Markov chain Monte Carlo (MCMC) approach is an efficient estimation method to estimate the SV model combined with Gibbs sample algorithm method, which can be performed via WinBUGS. The basic idea behind MCMC is to specify a Markov chain that is convergent to a stationary distribution and to conduct Monte Carlo experiments to estimate parameters. Then a Lagrange multiplier (LM) test could be executed to test the volatility comovement, by testing whether the volatility processes of two series have correlated common volatility factor. However, this method is kind of complicated for this study. It could be used for further research.

Since the volatility comovement among East Asian financial markets is even little estimated in the literature, this study mainly focuses on the cross-country comovement of stock index return volatilities in the selected countries (regions) in East Asia to analyze how financial contagion shows in Asian nations over time and to investigate how the financial crises affect the degree of integration. To achieve these targets, two approaches are employed in the 10 regions with the largest market capitalization in East Asia, including the DCC-MGARCH model and the Impulse Response Function from VAR model.

CHAPTER 3
METHODOLOGY

Following the estimation approach proposed by R. Engle (2002), this study applied dynamic conditional correlation multivariate generalized autoregressive conditional heteroscedasticity (DCC-MGARCH) model to investigate the dynamic correlation between series and observe its time-varying property, with which we could know the volatility comovement between different stock markets.

Afterwards, based on Vector Autorepression (VAR) model and impulse response function, we could investigate the volatility spillover between each country pair.

3.1 DCC-MGARCH Model

The basic GARCH model assumes that the conditional variance of a series is not constant. It is now frequently used for capturing dynamic characteristics of financial time series. Univariate GARCH model tells the time-varying volatility of a time series by describing how the conditional variance of the series relies on the lagged disturbance term and lagged conditional variance. Meanwhile, the Multivariate GARCH (MGARCH) model is widely used to investigate the volatility comovement effects among different time series. Furthermore, DCC-MGARCH model, introduced by R. F. Engle and Sheppard (2001), could contribute to describe the time-varying volatility comovement, the trend convergence and information transfer among different markets, by obtaining the dynamic conditional correlations (DCCs) between stock markets of each country pairs.

3.1.1 Univariate GARCH model

Starting from the simple univariate GARCH (1, 1) model of daily return series in one stock market, it is defined as:

Mean equation:

$$r_t = E(r_t|I_{t-1}) + \varepsilon_t, t = 1, 2 \ldots, T.$$

$$\varepsilon_t|I_{t-1} \sim i.i.d.N(0, h_t)$$

Conditional variance equation:

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1}, \alpha > 0, \beta > 0 \text{ and } \alpha + \beta < 1$$

Where

r_t is the value of stock market return at period t.

$E(r_t|I_{t-1})$ is the expected value of return at period t.

ε_t is the disturbance of stock market return at period t.

h_t is the conditional variance of ε_t at period t which is a forecasting variance based on all information at period t-1.

The conditional variance of the return series in this GARCH (1, 1) model consists of three parts, a constant term ω, the lagged disturbance squared ε_{t-1}^2 (the ARCH term) and the lagged conditional variance h_{t-1} (the GARCH term).

The parameter α measures the extent to which the unexpected return is related to the conditional variance. In other words, it shows the effect of previous shock in the market on stock market volatility. The parameter β reflects the extent to which current conditional variance is related to previous conditional variance, which shows the continuity of volatility.

3.1.2 DCC-MGARCH model

To measure the volatility comovement among different markets, we need to consider the dynamic conditional correlations (DCCs) obtained from the DCC-MGARCH model involving k-dimensional dependent variables of daily returns. According to research of Hansen and Lunde (2005) which shows GARCH (1,1) model could depict the volatility property of financial asset returns quite well. Hence, this study would employ the DCC-MGARCH (1,1) model to study the volatility comovement in East Asian stock markets.

The idea of this model is that the conditional variance-covariance matrix of the disturbance terms, H_t, can be decomposed into conditional standard deviations matrix of disturbances, D_t, and DCC matrix, R_t. Here, all the matrixes of H_t, D_t, and R_t are designed as time-varying.

The model is specified as follows.

Mean equation:

$$\boldsymbol{r_t} = \boldsymbol{E}(\boldsymbol{r_t}|\Omega_{t-1}) + \boldsymbol{\varepsilon_t}, \boldsymbol{\varepsilon_t} \sim N(0, \boldsymbol{H_t}), \mathrm{t} = 1, 2 \ldots, \mathrm{T}.$$

Where

$\boldsymbol{r_t}$ is k*1 vector of variables of daily returns at period t.

$\boldsymbol{\varepsilon_t}$ is k*1 vector of disturbance of stock market return at period t.

Ω_{t-1} is the information set at period t-1.

$\boldsymbol{H_t}$ is k*k conditional variance-covariance matrix of the disturbance terms.

The dynamic correlation structure is specified as:

$$H_t = D_t R_t D_t$$

$$D_t = \begin{bmatrix} \sqrt{h_{1,t}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sqrt{h_{k,t}} \end{bmatrix}$$

R_t is the DCC matrix of the standardized disturbances μ_t, in which the magnitude of each element, $\rho_{ij,t}$, shows the DCC relationship between two series.

D_t is the diagonal matrix with standard deviations of disturbances as the elements.

Here, μ_{it} is the standardized disturbance term measured by the standardized residual series in the i^{th} stock market. Therefore, μ_t is k*1 vector of the standardized residuals in different markets.

$$\mu_{it} = \frac{\varepsilon_{i,t}}{\sqrt{h_{i,t}}}, i = 1,2,3, \dots, k$$

There are two requirements to specify the form of R_t.

(1) H_t has to be positive because it is a variance-covariance matrix. Then R_t has to be positive to ensure the positive H_t.

(2) All the elements in DCC matrix have to be less than or equal to one by definition.

To satisfy these requirements, R_t is decomposed as:

$$R_t = Q_t^{*\,-1} Q_t Q_t^{*\,-1} = \{\rho_{ij,t}\}$$

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha\mu_{t-1}\mu_{t-1}^T + \beta Q_{t-1} = \{q_{ij,t}\}$$

$\bar{Q}$ is the unconditional variance-covariance matrix of μ_t, estimated as:

$$\bar{Q} = \frac{1}{T}\sum_{t-1}^{T} \mu_t \mu_t^T$$

Q_t^* is a diagonal matrix with the diagonal elements being the square root of the diagonal elements of Q_t.

$$Q_t^* = \begin{bmatrix} \sqrt{q_{11,t}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sqrt{q_{kk,t}} \end{bmatrix}$$

To guarantee H_t to be positive, Q_t has to be positive to ensure R_t to be positive. Therefore, we set some criteria on the parameters α and β, such as $\alpha \geq 0$, $\beta \geq 0$ and $\alpha + \beta < 1$.

3.1.3 Estimation of DCC-MGARCH model

A 2-stage process proposed by R. F. Engle and Sheppard (2001) would be executed to estimate this model via maximum likelihood estimation approach. In the first step, univariate GARCH models are applied to each market. The estimation results of step one would be used to estimate the next step.

Let the parameters of univariate GARCH models for the 10 series be denoted $\theta = (\alpha_1, \alpha_2, \ldots, \alpha_{10}, \beta_1, \beta_2, \ldots, \beta_{10})$, and the additional parameters in R_t, $\alpha\ and\ \beta$, be denoted ϕ. The log-likelihood function could be written as the sum of a volatility part and a correlation part:

$$L(\theta,\phi) = L_V(\theta) + L_C(\phi)$$

The volatility part is

$$L_V(\theta) = -\frac{1}{2}\sum_t \left(n\ln(2\pi) + \ln|D_t|^2 + \varepsilon_t' {D_t}^{-2}\varepsilon_t\right)$$

The correlation component is

$$L_C(\phi) = -\frac{1}{2}\sum_t \left(\ln|R_t| + \mu_t' {R_t}^{-1}\mu_t - \mu_t'\mu_t\right)$$

The first step:

Univariate GARCH models are applied in each stock market. In this study, the mean equation in the univariate GARCH model applied the AR(1) model. Hence, for country i, the univariate model is

$$r_{i,t} = c_i + b_i r_{i,t-1} + \varepsilon_{it}, \varepsilon_{i,t}|I_{t-1} \sim i.i.d.N(0,h_{it})$$

$$h_{it} = \omega_i + \alpha_i\varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1}$$

Parameters in θ are estimated by maximizing the likelihood function of volatility part:

$$L_V(\theta) = -\frac{1}{2}\sum_t\sum_{i=1}^{n}(\log(2\pi) + \log(h_{i,t}) + \frac{\varepsilon_{i,t}^2}{h_{i,t}})$$

With the estimator of $\hat{\theta}$, we could obtain the time-varying conditional variance of each stock market return series $h_{i,t}$ and the disturbance term ε_{it}, with which the vector of standardized disturbance terms μ_t and the unconditional variance-covariance matrix $\bar{Q}$ can be estimated.

The second step:

In the second step, parameters of ϕ, α and β, are estimated through

$$\max_{\phi}\{L_C(\hat{\theta},\phi)\}.$$

Then we could estimate the DCC matrix R_t to investigate the extent to which the volatility comovement performed in East Asian stock market. The DCC value of each market-pair reflects the dynamic correlation between the two markets. The larger the DCC value is, the more trend convergence and higher volatility comovement degree they have. See R. Engle (2002) and Orskaug (2009) for more on the DCC-MGARCH model specification.

Then the correlation relationship would be illustrated in graphs to analyze to what extent the volatility comovement performed in East Asian stock markets, what kind of property and trend convergence characteristics the comovement relationships show, which country pairs volatile more synchronously, and the relationship between comovement degree and time period, for example financial crisis etc.

3.2 Impulse Response Function from VAR Model

To measure volatility spillover between equity markets in East Asia, this study employs impulse response function from VAR approach.

Firstly, we build VAR model applying the 10 conditional variance series obtained from the first step of DCC-MGARCH model, namely the univariate GARCH model. The framework of VAR model with 10 endogenous variables and p lags is as follows:

$$\begin{aligned} VCHN_t = \ & \alpha_1 + \beta_{11}VCHN_{t-1} + \beta_{12}VJPN_{t-1} + \beta_{13}VHKG_{t-1} + \beta_{14}VIND_{t-1} \\ & + \beta_{15}VKOR_{t-1} + \beta_{16}VSGP_{t-1} + \beta_{17}VTHA_{t-1} + \beta_{18}VIDN_{t-1} \\ & + \beta_{19}VMYS_{t-1} + \beta_{1,10}VPHL_{t-1} + \cdots + \varepsilon_{1t} \end{aligned}$$

$$\begin{aligned} VJPN_t = \ & \alpha_2 + \beta_{21}VCHN_{t-1} + \beta_{22}VJPN_{t-1} + \beta_{23}VHKG_{t-1} + \beta_{24}VIND_{t-1} \\ & + \beta_{25}VKOR_{t-1} + \beta_{26}VSGP_{t-1} + \beta_{27}VTHA_{t-1} + \beta_{28}VIDN_{t-1} \\ & + \beta_{29}VMYS_{t-1} + \beta_{2,10}VPHL_{t-1} + \cdots + \varepsilon_{2t} \end{aligned}$$

$$
\begin{aligned}
VHKG_t = \ & \alpha_3 + \beta_{31}VCHN_{t-1} + \beta_{32}VJPN_{t-1} + \beta_{33}VHKG_{t-1} + \beta_{34}VIND_{t-1} \\
& + \beta_{35}VKOR_{t-1} + \beta_{36}VSGP_{t-1} + \beta_{37}VTHA_{t-1} + \beta_{38}VIDN_{t-1} \\
& + \beta_{39}VMYS_{t-1} + \beta_{3,10}VPHL_{t-1} + \cdots + \varepsilon_{3t}
\end{aligned}
$$

$$
\begin{aligned}
VIND_t = \ & \alpha_4 + \beta_{41}VCHN_{t-1} + \beta_{42}VJPN_{t-1} + \beta_{43}VHKG_{t-1} + \beta_{44}VIND_{t-1} \\
& + \beta_{45}VKOR_{t-1} + \beta_{46}VSGP_{t-1} + \beta_{47}VTHA_{t-1} + \beta_{48}VIDN_{t-1} \\
& + \beta_{49}VMYS_{t-1} + \beta_{4,10}VPHL_{t-1} + \cdots + \varepsilon_{4t}
\end{aligned}
$$

$$
\begin{aligned}
VKOR_t = \ & \alpha_5 + \beta_{51}VCHN_{t-1} + \beta_{52}VJPN_{t-1} + \beta_{53}VHKG_{t-1} + \beta_{54}VIND_{t-1} \\
& + \beta_{55}VKOR_{t-1} + \beta_{56}VSGP_{t-1} + \beta_{57}VTHA_{t-1} + \beta_{58}VIDN_{t-1} \\
& + \beta_{59}VMYS_{t-1} + \beta_{5,10}VPHL_{t-1} + \cdots + \varepsilon_{5t}
\end{aligned}
$$

$$
\begin{aligned}
VSGP_t = \ & \alpha_6 + \beta_{61}VCHN_{t-1} + \beta_{62}VJPN_{t-1} + \beta_{63}VHKG_{t-1} + \beta_{64}VIND_{t-1} \\
& + \beta_{65}VKOR_{t-1} + \beta_{66}VSGP_{t-1} + \beta_{67}VTHA_{t-1} + \beta_{68}VIDN_{t-1} \\
& + \beta_{69}VMYS_{t-1} + \beta_{6,10}VPHL_{t-1} + \cdots + \varepsilon_{6t}
\end{aligned}
$$

$$
\begin{aligned}
VTHA_t = \ & \alpha_7 + \beta_{71}VCHN_{t-1} + \beta_{72}VJPN_{t-1} + \beta_{73}VHKG_{t-1} + \beta_{74}VIND_{t-1} \\
& + \beta_{75}VKOR_{t-1} + \beta_{76}VSGP_{t-1} + \beta_{77}VTHA_{t-1} + \beta_{78}VIDN_{t-1} \\
& + \beta_{79}VMYS_{t-1} + \beta_{7,10}VPHL_{t-1} + \cdots + \varepsilon_{7t}
\end{aligned}
$$

$$
\begin{aligned}
VIDN_t = \ & \alpha_8 + \beta_{81}VCHN_{t-1} + \beta_{82}VJPN_{t-1} + \beta_{83}VHKG_{t-1} + \beta_{84}VIND_{t-1} \\
& + \beta_{85}VKOR_{t-1} + \beta_{86}VSGP_{t-1} + \beta_{87}VTHA_{t-1} + \beta_{88}VIDN_{t-1} \\
& + \beta_{89}VMYS_{t-1} + \beta_{8,10}VPHL_{t-1} + \cdots + \varepsilon_{8t}
\end{aligned}
$$

$$
\begin{aligned}
VMYS_t = \ & \alpha_9 + \beta_{91}VCHN_{t-1} + \beta_{92}VJPN_{t-1} + \beta_{93}VHKG_{t-1} + \beta_{94}VIND_{t-1} \\
& + \beta_{95}VKOR_{t-1} + \beta_{96}VSGP_{t-1} + \beta_{97}VTHA_{t-1} + \beta_{98}VIDN_{t-1} \\
& + \beta_{99}VMYS_{t-1} + \beta_{9,10}VPHL_{t-1} + \cdots + \varepsilon_{9t}
\end{aligned}
$$

$$
\begin{aligned}
VPHL_t = \ & \alpha_{10} + \beta_{10,1}VCHN_{t-1} + \beta_{10,2}VJPN_{t-1} + \beta_{10,3}VHKG_{t-1} + \beta_{10,4}VIND_{t-1} \\
& + \beta_{10,5}VKOR_{t-1} + \beta_{10,6}VSGP_{t-1} + \beta_{10,7}VTHA_{t-1} + \beta_{10,8}VIDN_{t-1} \\
& + \beta_{10,9}VMYS_{t-1} + \beta_{10,10}VPHL_{t-1} + \cdots + \varepsilon_{10t}
\end{aligned}
$$

Where

$$VCHN_t = Conditional\ variance\ of\ Chinese\ stock\ market\ return, at\ time\ t$$

$$VJPN_t = Conditional\ variance\ of\ Japanese\ stock\ market\ return, at\ time\ t$$

$$VHKG_t = Conditional\ variance\ of\ Hong\ Kong\ stock\ matket\ return, at\ time\ t$$

$$VIND_t = Conditional\ variance\ of\ Indian\ stock\ matket\ return, at\ time\ t$$

$$VKOR_t = Conditional\ variance\ of\ Korea\ stock\ matket\ return, at\ time\ t$$

$$VSGP_t = Conditional\ variance\ of\ Singapore\ stock\ matket\ return, at\ time\ t$$

$$VTHA_t = Conditional\ variance\ of\ Thailand\ stock\ matket\ return, at\ time\ t$$

$$VIDN_t = Conditional\ variance\ of\ Indian\ stock\ matket\ return, at\ time\ t$$

$$VMYS_t = Conditional\ variance\ of\ Malaysian\ stock\ matket\ return, at\ time\ t$$

$$VPHL_t = Conditional\ variance\ of\ Philipine\ stock\ matket\ return, at\ time\ t$$

$$\varepsilon_{it}\ \ is\ an\ idiosyncratic\ white\ noise\ error\ term.$$

Based on the VAR lag order selection criteria, mainly the Akaike info criterion (AIC), we could get that the optimal length of lags and specify the VAR model. The lag length which results to the smallest value of AIC is chosen as the optimal, in which case the VAR system performs best to catch the dynamics among the endogenous variables without losing unnecessarily more degrees of freedom.

Then the generalized impulse response function analysis from the VAR model would be executed to detect how one stock market would react to shocks from other markets, and thereby to see how the East Asian stock markets exhibit volatility spillover effects.

CHAPTER 4
DATA

In this study, daily closing stock market indices of the 10 East Asian countries are obtained from the CEIC database, accessed in January 2019. The rate of return is calculated as difference of the logarithmic daily closing index in the main stock market of each economy, namely $r_t = \ln(index_t) - \ln(index_{t-1})$. The first day of observation is 5 January, 1995 and the last day is 31 December 2018. Days without trading data of the observed stock market were computed with linear interpolation method. The total number of observations accounts to 6485 for each market. Table 2,3 and 4 present the stock market indices this study used, the data measurement and sources, and the descriptive statistics of the 10 daily index returns time series.

Table 2: Stock index variables

REGIONS	STOCK INDEX	VARIABLES
China	Shanghai Composite Index	CHN
Hong Kong	Hang Seng Index	HKG
Indonesia	JSX Composite Index	IDN
India	S&P BSE Sensex Index	IND
Japan	Nikkei 225 Index	JPN
Korea	KOSPI Composite Index	KOR
Malaysia	FTSE Bursa Malaysia KLCI (FBMKLCI)	MYS
Philippines	PSE Composite Index	PHL
Singapore	FTSE Straits Times Index	SGP
Thailand	SET Index	THA

Table 3: Data measurement and source

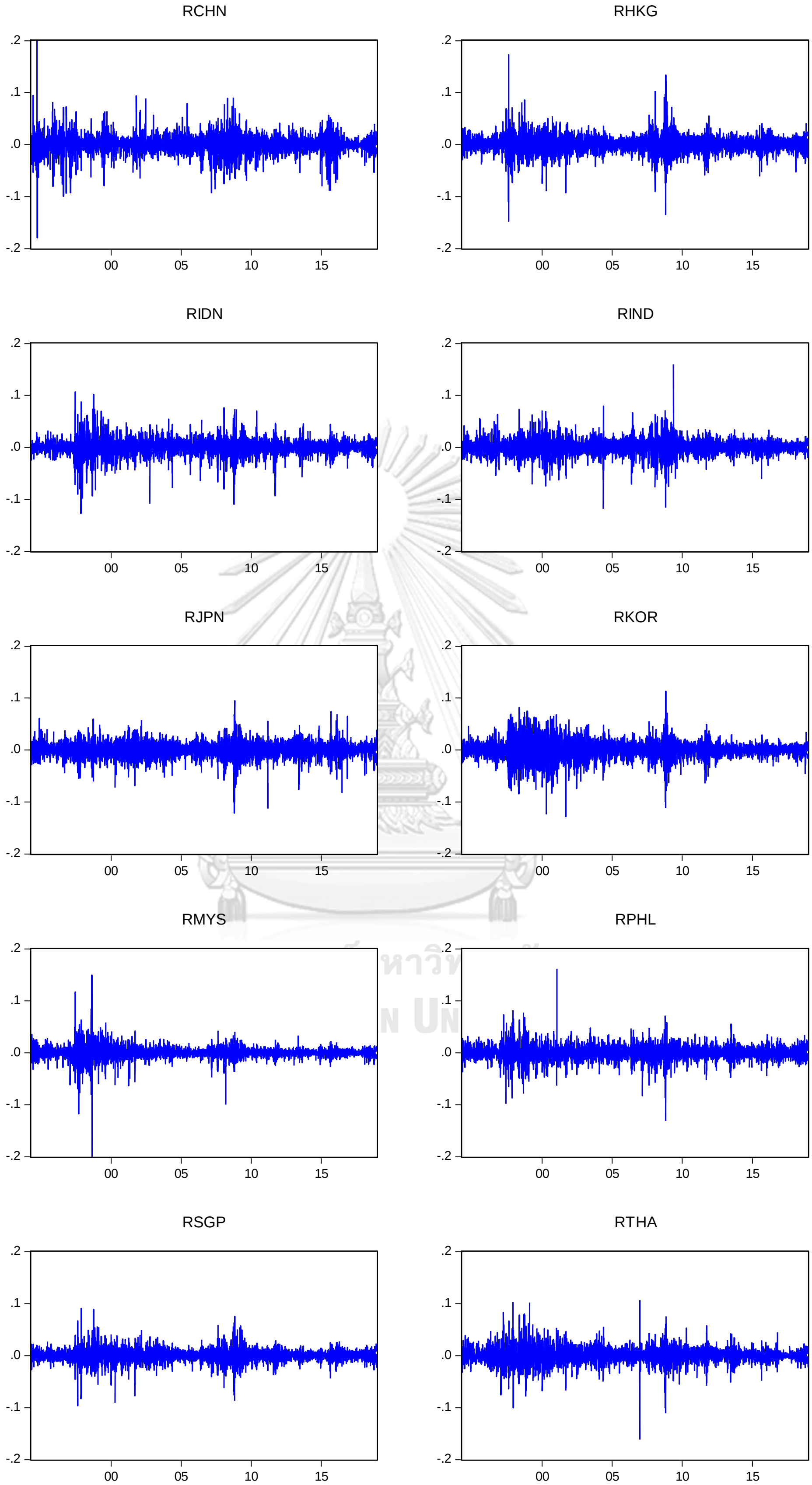
Variable	Measurement of variable	Data source
Stock Index	Daily closing stock indices for 10 East Asian countries/regions.	CEIC database
Market Capitalization	The market value of total stocks, equal to the share price times the number of shares for the listed companies.	World Federation of Exchanges database and CEIC database

Table 4: Descriptive statistics of stock market daily returns time series

	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis	Obs.
R_CHN	0.00021	0.00055	0.26993	-0.17905	0.01603	0.22354	22.68417	6485
R_HKG	0.00018	0.00044	0.17247	-0.14735	0.01465	0.01260	14.62761	6485
R_IDN	0.00040	0.00079	0.10691	-0.12732	0.01388	-0.34504	11.62392	6485
R_IND	0.00034	0.00076	0.15990	-0.11809	0.01383	-0.09422	10.47055	6485
R_JPN	0.00000	0.00022	0.09494	-0.12111	0.01377	-0.50339	8.76912	6485
R_KOR	0.00011	0.00049	0.11284	-0.12805	0.01570	-0.36150	8.89999	6485
R_MYS	0.00009	0.00018	0.14919	-0.24153	0.01108	-1.00734	57.78561	6485
R_PHL	0.00015	0.00028	0.16178	-0.13089	0.01270	-0.09198	13.22101	6485
R_SGP	0.00008	0.00012	0.09081	-0.09672	0.01139	-0.23629	10.53207	6485
R_THA	0.00002	0.00006	0.10577	-0.16063	0.01374	-0.07039	12.05840	6485

Figure 3 illustrates the stock market daily returns in these 10 countries for the period 1995 to 2018. We can observe that for each market, by and large, the rate of return fluctuated around 0 and the volatilities of returns are not consistent as time goes by, showing clustering phenomenon for some periods. For instance, there existed dramatically increasing volatilities in some countries during 1997 Asian financial crisis period, such as Hong Kong, Indonesia, Singapore, Malaysia, and Thailand, and in all the 10 countries during 2008 financial crisis.

Figure 3: Daily returns of 10 stock indices in East Asia, January 1995 to December 2018



Source: calculated by author, based on CEIC database

CHAPTER 5
EMPIRICAL RESULTS

In this section, I discuss the empirical results of volatility comovement through DCCs and the volatility spillover through impulse response function from the VAR system.

5.1 Volatility Comovement

Firstly, I modeled the 10 series of national stock market returns with the DCC-MGARCH model, based on the 2-step estimation method. The estimation results demonstrate that the extent of volatility comovement of stock market returns differs across the country pairs in East Asia and varies over time. And to analyze these 10 markets, this study regards them as two groups based on the MIF classification criteria(IMF, 2019), namely Developed-Country Group and Emerging-Country Group. The Developed-Country group comprises Singapore, Hong Kong, Japan and Korea, with the other countries in the Emerging-Country group.

5.1.1 Developed-Country group

(1) Singapore

The estimation results demonstrate that Singaporean stock market is highly correlated with most of the Asian stock markets, which means the volatility tendency of Singaporean stock returns is kind of consistent with other markets. Figure 4 exhibits the DCCs between Singaporean stock market and other markets. Comparing with the emerging country group, the correlations between Singapore and developed countries (Hong Kong, Japan, and Korea) are significantly larger, while it is least correlated with Chinese stock market in terms of the volatility of stock returns.

Over the whole period, the degree of volatility comovement between Singaporean stock market and Hong Kong stock market has been the highest, with the DCC being more than 0.5 most of the time and fluctuating around 0.6. Furthermore, the financial crises threw quite positive impact on the volatility comovement between Singapore and Hong Kong, especially the 2008 global financial crisis pushed the correlation even higher than 0.7. The effects of both 1997 Asian Financial Crisis and 2008 Global Financial

Crisis persisted for about 6-7 years. We can also observe another surging period for DCC between Singapore and Hong Kong, from the second half of 2015 to 2016.

Apart from that, Singaporean stock market is also strongly correlated with Japan and Korea. These two relationships have developed nearly along the same path since 1995. From the second half of 1997 till the end of 2008, the correlations were generally increasing to the peak at about 0.63, with a small scale of decrease over 2002-2005. Since 2009, the volatility comovement of Singapore with these two markets slowly returned with fluctuations, both of which were about 0.53 at the end of 2018.

As to the relationships between Singapore and other emerging countries in East Asia, the tendencies for volatility comovement between Singapore and other ASEAN countries (Indonesia, Malaysia, Philippines, and Thailand) were quite similar. It worth to mention that the Association of Southeast Asian Nations (ASEAN) has been established since August 1967, with Indonesia, Malaysia, Philippines, Singapore and Thailand being the Founding Fathers[1]. Since then, these countries started to cooperate in politics, economics and culture, which leads to increasingly closer linkage among these nations and promotes the process of market integration of Southeast Asia. This might be a reasonable explanation for the consistent time-varying property of volatility comovement between these four market-pairs and for the relatively significant comovement phenomenon. The results depict that these correlations rose significantly in 1997 Asian financial crisis and then reverted to the normal values. During the 2008 global financial crisis, the volatility comovement surged to even higher levels and fluctuated in the high levels for several years. Then they started to decrease slightly with another small peak during 2015-2016 and followed by an upward tendency at the end of 2018. In the late 1990s, DCCs between Singapore and India kept low. In the 21st century, they shared the same trend with other emerging countries. The relationship between Singapore and China fluctuated around only 0.1 until 2007. After that, the correlation started to rise, whereas still in the very low level.

[1] https://asean.org/asean/about-asean/

Figure 4: DCCs between Singaporean stock market and other markets

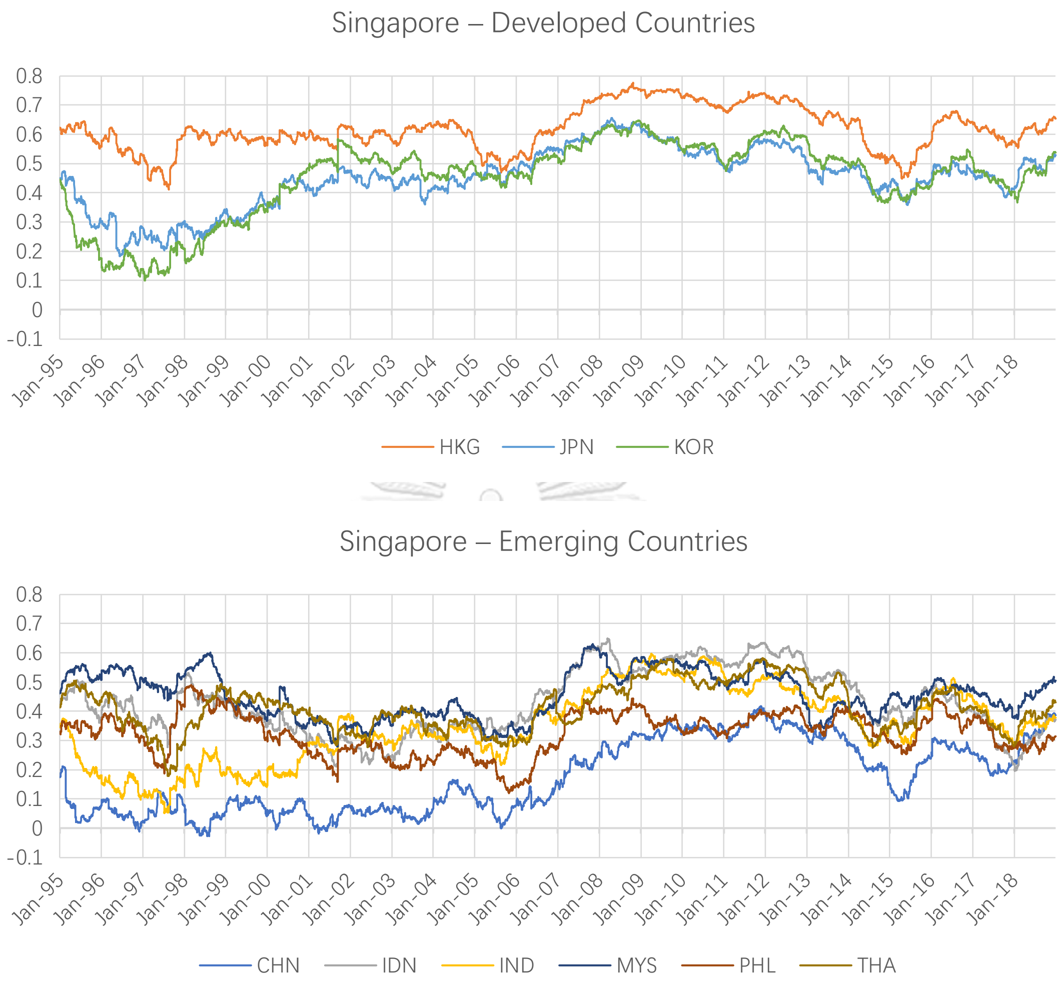
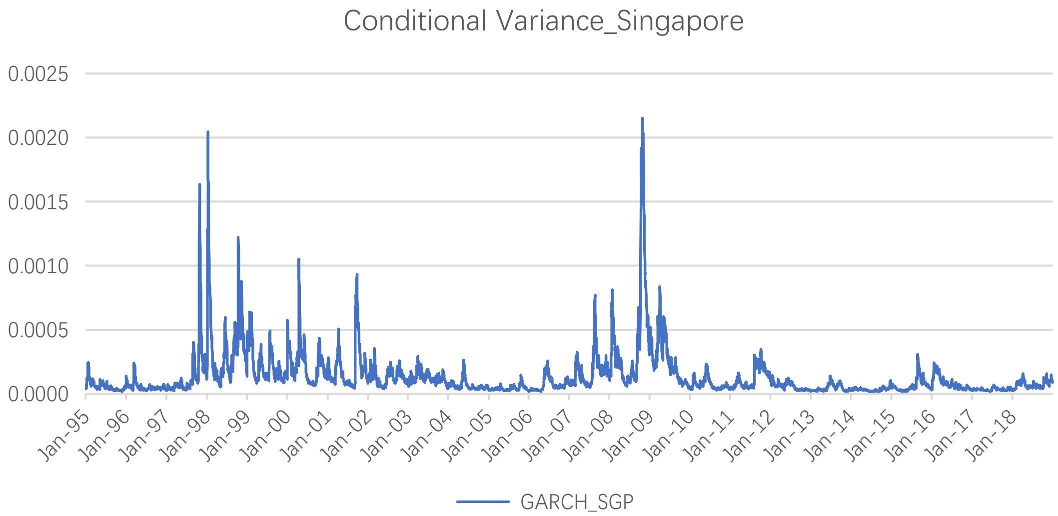


Figure 5: Conditional variance of Singaporean stock market returns



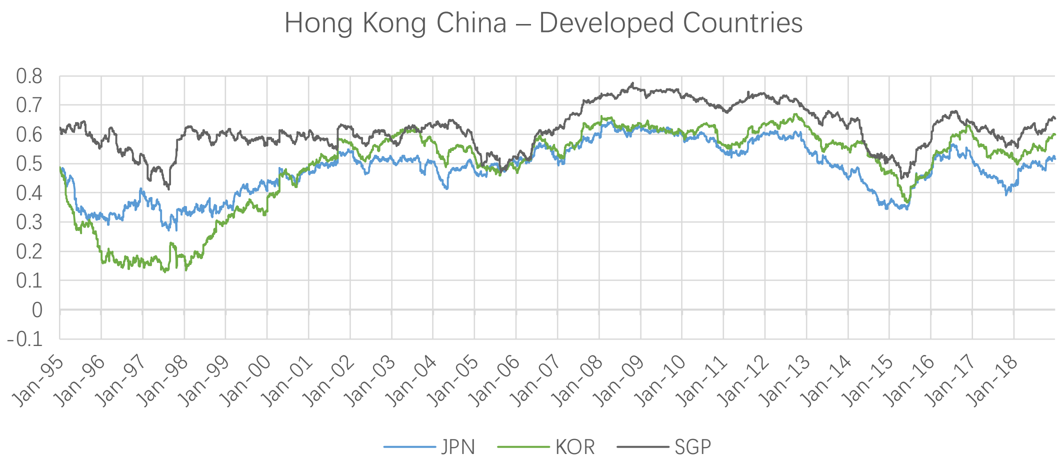
(2) Hong Kong China

Correlations between Hong Kong and every other country are quite strong and fluctuant over time. Specifically, Hong Kong stock market is strongly correlated with the developed stock markets in Japan, Korea and Singapore, especially with Singapore (Figure 6).

Basically, since the 1997 Asian Financial Crisis the correlations between Hong Kong stock market and other markets increased except mainland China. Afterwards, it fluctuated with different trends in different markets. For instance, the volatility comovement between Hong Kong and ASEAN emerging countries (Indonesia, Malaysia, Philippines, and Thailand) fluctuated with downward tendency, while India, Japan, and Korea with upward tendency. As to the other countries (Singapore and China), it stayed more stable oscillating around some certain levels. This is in line with Jin (2015)'s finding that Asian financial crisis has significant impact on Hong Kong market and the length of the impact is relatively protracted.

Then, for all these countries, the correlations went up consistently from 2007 to 2009 and kept in the high level for several years till about in 2013. During this period, the DCCs with developed partners fluctuated in range from 0.5 to 0.8, and the DCCs with emerging partners fluctuated in range from 0.4 to 0.6. Then these correlations of Hong Kong with all countries except China started to turned down to the valley value in about 2015, followed by peaks around at the end of 2015 or in 2016. The development of HongKong-China DCCs only slightly declined after 2012, even exceeding other emerging countries most of the time. Affected by the trade war between America and China, the DCCs with all these partners have presented clearly upward trend since 2018, with China being especially outstanding reaching 0.59 at the end of 2018, even higher than HongKong-Korea and HongKong-Japan DCCs.

Figure 6: DCCs between Hong Kong stock market and other markets



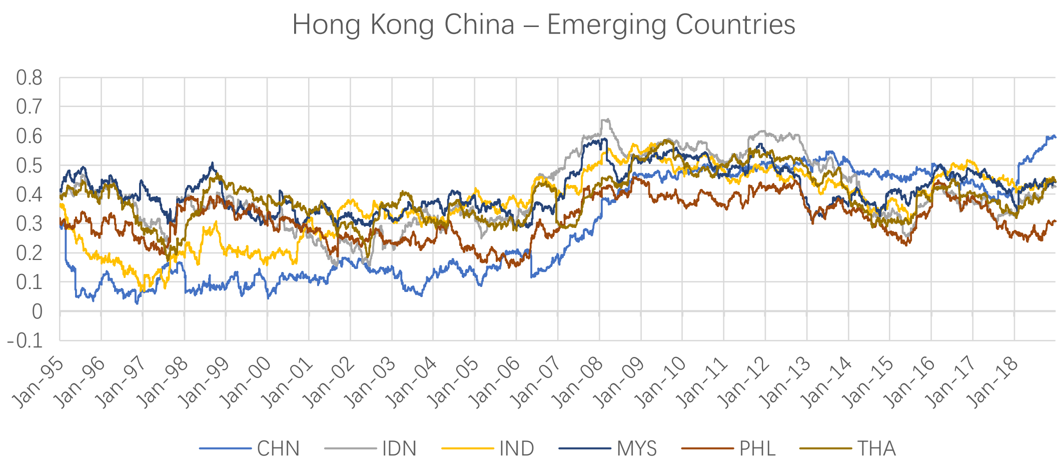
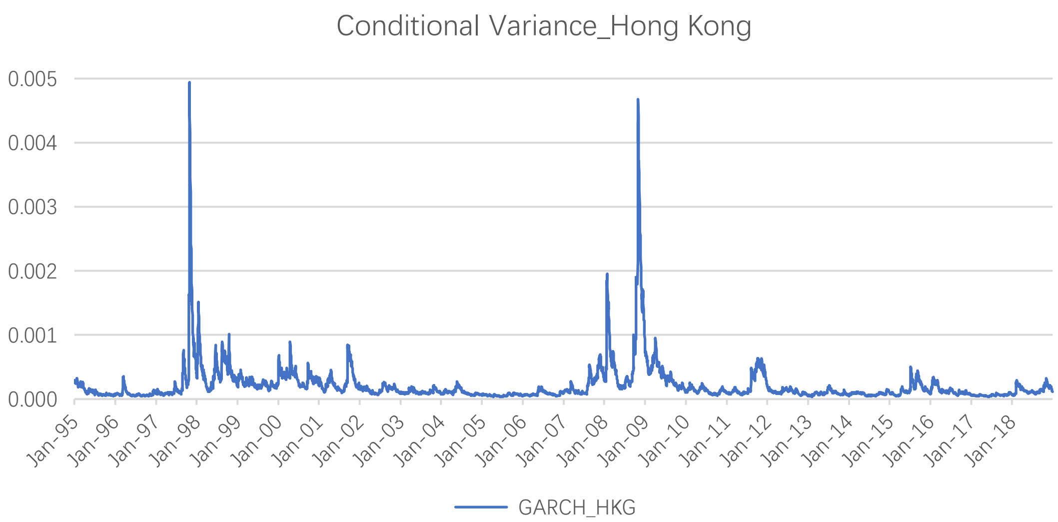


Figure 7: Conditional variance of Hong Kong stock market returns



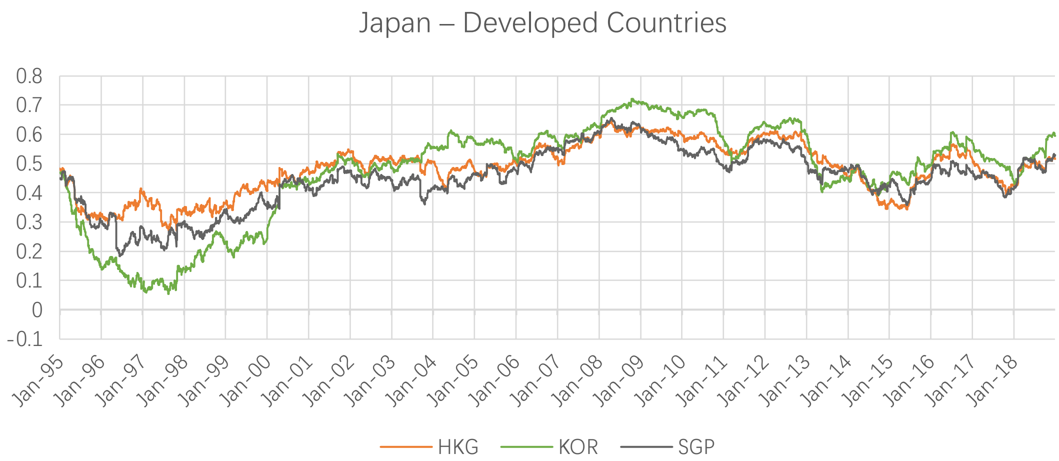
(3) Japan

Figure 8 shows the volatility comovement between Japanese stock market and other East Asian markets. Japanese stock market has strong volatility comovement with those developed markets, Hong Kong, Korea and Singapore, with the DCC degrees being about 0.52 averagely in the 2000s. The DCC relationships with emerging markets have been around 0.29 on average during the same time period.

Unlike Singapore and Hong Kong, the Asian Financial crisis seems to cause little instant effects on DCCs of Japan with other markets, possibly because Japan was suffering the so-called Lost Decade when experiencing low economic growth and low investment. After entering to the 21st century, the DCC curves depict that Japanese stock market has been more and more sensitive to other Asian markets, both developed and emerging markets, and has been most closely correlated with Korean stock market. The DCC degrees climbed up and keeping at the peak level over 2007-2012 for all these stock markets. During these high-comovement years, the degree of DCCs with developed countries distributed from 0.5 to 0.7, while the DCCs with emerging countries distributed from 0.3-0.5. After the Global Financial Crisis, the volatility comovement started to weaken to fluctuate around their normal values and somehow reversed back at another peak in 2015-2016. Among these emerging countries, Malaysia has been more integrated with Japanese stock market. However, DCCs of Japan-China were far below DCCs between Japan and other emerging countries before 2008 but exceeded in 2018. In general, Japanese stock market has been much more corelated with the external East Asian markets than before.

In addition, the America-China trade war seems to positively affect the volatility comovement between Japan and other markets as well. Since 2018, all the DCC curves of Japanese stock market have been rising.

Figure 8: DCCs between Japanese stock market and other markets



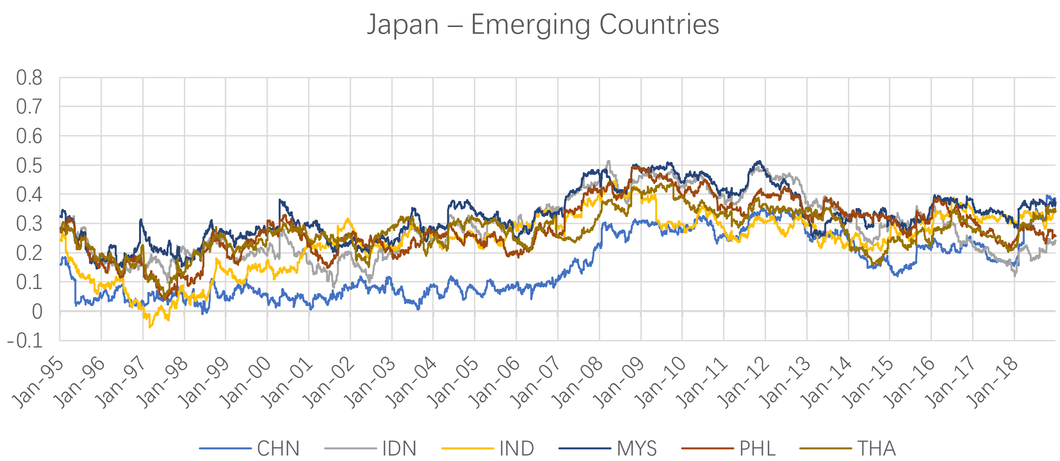
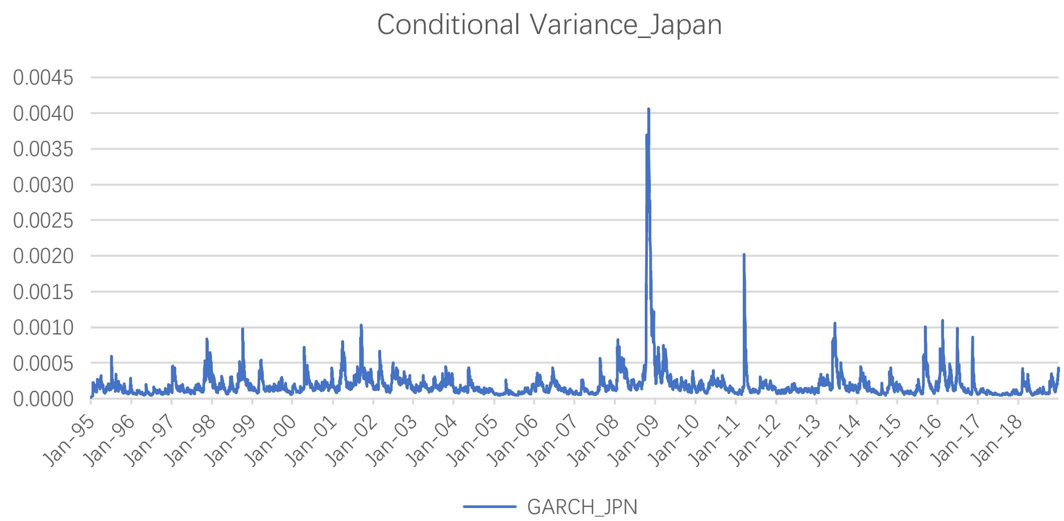


Figure 9: Conditional variance of Japanese stock market returns



(4) Republic of Korea

Figure 10 shows the volatility comovement between Korean stock market and other East Asian markets. Similar with Japan, as one of the developed countries in East Asia, Korea is also more significantly sensitive to the developed markets, namely Hong Kong, Japan and Singapore. Since the 21st century, the conditional correlations with developed markets are slightly higher than Japan, averagely around 0.54, while its' average volatility comovement degrees with emerging countries are sort of higher than Japan as well, about 0.32.

Korea suffered a lot due to the 1997 Asian financial crisis involving currency depreciation, debt crisis and capital outflows. To deal with the destructions of the financial crisis, Korea started to implement financial liberalization reform to strengthen the regulations, enhance the systematic efficiency and open up financial markets, under propellant power of chaebols, United States, and international organizations (especially the OECD and the IMF)(Kwon, 2004). Since then, Korea got through the crisis and the economy was resurgent, along with more deeply integrating into the globalization. Figure 10 shows that nearly all the volatility correlations between Korean stock market and other markets also surged continuously since 1997. For developed-country group, the DCCs increased from around 0.1 to 0.5, while for emerging-country group, from 0.1 to 0.3. The only exception case is Korea-China correlation, almost keeping low (less than 0.1) until 2007.

The pattern and the trend of the DCC curves between Korean stock market and other Asian stock markets kind of resemble the DCC curves of Japanese stock market after entering the 21st century, including the global financial crisis and the Korea-China DCCs exceeding Korea-OtherEmergingMarket in 2018. Apart from that, it is clear that Korea is basically more correlated with other markets in East Asia nowadays compared with the first half of the whole period.

Figure 10: DCCs between Korean stock market and other markets

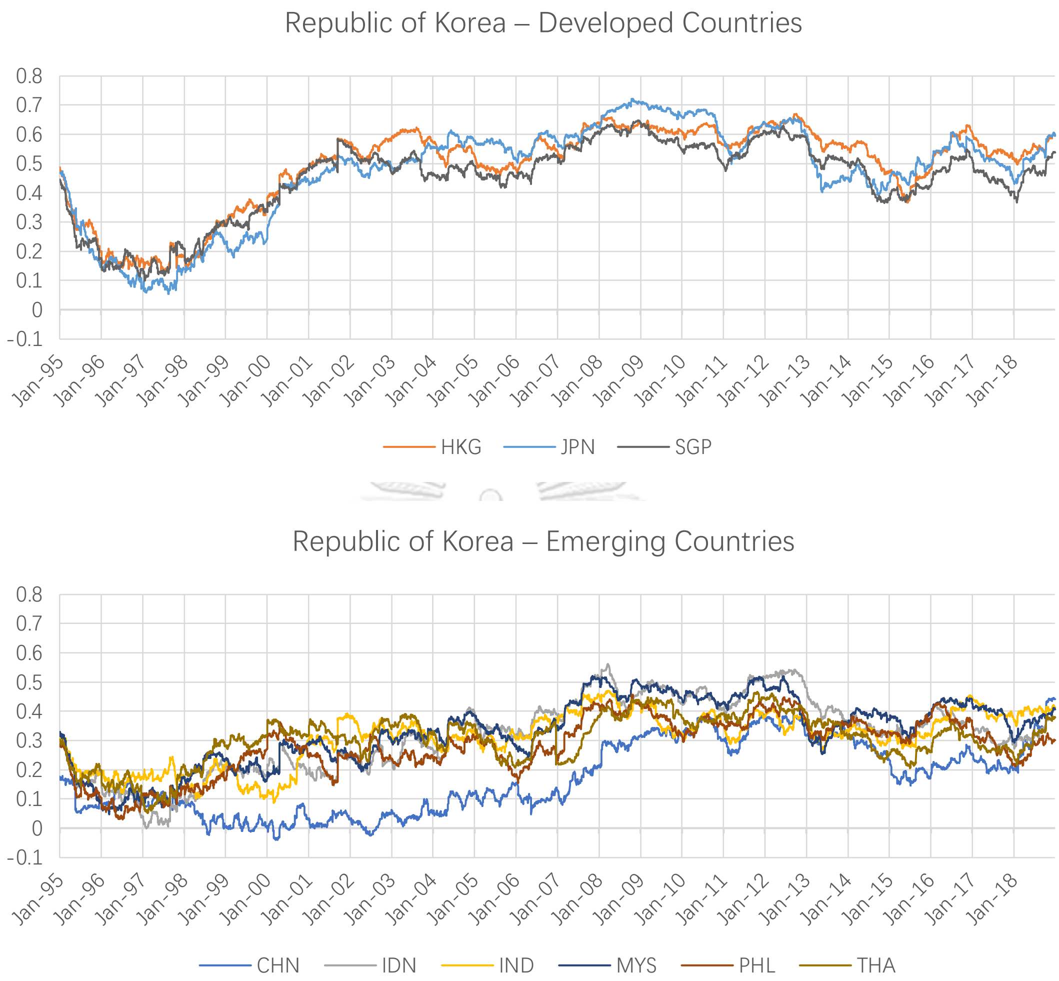
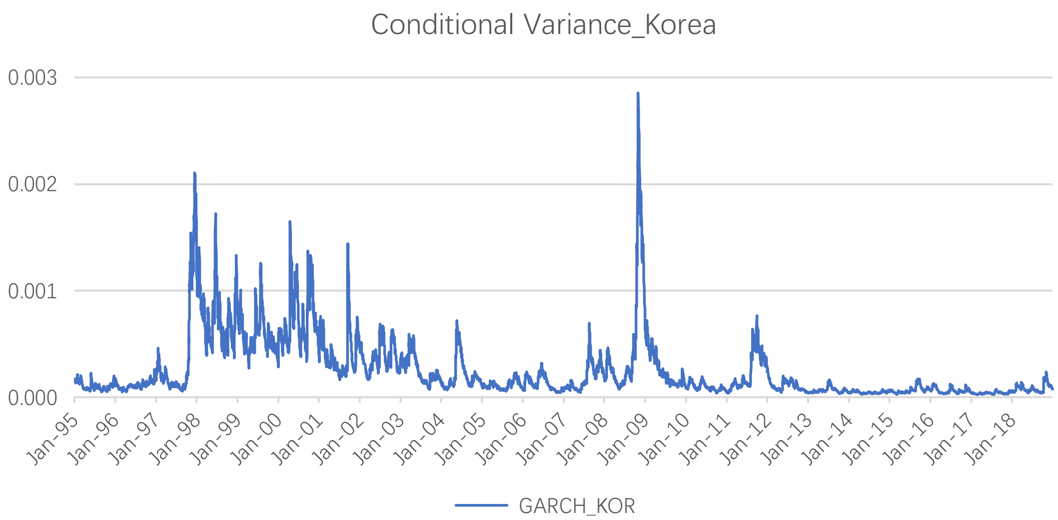


Figure 11: Conditional variance of Korean stock market returns



5.1.2 Emerging-Country group

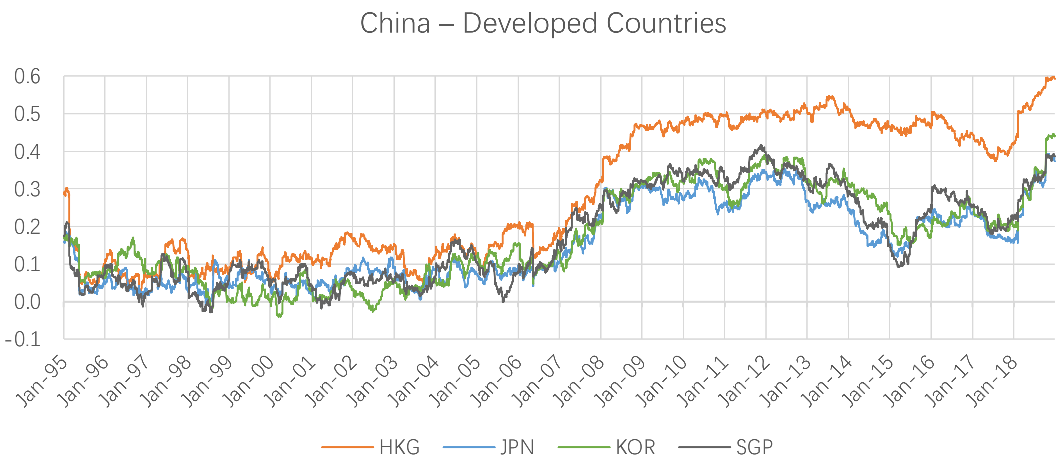
(1) China

Consistent with empirical result of Shen (2018) that Chinese stock market shows more immune to international shocks, our results also show that Chinese stock market possesses the least volatility comovement with other Asian markets among which the correlation of Chinese stock market with Hong Kong stock market is slightly higher, compared with the correlation between China and other countries which are basically less than 0.3.

Generally, from 1995 to 2007 Chinese stock market was little correlated with other stock markets, with the dynamic conditional correlations keeping about 0.1 or under 0.1 for almost all the countries. Since 2007 the correlations started to climb up continuously and fluctuated at higher level, when Hong Kong increased at a faster pace. Then, all the correlations except China-HongKong DCCs turned down from 2014 to first half of 2015, and reverted in the second half of 2015 to arrive at peak in 2016. On the other hand, the correlation between Chinese stock market and Hong Kong market has kept a relatively high level (about 0.5) since 2009 and reached 0.6 at the end of 2018.

Referring to Lee and Wong (2012), since 2003, China started to open up domestic stock market to foreign investors by allocating investment quota to Qualified Foreign Institutional Investors (QFII). Apart from that, before July 2005 China was under fixed exchange rate system and Chinese currency renminbi started to adopt the managed floating exchange rate system since 21st July 2005. These led to the very limited connection with other countries and therefore avoiding large impact from the 1997 Asian Financial Crisis. In the following years, China has tried to promote the financial liberalization reform to open financial market and to loosen their capital account regulation step by step. In this process, we could observe the continuing increase of the DCCs with other countries. Moreover, the America-China trade war has triggered DCCs of China to surge dramatically, at the pace even faster than that in 2008 crisis. To relieve its loss of this trade war, China has to rely more on international markets, especially the Belt-and-Road partners, and to open up at larger scale and at higher speed. In this sense, Chinese volatility comovement with other East Asian countries could rise to higher levels in the future.

Figure 12: DCCs between Chinese stock market and other markets



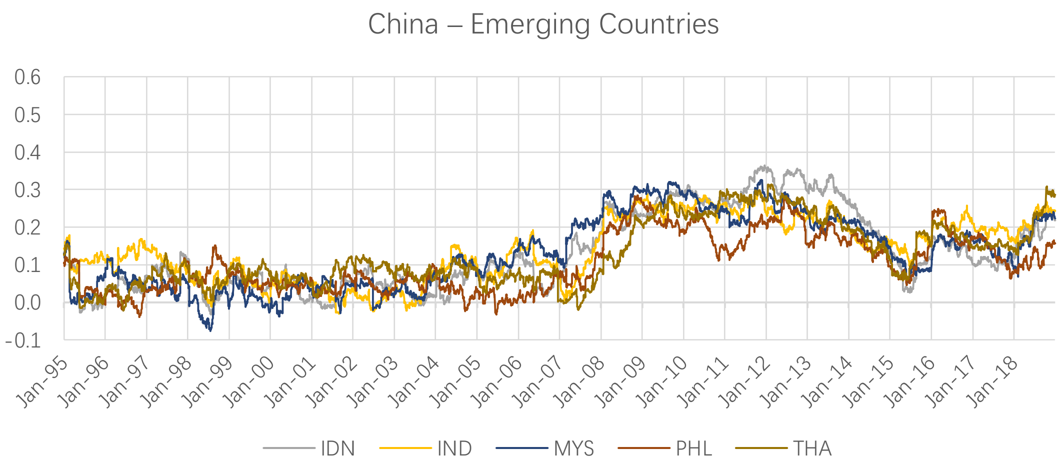
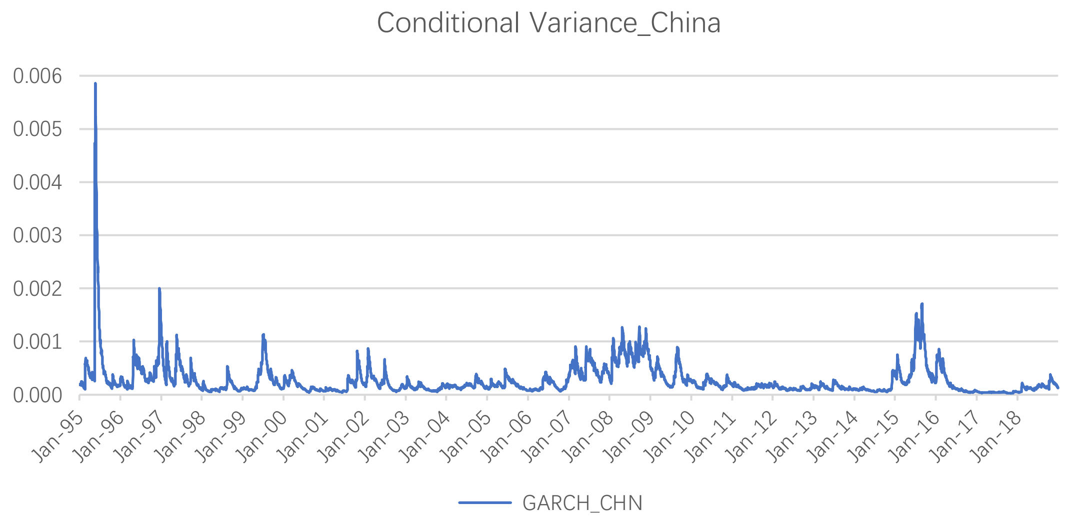


Figure 13: Conditional variance of Chinese stock market returns

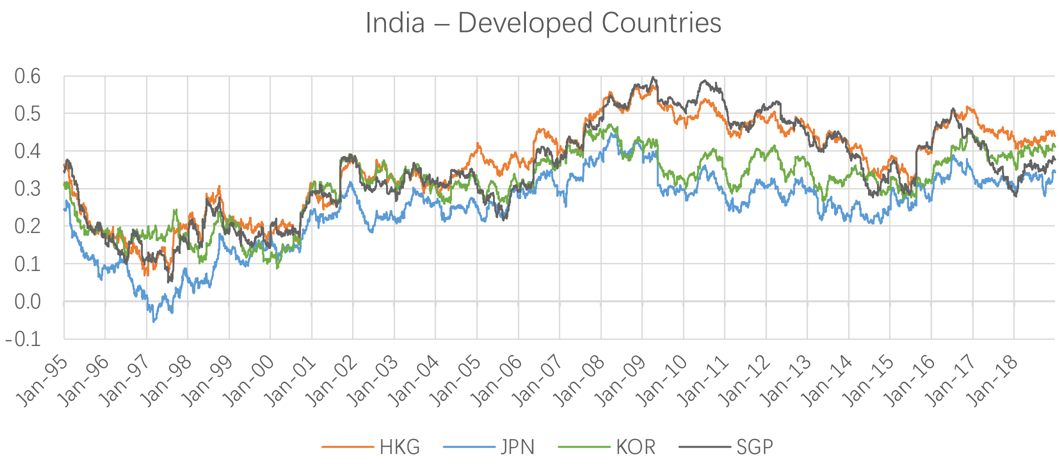


(2) India

Figure 14 shows the volatility comovement between Indian stock market and other stock markets in East Asia. Indian stock market is weakly correlated with Chinese stock market and Philippine stock market, hardly exceeding 0.3 within the latest 23 years. It shows much closer correlation with Hong Kong stock market and Singaporean stock market, which reached as much as nearly 0.6 during 2008 financial crisis. DCCs of India with Japan and Korea perform sort of similar to DCCs with Emerging-country group, and all of them are less than 0.5 most of time.

As time goes by, it seems like that Indian stock market is getting more and more correlated with other Asian markets, reflected by the rising tendency of the DCCs. The DCC curves also imply that the 1998 Asian Financial crisis did not make large impact on Indian financial market. The comovement correlations with other markets increased at most by 0.2 and recovered soon. In India, the period with the highest volatility comovement with other Asian markets appears also from 2007 to 2012, increased by 0.4 for correlations with Hong Kong and Singapore and by around 0.3 for other countries. Then, it was followed by fluctuations around 0.3 with emerging markets and 0.4 with developed markets.

Figure 14: DCCs between Indian stock market and other markets



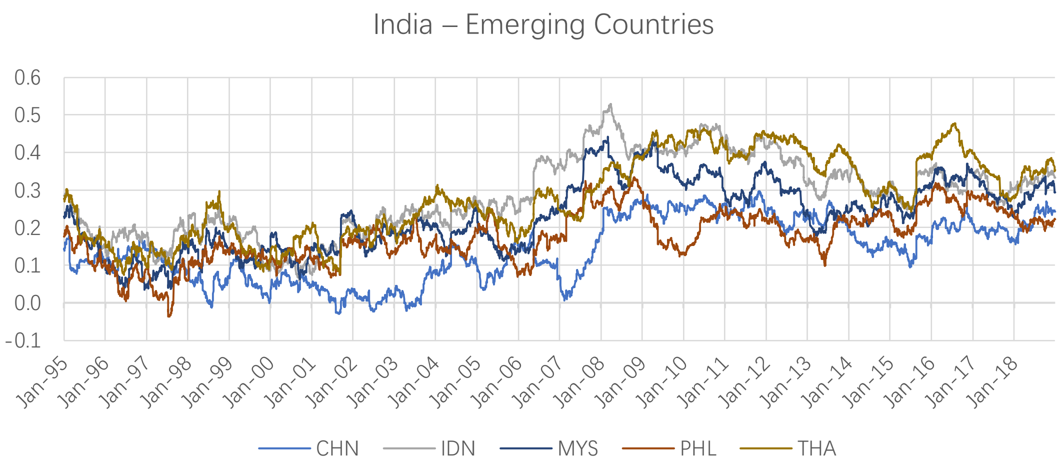
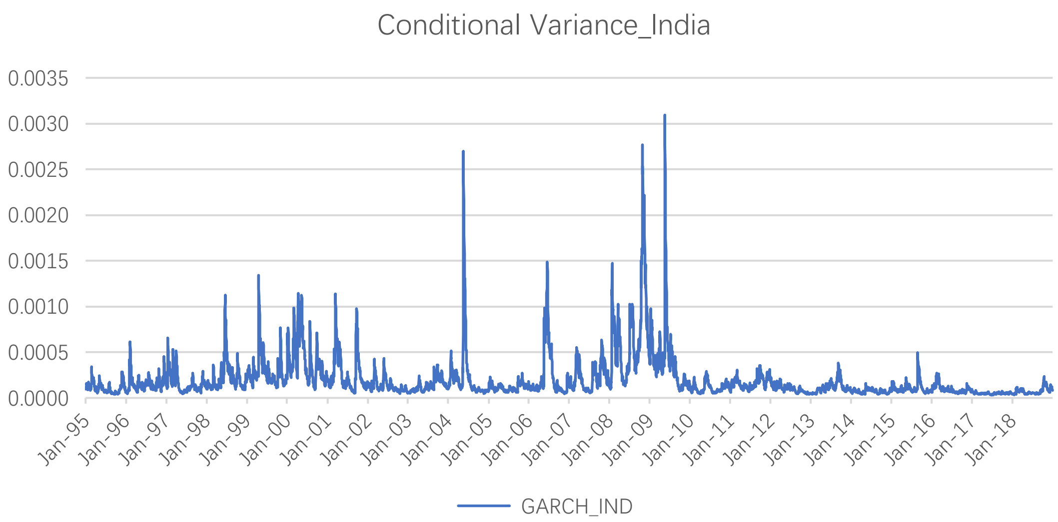


Figure 15: Conditional variance of Indian stock market returns



(3) Thailand

According to figure 16, we get that in the perspective of individual country partners, Thai stock market is slightly more related to stock markets in Hong Kong, Singapore and Indonesia, while clearly less related to Chinese stock market and Philippine stock market. In latest decade, the DCC curves exhibit slightly strong correlation with India.

Since the 1997 Asian Financial Crisis started from Thailand, during the crisis Thailand experienced severe currency depreciation and large-scale capital outflows. The economy and financial market in Thailand suffered extremely huge damages and the market was quite vulnerable and sensitive to disturbances from other markets. This results that the volatility comovement between Thai stock market and other markets, except Chinese stock market, increased dramatically during the following two years since the breakout of the 1997 crisis, with the dynamic conditional correlations of Thailand increasing around by 0.3 with developed countries and by 0.25 with the emerging countries. Then it went to adjustment phase, when the correlation decreased from the abnormally high level and fluctuated following the law of the market. Before the global financial crisis, the volatility comovement between Thai stock market and other Asian markets increased and kept at high levels during the 2008 Financial crisis and the following global recession (2007-2013). It seems that the trade war in 2018 has positively affected the Thai volatility comovement with developed-country group, whereas the emerging-country group just shows mild upward tendency in 2018. Till the end of 2018, most of the correlations are about 0.3, and correlations with Hong Kong and Singapore are higher, as much as 0.45 and 0.43 respectively.

Figure 16: DCCs between Thai stock market and other markets

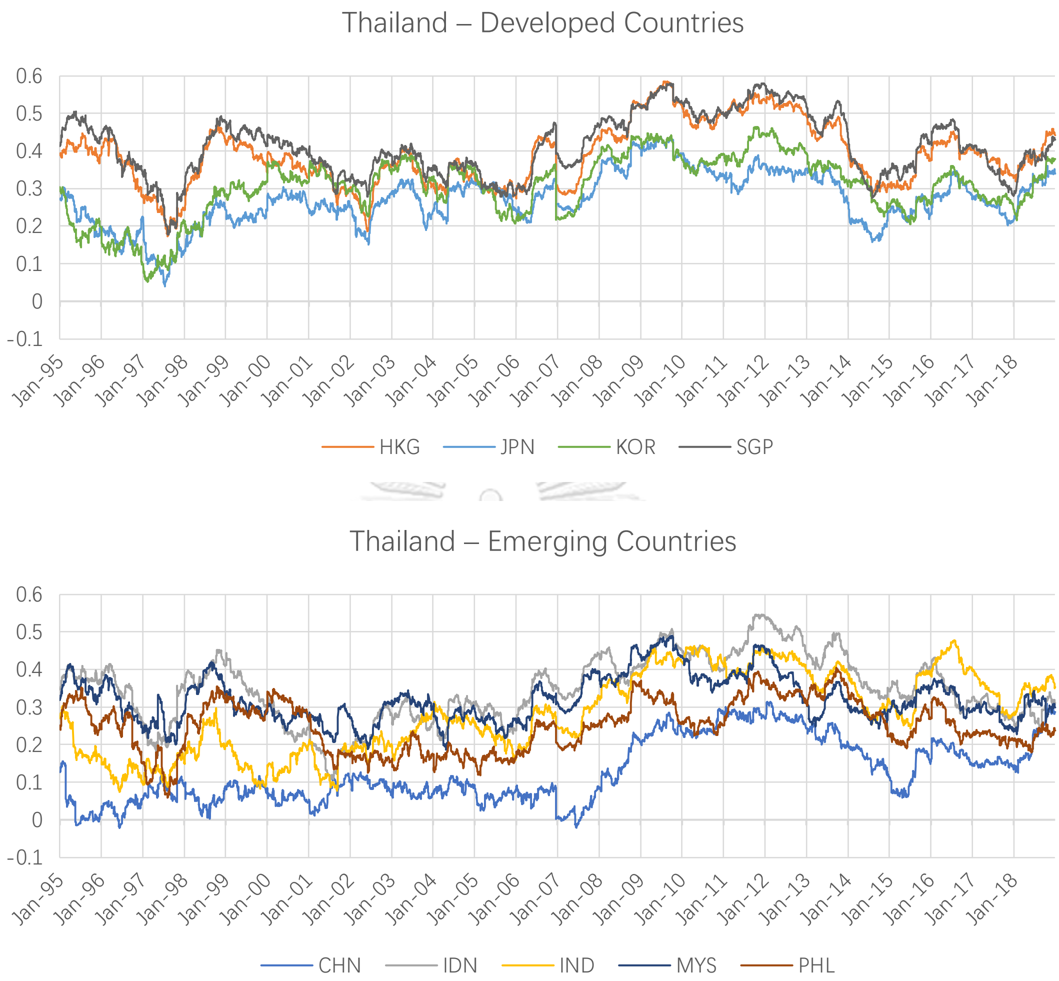
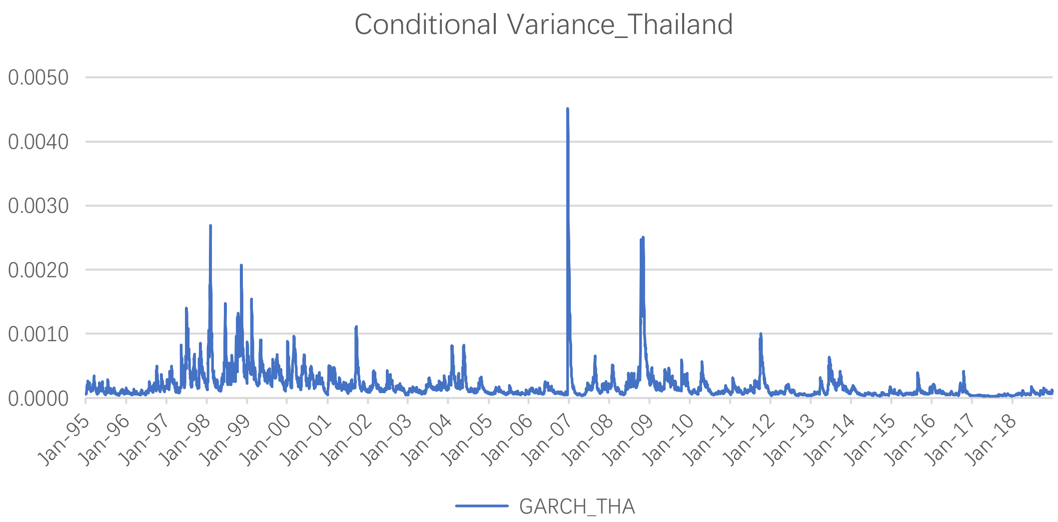


Figure 17: Conditional variance of Thai stock market returns



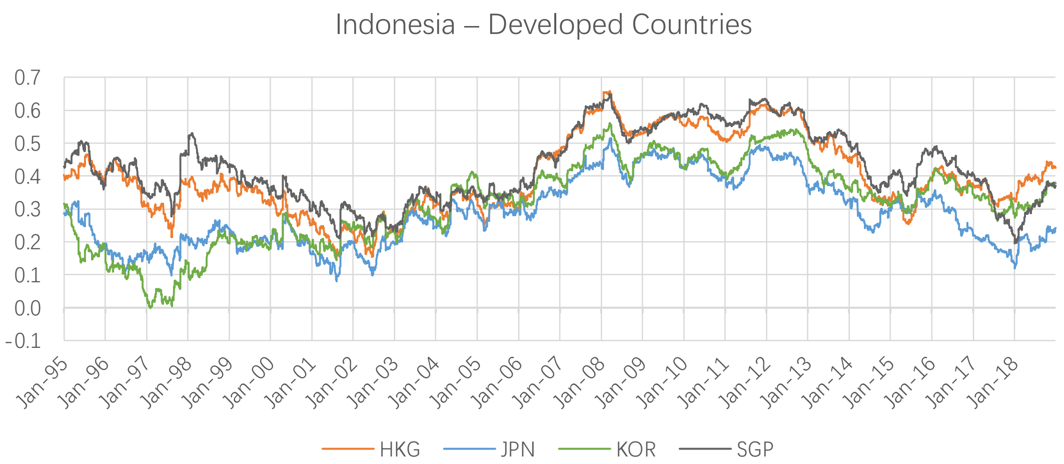
(4) Indonesia

By and large, figure 18 illustrates the differences of volatility comovement degrees of Indonesia between two groups are not remarkable, in terms of both tendency and magnitude. Here, correlation with China has its unique pattern.

In the country level, Indonesian stock market has the lowest level of volatility comovement with Chinese stock market (hardly exceeding 0.3). Whereas high-level volatility comovement shows up between Indonesia and Hong Kong, Malaysia and Singapore, especially during the period of 2007-2013.

In general, the DCC degrees between Indonesian stock market and other markets illustrate some different phases during 1995-2018 period. Before 2002, the volatility comovement fluctuated around some certain levels, with a peak around in 1997-1998 and followed by a downward recovery. Indonesia suffered huge damage of economy recession, together with severe currency depreciation and capital outflows because of the Asian financial crisis. Then, 2002-2013 period is an upward period of the volatility comovement with all partners including Chinese stock market and the correlations turned downward with fluctuations in the following years. DCCs with Singapore and Hong Kong increased more than other partners during the 2008 crisis, maintaining around 0.6 most of time. Since 2018, DCCs with developed countries and China has been showing obviously rising tendency.

Figure 18: DCCs between Indonesian stock market and other markets



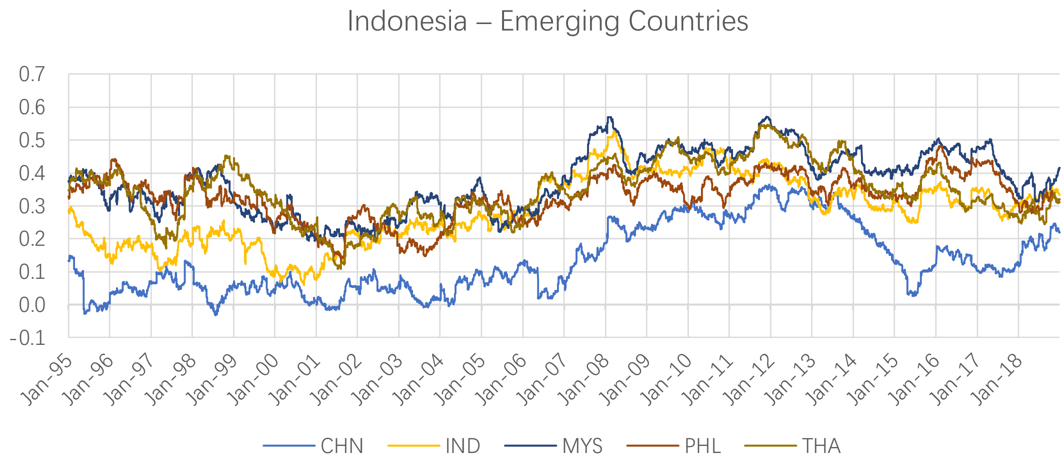
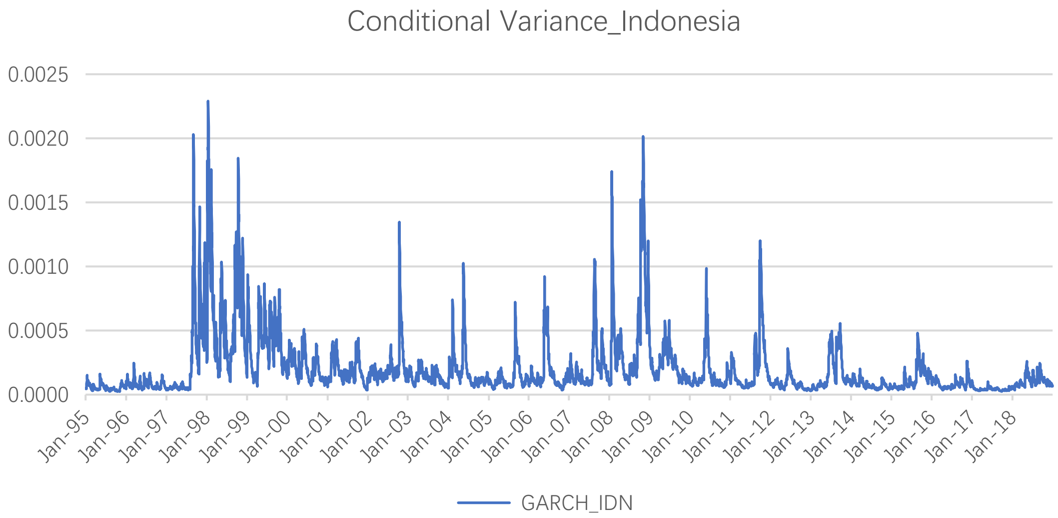


Figure 19: Conditional variance of Indonesian stock market returns



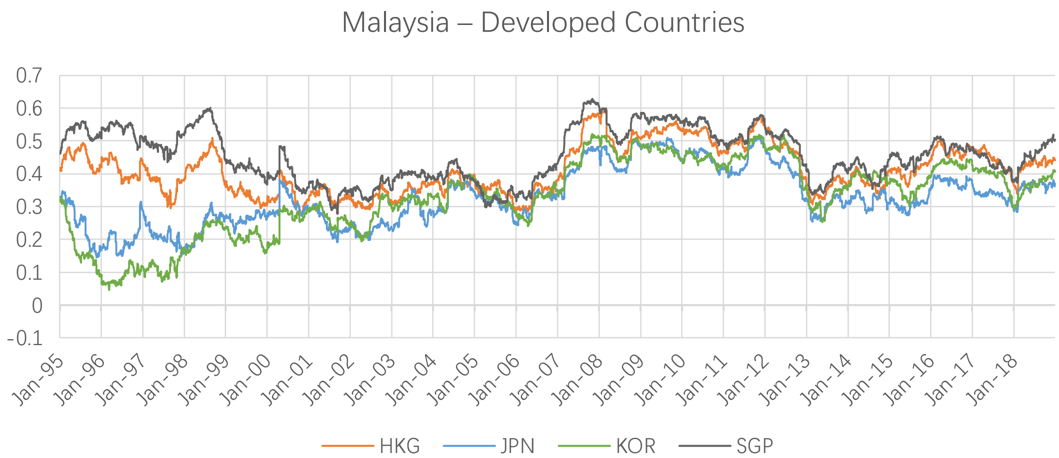
(5) Malaysia

The trend of the volatility comovement between Malaysia and developed markets has been quite consistent with the relationship between Malaysia and emerging markets over the period 1997-2018, although basically the magnitude is sort of larger with developed-country group than emerging-country group.

Malaysian stock market is more sensitive to Singaporean stock market and Hong Kong stock market, while least correlated with Chinese stock market for the whole period (less than 0.2 during non-crisis period, and even less than 0.3 under crisis). Volatility comovement between Malaysian stock market and Indonesian stock market is outstanding among the emerging-country group, especially since the 2008 financial crisis.

Before the Asian Financial Crisis, Malaysia was relatively more related with Singapore stock market, partially due to the geographical proximity. After the breakout of the Asian crisis, almost all correlations (except China) surged dramatically (especially arriving 0.6 with Singapore and 0.52 with Hong Kong), and then they decreased rapidly and fluctuated in lower range of 0.2-0.4. All the correlations clearly increased in early 2007. Since then, the correlations kept in higher level (0.4-0.6 with developed countries and 0.3-0.5 with emerging countries) for nearly 6 years. Later, the DCCs quickly dropped to the pre-crisis values, within half year in developed-country group and within one year in emerging-country group. They have been experiencing another rising trend since 2018.

Figure 20: DCCs between Malaysian stock market and other markets



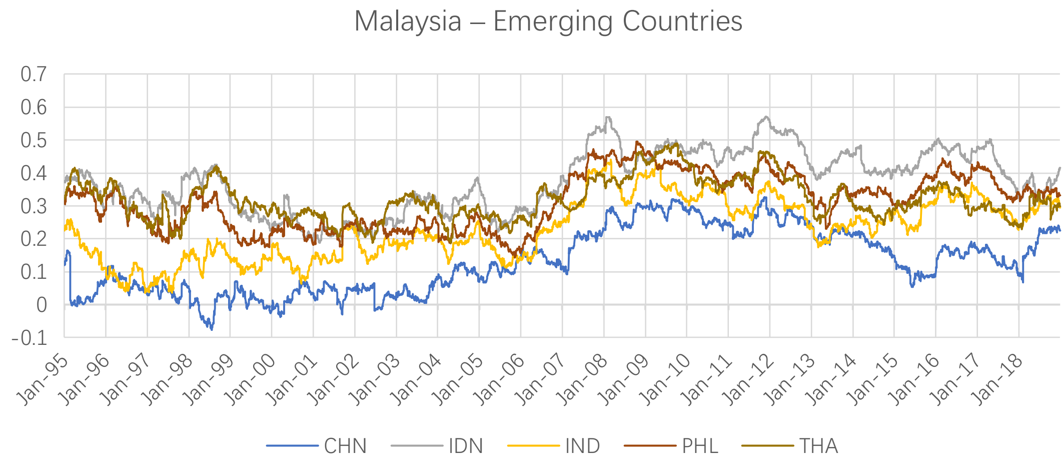
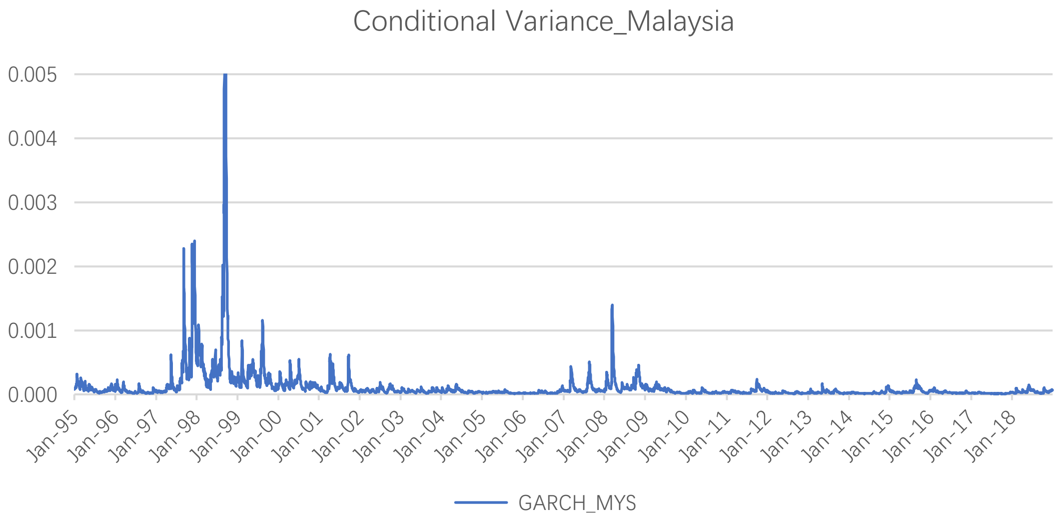


Figure 21: Conditional variance of Malaysian stock market returns



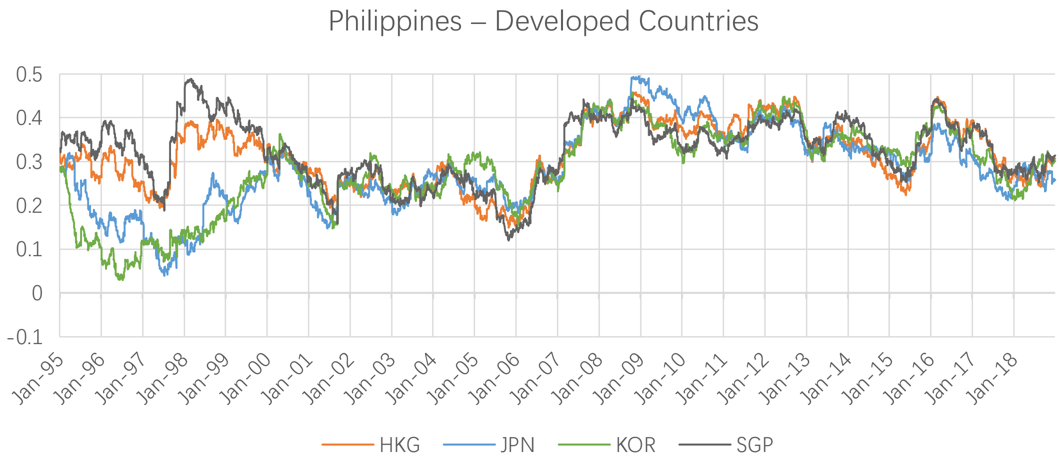
Note: *1998/9/7-1998/9/19, data in Malaysia are much higher than 0.005, even as much as 0.0134 on 1998/9/10.*

(6) Philippines

Philippine stock market is another market exhibiting low volatility comovement with other Asian stock markets, with the DCCs never reaching at 0.5. Though, the volatility comovement illustrated rise trend as time goes by, reflecting the increasing connections between Philippines and other Asian markets.

Specifically, it illustrates the least correlations with Stock markets in China (hardly exceeding 0.2) and India (fluctuating around 0.2). Relatively, it is more correlated with developed countries, Malaysia and Indonesia. In 1997, the financial risk spread to Philippines causing economic turbulence. Affected by the Asian Financial Crisis, the volatility comovement degrees of Philippines with Singaporean stock market, Hong Kong stock market and other ASEAN stock markets increased rapidly and turned downward with fluctuations. After entering the 2000s, the comovement relationships with developed countries have been quite consistent. Since the end of 2005, the correlations between Philippine stock market and other Asian markets simultaneously climbed up and the high-level volatility comovement periods showed up from 2007 to 2016. Affected by the global financial crisis, Philippine volatility movement correlations increased by 0.3 with emerging-country group and by 0.4 with developed-country group.

Figure 22: DCCs between Philippine stock market and other markets



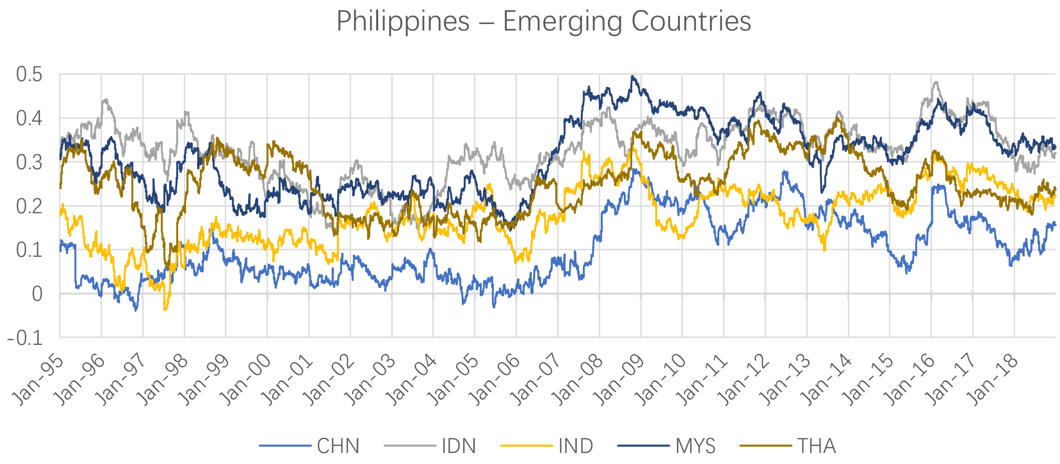
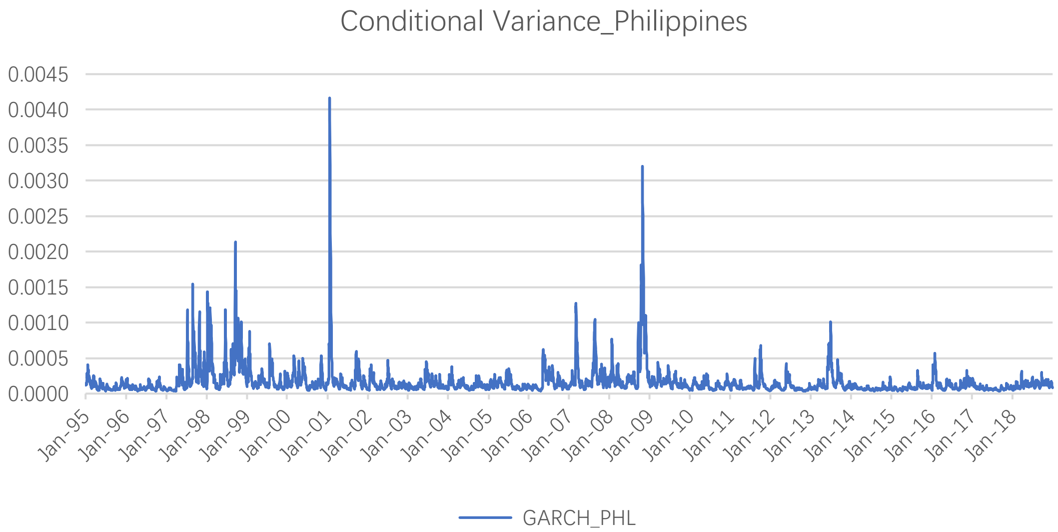


Figure 23: Conditional variance of Philippine stock market returns



5.1.3 Discussion of the volatility comovement

Some literature of finance has found developed economies showing the return comovement phenomenon (Morana and Beltratti (2008), Dajcman et al. (2012), Chen et al. (2017)). Findings of this research give some more empirical evidence of volatility comovement phenomenon. In East Asia, the developed markets (Hong Kong, Singapore, Korea and Japan) by-and-large are also more integrated to each other in respect to volatility of returns. Their volatility comovement may result from the volatility linkage of common information. These developed countries possess more mature stock markets and higher degree of openness. It's more efficient for them to get access to both common information and information spillover from other markets. As a result, their volatility would change synchronously. Furthermore, Hong Kong and Singapore exhibit the strongest volatility comovement with other markets. Possibly because they are international financial centers, which means they are also the centers of collecting and distributing information regarding financial markets, especially the common information that can affect these Asian counties at the same time. Therefore, other countries exhibit remarkable volatility comovement with them.

Another observation is the ASEAN countries have significant volatility comovement and their correlations have increased a lot over 1995-2018. Besides, the ASEAN emerging countries share quite consistent characteristics regarding volatility comovement. This result could be explained to some extent through the economic linkage. To increase the competitive advantage of ASEAN and attract more FDI to this region, the ASEAN Free Trade Area (AFTA) agreement was signed on 28th January 1992 with Singapore, Indonesia, Malaysia, Philippines, and Thailand being the original members[2]. The agreement supports the trade cooperation and economic integration by eliminate tariffs and non-tariff barriers among the member countries. This has driven the intra-regional integration and trade interdependence to higher levels. Theories of non-contingent crisis mentions the positive correlation between trade intensity and volatility comovement. In addition, as this region gets more connected, these member countries would share more regional systematic risk, namely more common information. Besides, the cross-border information spillover would also happen more often and faster within this region. Hence, it's rational for these ASEAN markets illustrate strong volatility connection. Despite that, Philippines shows slightly lower volatility comovement with other markets, possibly due to geographically long distance with other partners and being separated by the ocean. This leads to sort of independence for Philippines, therefore more difficulty to boost trade and to promote information transmission.

When we look at the financial crisis, the analysis above shows that the Asian financial crisis obviously impacted nearly all these Asian countries except China and Japan.

[2] https://en.wikipedia.org/wiki/ASEAN_Free_Trade_Area

During the 2008 Global Financial Crisis and the following Global Recession, from 2007 to 2013, the correlations among these East Asian markets increased in all cases. And they demonstrated even quite higher degree of volatility comovement than the 1997 Asian Financial Crisis, and it took even longer time to adjust to their normal values. These results in part support previous researches. Basically, financial crisis is the result of international or regional systematical risk together with herding behaviors of investment participants. It's essentially the result of common information transmission. When it comes to financial crisis, the mutual disturbance of common information would be propagated widely and quickly. Based on the expectation theory, investors face or expect a high probability of big loss, and they tend to be especially risk-averse. With lots of investors changing their investment strategies, wide-range fluctuances show up, namely the degree of volatility comovement would be pushed up to a large scale. Therefore, crisis might go together with higher extent of cross-country stock market volatility comovement.

5.1.4 A panel data analysis of the volatility comovement

What kind of factors can affect these volatility comovement relationships? There are several possible explanatory variables such as GDP, trade value, and the openness degree which is measured by the percentage of trade value to GDP. Therefore, I built panel data framework to test how these variables relate to the volatility comovement degree, setting the country paired as the cross sections, the DCCs of each country-pair as dependent variable and those alternative variables as endogenous variables separately. Apart from that, the panel data model allows us to examine the cross-section fixed effects and period fixed effects. In other words, we could recognize the exact period with high or low volatility comovement degree and the intercept differences of each cross-section, namely each country pair.

Some research found trade is a key factor to stock market return comovement phenomenon (Johnson and Soenen (2003), Drakos and Kutan (2005), Walti (2005)). The estimation result of panel data model in this study, however, shows that trade value is kind of not significant to explain return volatility comovement. Likewise, the openness degree is eliminated. On the other hand, it shows GDP plays a remarkable role to affect volatility comovement. Therefore, in the eventual panel data model, the natural logarithm of GDP is put as endogenous variable.

Figure 24 exhibits the period fixed effects of this model. After picking the GDP impact and cross-section individual difference out of the DCCs, we can observe the clearly positive volatility comovement of 0.23 in 1998, and gradually decreased effects from 1999 to 2007. Then larger-scale and longer-lasting positive comovement was followed: from 2008 to 2013, right exactly the global financial crisis and recession. The period fixed effects reached as much as 0.64 in 2008 and 0.68 in 2009. Even in 2012, it still remained at 0.58. Comparing with 1997 Asian financial crisis, the 2008 crisis caused much more remarkable impacts on the East Asian financial system. These results are consistent with my findings mentioned above.

Figure 24: Period fixed effects of volatility comovement in East Asia, 1995 to 2016

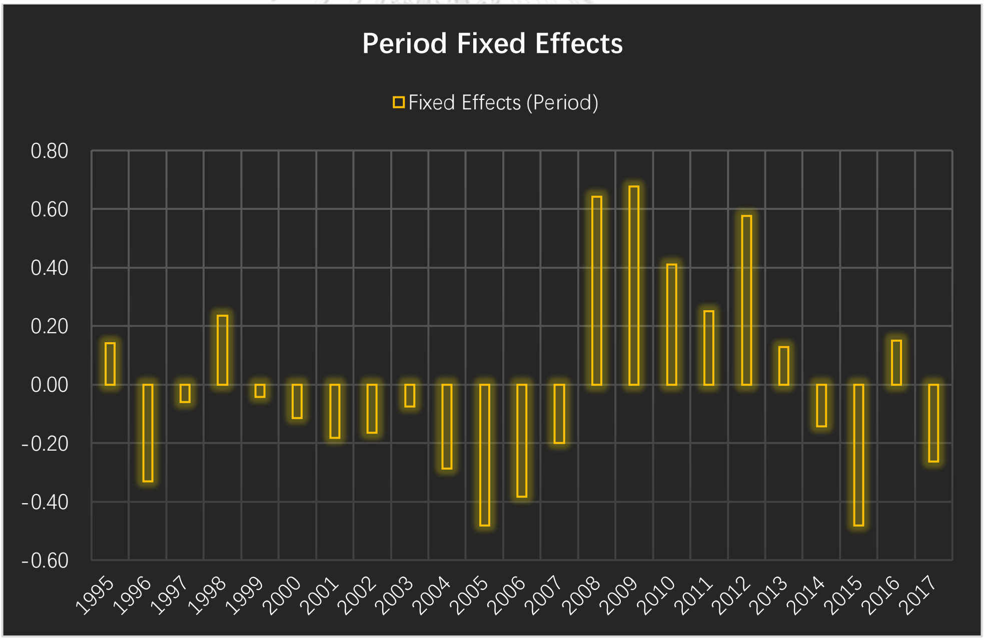
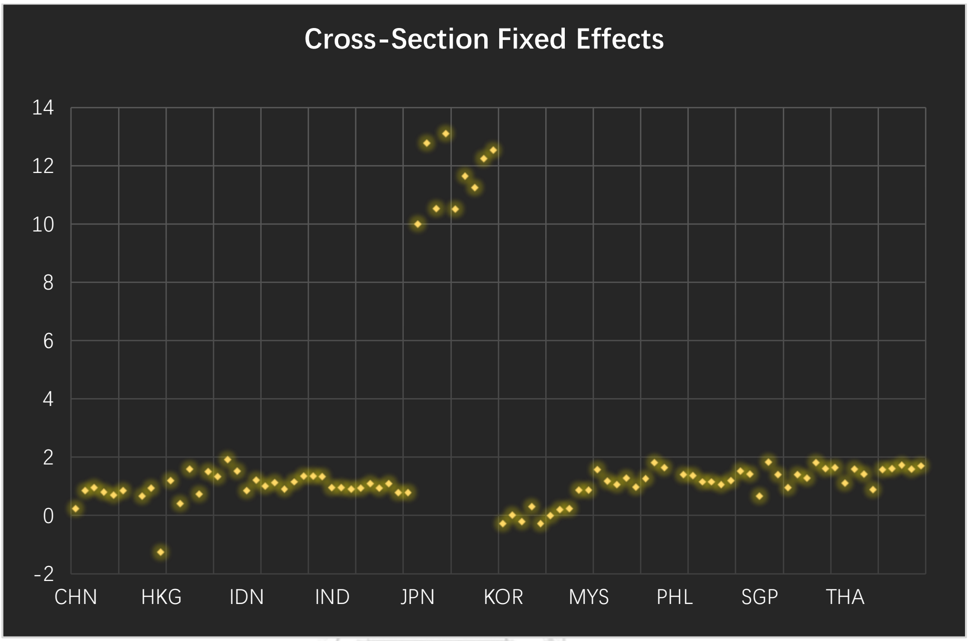


Figure 25 exhibits the cross-section fixed effects, which shed light on the individual differences of East Asian stock market. Most of the fixed effects are positive and less than 2. Among them, Hong Kong and ASEAN countries are slightly higher, more than 1, and Korean fixed effects are relatively lower ranging from -0.28 to 0.86. However, Japanese fixed effects are extremely high (ranging from 10 to 13). These results suggest that the volatility comovement relationships in East Asia are naturally positive and these markets are rarely independent essentially from other countries.

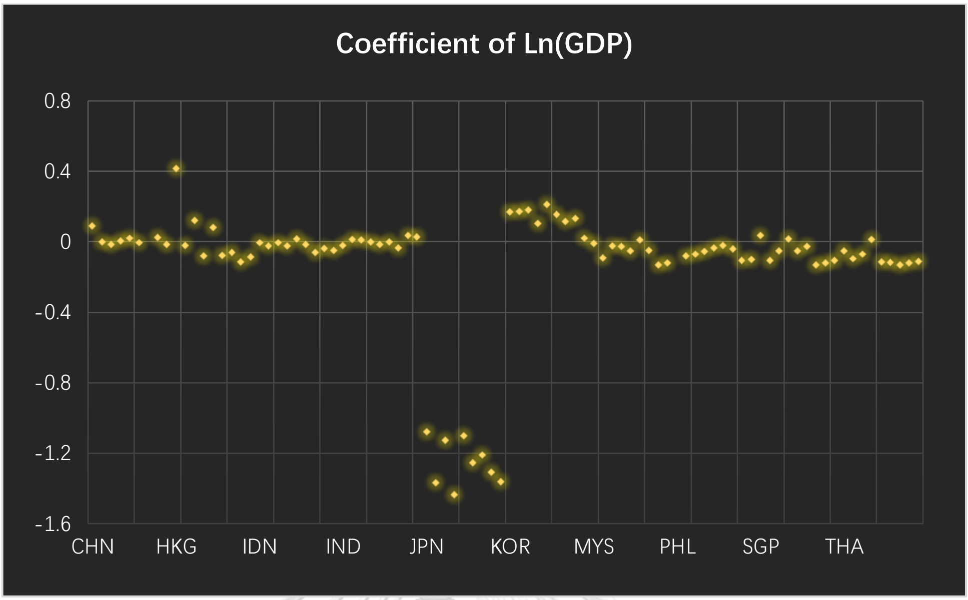
Figure 25: Cross-section fixed effects of volatility comovement in East Asia, 1995 to 2016



Note: Every point represents one country-pair. From left side to right side, every 9 points belong to one market. Here is order of markets: China, Hong Kong, Indonesia, India, Japan, Korea, Malaysia, Philippines, Singapore and Thailand.

Figure 26 exhibits the parameter estimation results of LN (GDP) for each country. For China, India, Indonesia and Malaysia, the growth of economy hardly affects their volatility comovement with other markets. Increase in Korean GDP by 1% would cause its volatility comovement rising by 0.1 to 0.2. 1% Economic growth in Singapore, Philippines and Thailand could offset their volatility comovement with other markets excluding China and India, at most by 0.1. Japan is outstanding again because 1% increase in GDP leads to volatility comovement degree decrease by more than 1. On the other hand, when combining the Japanese fixed effects results, we would say the degree of Japanese volatility comovement with other East Asian stock markets is quite sensitive with its economic growth.

Figure 26: Parameter estimation results of LN (GDP) in East Asia, 1995 to 2016



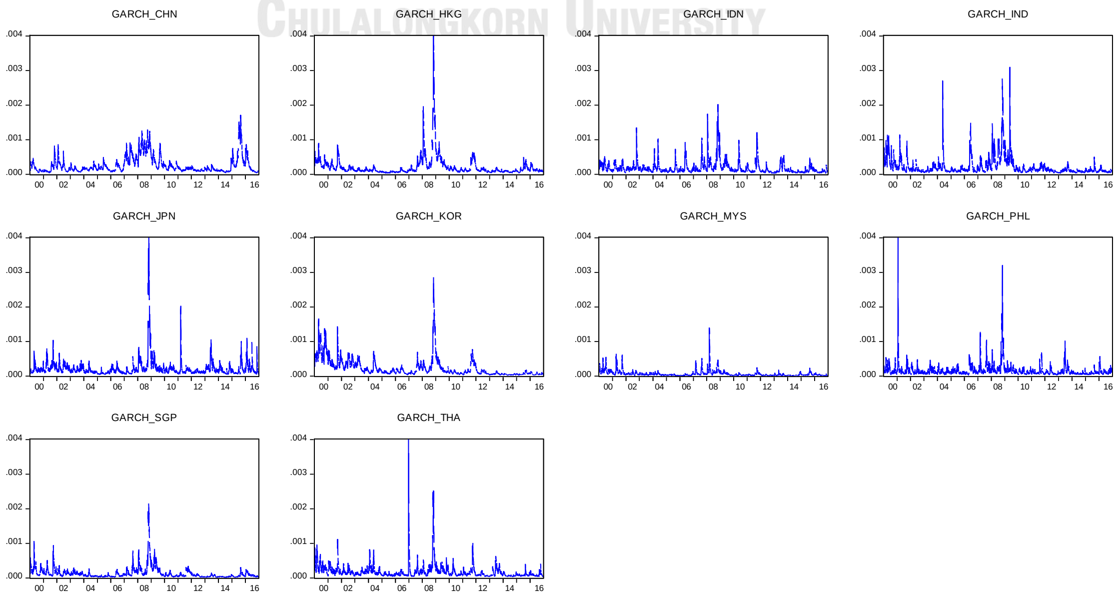
Note: Every point represents one country-pair. From left side to right side, every 9 points belong to one market. Here is order of markets: China, Hong Kong, Indonesia, India, Japan, Korea, Malaysia, Philippines, Singapore and Thailand.

5.2 Volatility Spillover Effects

According to the analysis above, the volatility comovement effects are time-varying and market specific. Besides, the 2008 global financial crisis has caused even larger fluctuation in stock markets of East Asia and the effects persisted quite longer, comparing with the 1997 Asian Financial Crisis. To investigate how the financial system affected by the shocks and how the spillover effects varied in different stages of financial crisis, this study mainly focuses on the 2008 global financial crisis and split the time period into three sub-groups referring to pre-crisis period (3 January 2000 to 29 December 2006), crisis period (2 January 2007 to 31 December 2009) and post-crisis period (4 January 2010 to 30 December 2018).

Based on the first step of DCC-MGARCH model estimation, series of the time-varying conditional variance in each market were obtained, namely the GARCH terms, with which VAR models would be built to simulate the reactions of these markets in different stages of financial crisis when being disturbed by unpredictable shocks from both domestic and abroad. Figure 27 illustrates the conditional variances series of each stock index returns in East Asia throughout the 2008 financial crisis, from 3 January 2000 to 31 December 2018.

Figure 27: Conditional variances of stock index returns in East Asia, 3 January 2000 to 31 December 2016

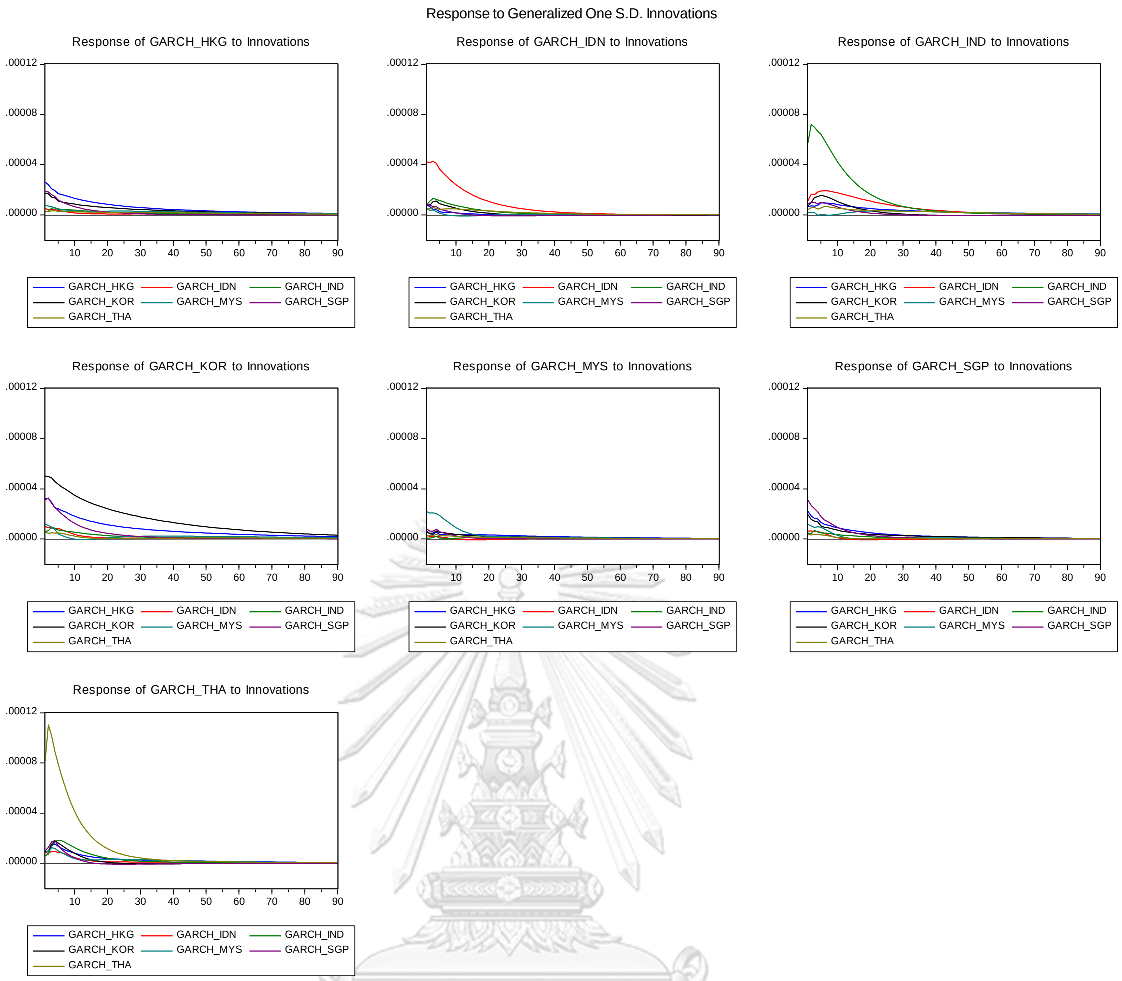


5.2.1 Pre-Crisis period (3 January 2000 to 29 December 2006)

Firstly, the base VAR model was built with 10 variables. Then based on the lag length criteria and Granger causality test, we found that Chinese stock market, Japanese stock market and Philippine stock market are exogenous in this VAR system. Therefore, the model was rebuilt with these series as exogenous variables and the optimized lag number is 5, according to the minimum AIC. The AR Roots graph depicts this system is stationary. Then generalized impulse response functions are executed and the results are illustrated in Figure 28.

The graphs display that before the financial crisis of 2008, the financial system in East Asia was quite stable according to the volatility spillover effects. Self-spillover effects dominant the volatility in each market. As to the cross-volatility spillover, Hong Kong showed some slight power to spill its shocks to Korea, Malaysia and Singapore temporarily. Singapore slightly affected Hong Kong, Korea and Malaysia. India absorbed a little disturbance from Indonesia. Indonesia and Thailand mainly affected by innovations of themselves but the effects only last less than one month. During this period, all the cross-volatility spillover effects and self-volatility spillover effects were just mild and disappeared nearly with a month, even 20 days.

Figure 28: Impulse response functions during pre-crisis period, 3 January 2000 to 29 December 2006



When executing the Granger causality test, we found some volatility causality relationship among these countries during pre-crisis stage. Taking 95% confidence level as criteria, volatility in India and Singapore Granger caused Hong Kong volatility. Hong Kong, India, and Malaysia Granger caused Singapore. Hong Kong and Singapore Granger caused Korea as well as Malaysia. Indonesia and Korea Granger caused India. Hong Kong, India and Korea were the Granger causes of Indonesia. India was the only Granger cause of Thailand. (Table 5)

Table 5: Granger Causality Test Results (Pre-Crisis VAR model)

VAR Granger Causality/Block Exogeneity Wald Tests
Date: 05/04/19 Time: 14:34
Sample: 1/03/2000 12/29/2006
Included observations: 1837

Dependent variable: GARCH_HKG

Excluded	Chi-sq	df	Prob.

GARCH_IDN	1.746825	5	0.8829
GARCH_IND	20.93518	5	0.0008***
GARCH_KOR	10.05764	5	0.0736
GARCH_MYS	5.081161	5	0.4061
GARCH_SGP	40.79874	5	0.0000***
GARCH_THA	1.850434	5	0.8694
All	83.11330	30	0.0000

Dependent variable: GARCH_IDN

Excluded	Chi-sq	df	Prob.
GARCH_HKG	17.43776	5	0.0037***
GARCH_IND	14.16052	5	0.0146**
GARCH_KOR	33.42956	5	0.0000***
GARCH_MYS	4.724009	5	0.4505
GARCH_SGP	8.751036	5	0.1194
GARCH_THA	2.053557	5	0.8417
All	68.19272	30	0.0001

Dependent variable: GARCH_IND

Excluded	Chi-sq	df	Prob.
GARCH_HKG	9.225239	5	0.1004
GARCH_IDN	13.93177	5	0.0160**
GARCH_KOR	18.32544	5	0.0026***
GARCH_MYS	2.503265	5	0.7760
GARCH_SGP	3.815082	5	0.5763
GARCH_THA	1.869450	5	0.8669
All	44.64694	30	0.0416

Dependent variable: GARCH_KOR

Excluded	Chi-sq	df	Prob.
GARCH_HKG	14.96350	5	0.0105**
GARCH_IDN	3.539966	5	0.6173
GARCH_IND	10.93815	5	0.0526
GARCH_MYS	10.50954	5	0.0620
GARCH_SGP	36.73269	5	0.0000***
GARCH_THA	1.763863	5	0.8808
All	75.65780	30	0.0000

Dependent variable: GARCH_MYS

Excluded	Chi-sq	df	Prob.
GARCH_HKG	36.08143	5	0.0000***
GARCH_IDN	5.390250	5	0.3701
GARCH_IND	8.628378	5	0.1248
GARCH_KOR	8.764299	5	0.1188
GARCH_SGP	19.63461	5	0.0015***
GARCH_THA	3.753587	5	0.5854
All	101.0811	30	0.0000

Dependent variable: GARCH_SGP

Excluded	Chi-sq	df	Prob.
GARCH_HKG	16.12887	5	0.0065***
GARCH_IDN	9.498867	5	0.0907

GARCH_IND	14.96528	5	0.0105**
GARCH_KOR	10.86475	5	0.0541
GARCH_MYS	11.45596	5	0.0431**
GARCH_THA	1.471448	5	0.9163
All	74.55132	30	0.0000

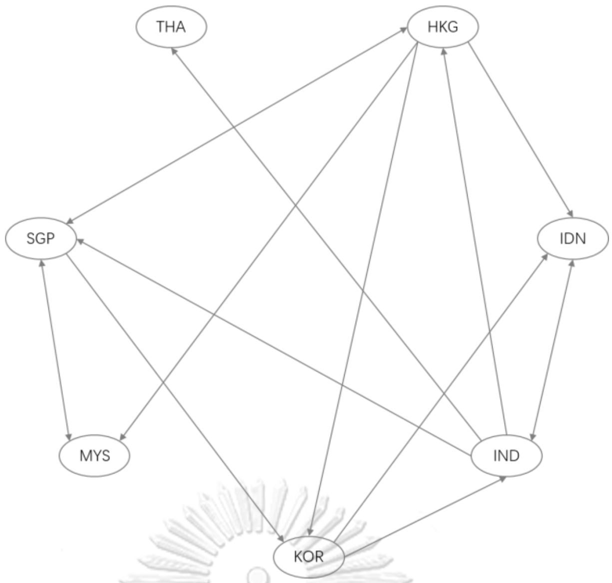
Dependent variable: GARCH_THA

Excluded	Chi-sq	df	Prob.
GARCH_HKG	3.646755	5	0.6013
GARCH_IDN	4.664819	5	0.4581
GARCH_IND	14.47548	5	0.0129**
GARCH_KOR	5.709845	5	0.3355
GARCH_MYS	1.991094	5	0.8504
GARCH_SGP	4.583388	5	0.4688
All	47.82347	30	0.0206

Note: ** and *** denote the significance at 5%, and 1% level, respectively.

Figure 29 exhibits the Granger causality test results in pre-crisis period, where the arrow starts from the Granger cause and the two-way arrow represents there exists bidirectional Granger causality relationship between the two markets. All the causality relationships showed in the graph are statistically significant at 95% confidence level. Before the breakout of the crisis, the Granger relationships among these markets were quite simple and most of them were unidirectional Granger causality. Specifically, the mutual Granger causality only showed up between Hong Kong and Singapore, Singapore and Malaysia, India and Indonesia. Although the Granger causality cannot tell the exact and real causal relationships, it partially reflects their order of volatility transmission.

Figure 29: Granger causality relationships during pre-crisis period, 3 January 2000 to 29 December 2006



Note: The arrow starts from the Granger cause and the two-way arrow represents there exists bidirectional Granger causality relationship between the two markets. All the causality relationships showed in the graph are statistically significant at 95% confidence level.

5.2.2 Crisis period (2 January 2007 to 31 December 2009)

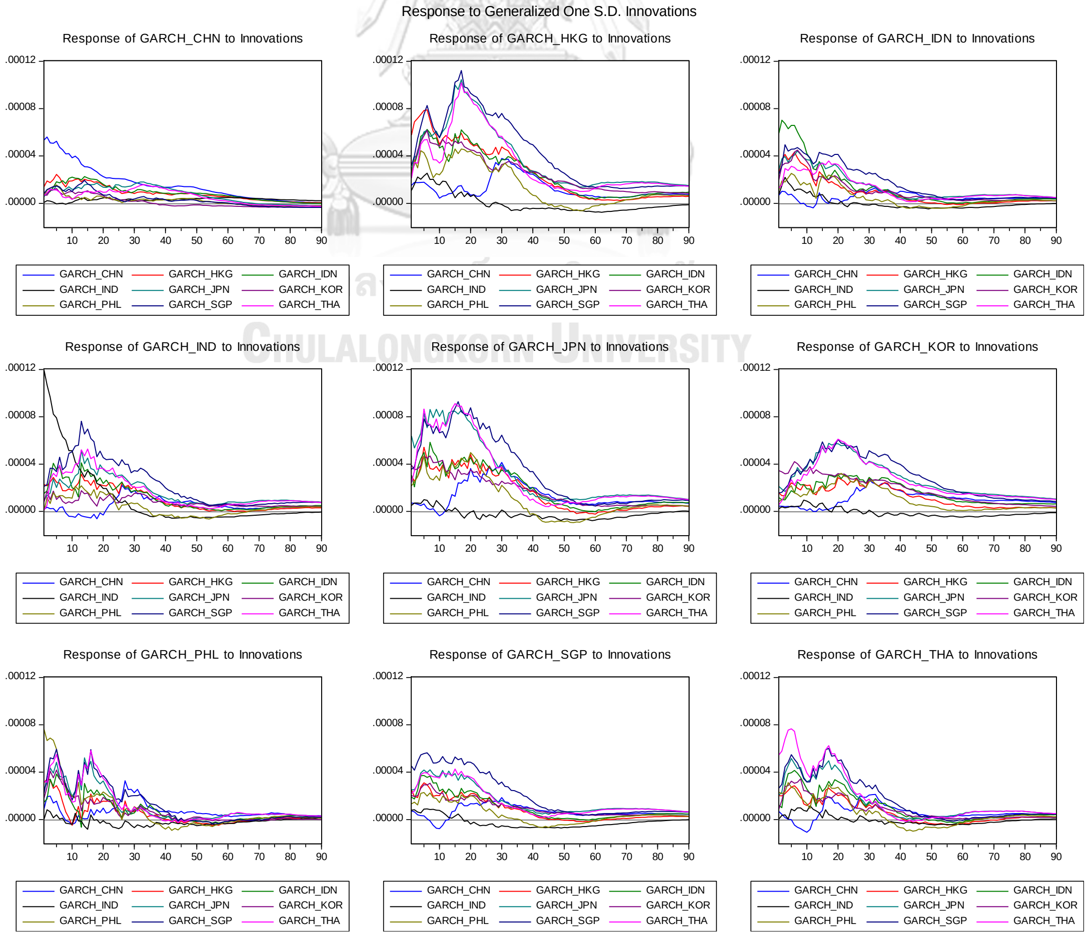
In the VAR model of crisis era, Malaysian stock market is exogenous in the system and the optimized lag number is 16, based on the minimum AIC. The AR Roots graph depicts this system is stationary. Then generalized impulse response functions are executed and the results are illustrated in Figure 30.

In the financial crisis of 2008, Hong Kong stock market and Japanese stock market were the most vulnerable markets. Especially, the disturbance from Singapore, Japan and Thailand were absorbed simultaneously by Hong Kong stock market and Japanese stock market, which caused large spillover effects for one month and then the influence decreased still sustaining for nearly another two months. The cross-nation spillover effects to these two markets increased in the first month and declined slowly in the next two months. On the other hand, the self-spillover of volatility came into play as soon as the shock occurred and faded away in the following 2 months.

Stock markets in China was the most stable market in the chaotic financial environment. The abroad shocks from East Asia only caused limited disturbance to Chinese markets' volatility. It was positively affected by its self-volatility spillover which could fade away within 2 months. Other countries (Korea, Singapore, India, Indonesia, Philippines and Thailand) were affected by the domestic and abroad innovations to some extent. All the dominant spillover effects came from Singapore, Japan and Thailand for all these cases both in respect to size and persistence. Spillover from Hong Kong and Indonesia positively affected these countries in smaller range within around 50 days.

On the other hand, it need to point out that the disturbance in Indian stock market generated negative and small-scale spillover to Hong Kong, Japan, Korea, Singapore and Philippines around 30 days later of the cross-volatility spillover, implying that when Indian stock market got more fluctuant somehow, other stock markets would experience 30-day-lagged stability instead.

Figure 30: Impulse response functions during crisis period, 2 January 2007 to 31 December 2009



The Granger causality results of crisis-era period reflect a much more complex system than before the crisis. Hong Kong and Korea shared the same Granger causes involving all other countries except China and India. All other countries except India were Granger causes of Japan. And the Granger causes of Singapore included all other countries except India and Thailand (namely China, Hong Kong, Indonesia, Japan, Korea, Philippines).

At 95% confidence level, there was no Granger cause of Chinese stock market volatility under 2008 financial crisis. Only Hong Kong and Japan Granger caused China at 90% level. Japan, Korea, Philippines, Singapore, and Thailand Granger caused Indonesia. Indonesia and Singapore Granger caused India. Hong Kong, Indonesia, Japan, Korea and Singapore were Granger causes of Philippines. And all other countries except China and India Granger caused Thai stock market volatility.

Table 6: Granger Causality Test Results (Crisis-Period VAR model)

VAR Granger Causality/Block Exogeneity Wald Tests
Date: 05/04/19 Time: 14:41
Sample: 1/02/2007 12/31/2009
Included observations: 785

Dependent variable: GARCH_CHN

Excluded	Chi-sq	df	Prob.
GARCH_HKG	25.70559	16	0.0583
GARCH_IDN	16.33761	16	0.4297
GARCH_IND	5.119643	16	0.9951
GARCH_JPN	23.71477	16	0.0959
GARCH_KOR	22.62869	16	0.1240
GARCH_PHL	11.85469	16	0.7539
GARCH_SGP	18.53932	16	0.2933
GARCH_THA	11.27150	16	0.7924
All	150.7532	128	0.0828

Dependent variable: GARCH_HKG

Excluded	Chi-sq	df	Prob.
GARCH_CHN	7.383991	16	0.9651
GARCH_IDN	37.40014	16	0.0018***
GARCH_IND	14.13030	16	0.5890
GARCH_JPN	75.00955	16	0.0000***
GARCH_KOR	33.60344	16	0.0061***
GARCH_PHL	59.27955	16	0.0000***
GARCH_SGP	63.07069	16	0.0000***
GARCH_THA	37.37172	16	0.0019***
All	1018.767	128	0.0000

Dependent variable: GARCH_IDN

Excluded	Chi-sq	df	Prob.
GARCH_CHN	23.33023	16	0.1052
GARCH_HKG	23.89482	16	0.0918
GARCH_IND	22.45327	16	0.1291
GARCH_JPN	45.02444	16	0.0001***
GARCH_KOR	39.71117	16	0.0009***
GARCH_PHL	70.32228	16	0.0000***
GARCH_SGP	66.15605	16	0.0000***
GARCH_THA	26.82090	16	0.0435**
All	435.2228	128	0.0000

Dependent variable: GARCH_IND

Excluded	Chi-sq	df	Prob.
GARCH_CHN	4.119091	16	0.9987
GARCH_HKG	10.64423	16	0.8309
GARCH_IDN	36.64914	16	0.0023***
GARCH_JPN	20.35398	16	0.2047
GARCH_KOR	20.19809	16	0.2114
GARCH_PHL	23.22490	16	0.1079
GARCH_SGP	48.94040	16	0.0000***
GARCH_THA	22.07486	16	0.1408
All	289.3177	128	0.0000

Dependent variable: GARCH_JPN

Excluded	Chi-sq	df	Prob.
GARCH_CHN	28.14103	16	0.0304**
GARCH_HKG	88.12803	16	0.0000***
GARCH_IDN	145.6907	16	0.0000***
GARCH_IND	7.378686	16	0.9653
GARCH_KOR	68.66471	16	0.0000***
GARCH_PHL	37.08154	16	0.0020***
GARCH_SGP	38.23027	16	0.0014***
GARCH_THA	115.4683	16	0.0000***
All	965.5187	128	0.0000

Dependent variable: GARCH_KOR

Excluded	Chi-sq	df	Prob.
GARCH_CHN	16.06678	16	0.4483
GARCH_HKG	63.78304	16	0.0000***
GARCH_IDN	58.46706	16	0.0000***
GARCH_IND	10.81534	16	0.8207
GARCH_JPN	123.5439	16	0.0000***
GARCH_PHL	50.67522	16	0.0000***
GARCH_SGP	45.03169	16	0.0001***
GARCH_THA	51.42382	16	0.0000***
All	1084.292	128	0.0000

Dependent variable: GARCH_PHL

Excluded	Chi-sq	df	Prob.
GARCH_CHN	19.80356	16	0.2292
GARCH_HKG	64.24773	16	0.0000***
GARCH_IDN	41.33305	16	0.0005***
GARCH_IND	14.05232	16	0.5948

GARCH_JPN	42.46999	16	0.0003***
GARCH_KOR	31.89809	16	0.0103**
GARCH_SGP	52.05803	16	0.0000***
GARCH_THA	18.78153	16	0.2802
All	909.3661	128	0.0000

Dependent variable: GARCH_SGP

Excluded	Chi-sq	df	Prob.
GARCH_CHN	28.39459	16	0.0284**
GARCH_HKG	70.18677	16	0.0000***
GARCH_IDN	84.53332	16	0.0000***
GARCH_IND	14.47792	16	0.5632
GARCH_JPN	28.81298	16	0.0252**
GARCH_KOR	27.87524	16	0.0327**
GARCH_PHL	32.13253	16	0.0096***
GARCH_THA	21.22787	16	0.1699
All	540.2464	128	0.0000

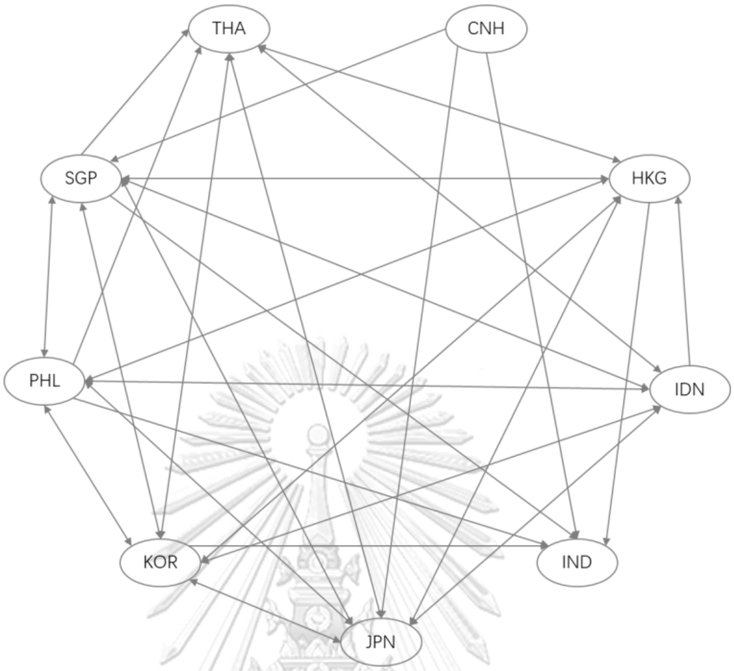
Dependent variable: GARCH_THA

Excluded	Chi-sq	df	Prob.
GARCH_CHN	16.13339	16	0.4437
GARCH_HKG	62.82409	16	0.0000***
GARCH_IDN	104.8568	16	0.0000***
GARCH_IND	25.13633	16	0.0675
GARCH_JPN	36.88514	16	0.0022***
GARCH_KOR	43.96100	16	0.0002***
GARCH_PHL	48.12229	16	0.0000***
GARCH_SGP	40.07312	16	0.0008***
All	788.2163	128	0.0000

Note: ** and *** denote the significance at 5%, and 1% level, respectively.

By putting all these significant connections together, we can conclude that during financial crisis, the Granger causality system not only involved more participants, but also more connections as well as two-way causality relationships (Figure 31). These changes depict the individual stock markets were getting more integrated into the whole financial system under financial crisis. Their own risks would spill out to other partners in a larger range and they would have to pay more attention to prevent the potential risks spilling from the external markets.

Figure 31: Granger causality relationships during crisis period, 2 January 2007 to 31 December 2009



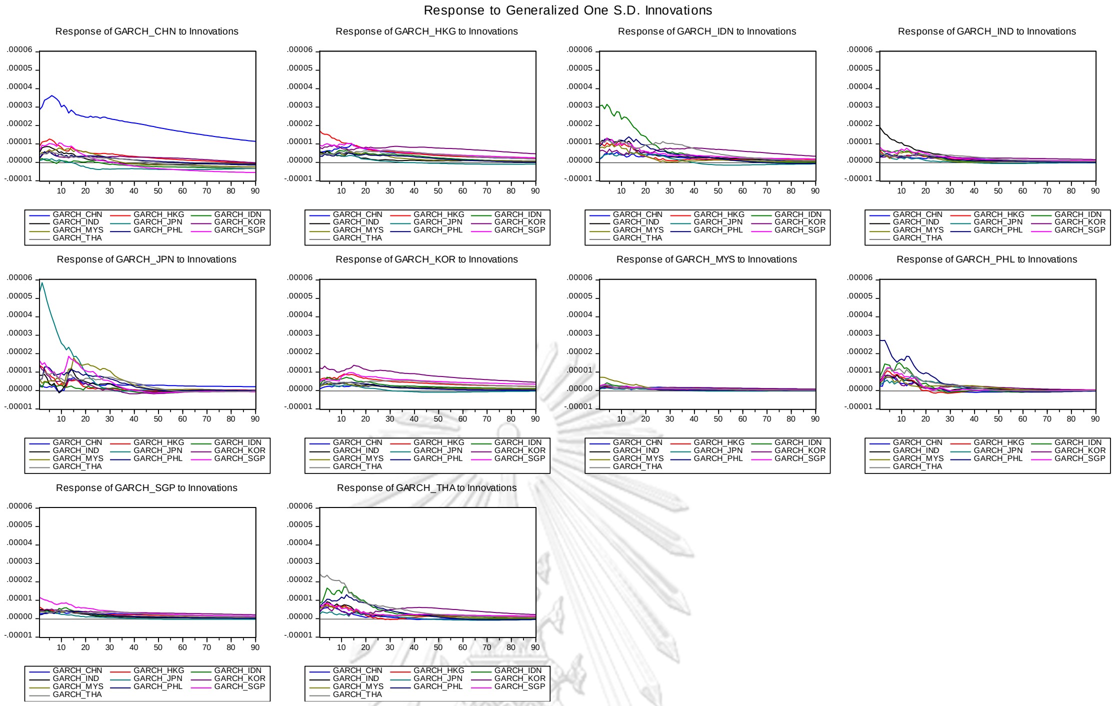
Note: The arrow starts from the Granger cause and the two-way arrow represents there exists bidirectional Granger causality relationship between the two markets. All the causality relationships showed in the graph are statistically significant at 95% confidence level.

5.2.3 Post-crisis period (4 January 2010 to 30 December 2018)

In the VAR model of post-crisis era, all the stock markets are endogenous in the system and the optimized lag number is 16, based on the minimum AIC. The AR Roots graph depicts this system is stationary. Then generalized impulse response functions are executed and the results are illustrated in Figure 32.

After the global financial crisis, the markets started to recover gradually from the great recession and the system became more stable and less sensitive to the shocks from other countries, with the spillover scale declining a lot and the persistence being shorter. Even shocks in their own markets could not cause large-scale fluctuation to themselves. Comparing with the pre-crisis scenario, the system has been stronger than before to immune the risk from East Asia.

Figure 32: Impulse response functions during post-crisis period, 4 January 2010 to 30 December 2018



On the other hand, the Granger causality test results reveal a more comprehensive and interconnected stock market system in East Asia, though the spillover scale has declined a lot.

All other countries except Japan and Malaysia Granger caused Hong Kong's stock market return volatility. Japan possesses 4 Granger causes, namely India, Malaysia, Philippines, and Singapore. 4 Granger causes of Korea are Hong Kong, Indonesia, Singapore, and Thailand. Singapore was Granger caused by Hong Kong, Indonesia, Korea, Malaysia, Philippines, and Thailand.

China has been more integrated involving Granger causes of volatilities in Hong Kong, Korea, Philippines, and Singapore. China, Hong Kong, Korea, Malaysia, Philippines, and Singapore Granger caused India. Indonesian Granger causes involve China, Hong Kong, Korea, Philippines, Singapore, and Thailand. Philippine Granger causes include all other countries except India and Malaysia. For Malaysia, it is

Granger caused by China, Indonesia, Korea, Philippines, and Singapore. Only Malaysia is the exception to Granger cause Thailand stock market volatility.

Table 7: Granger Causality Test Results (Post-Crisis VAR model)

VAR Granger Causality/Block Exogeneity Wald Tests
Date: 05/04/19 Time: 14:44
Sample: 1/04/2010 12/30/2016
Included observations: 1838

Dependent variable: GARCH_CHN

Excluded	Chi-sq	df	Prob.
GARCH_HKG	34.97226	16	0.0040***
GARCH_IDN	17.94796	16	0.3270
GARCH_IND	26.23976	16	0.0507
GARCH_JPN	9.230954	16	0.9036
GARCH_KOR	27.30165	16	0.0382**
GARCH_MYS	20.92973	16	0.1812
GARCH_PHL	31.22366	16	0.0126**
GARCH_SGP	35.47276	16	0.0034***
GARCH_THA	8.258021	16	0.9408
All	202.4587	144	0.0010

Dependent variable: GARCH_HKG

Excluded	Chi-sq	df	Prob.
GARCH_CHN	58.56618	16	0.0000***
GARCH_IDN	33.51866	16	0.0063***
GARCH_IND	55.23479	16	0.0000***
GARCH_JPN	4.424916	16	0.9980
GARCH_KOR	67.09807	16	0.0000***
GARCH_MYS	20.58233	16	0.1951
GARCH_PHL	32.90447	16	0.0076***
GARCH_SGP	38.91581	16	0.0011***
GARCH_THA	29.61076	16	0.0201**
All	356.8269	144	0.0000

Dependent variable: GARCH_IDN

Excluded	Chi-sq	df	Prob.
GARCH_CHN	31.24889	16	0.0125**
GARCH_HKG	46.85793	16	0.0001***
GARCH_IND	24.70003	16	0.0753
GARCH_JPN	7.640265	16	0.9589
GARCH_KOR	148.1336	16	0.0000***
GARCH_MYS	17.34354	16	0.3637
GARCH_PHL	46.66508	16	0.0001***
GARCH_SGP	38.34069	16	0.0014***
GARCH_THA	30.81884	16	0.0142**
All	399.4114	144	0.0000

Dependent variable: GARCH_IND

Excluded	Chi-sq	df	Prob.
GARCH_CHN	33.54390	16	0.0063***

GARCH_HKG	49.13020	16	0.0000***
GARCH_IDN	27.33363	16	0.0379**
GARCH_JPN	18.13552	16	0.3160
GARCH_KOR	35.08633	16	0.0039***
GARCH_MYS	52.05525	16	0.0000***
GARCH_PHL	27.18542	16	0.0395**
GARCH_SGP	50.43103	16	0.0000***
GARCH_THA	15.19885	16	0.5101
All	318.1009	144	0.0000

Dependent variable: GARCH_JPN

Excluded	Chi-sq	df	Prob.
GARCH_CHN	9.745507	16	0.8796
GARCH_HKG	15.14823	16	0.5138
GARCH_IDN	13.19648	16	0.6583
GARCH_IND	40.48427	16	0.0007***
GARCH_KOR	9.269570	16	0.9019
GARCH_MYS	65.56579	16	0.0000***
GARCH_PHL	31.50568	16	0.0116**
GARCH_SGP	40.89161	16	0.0006***
GARCH_THA	20.63206	16	0.1931
All	268.8094	144	0.0000

Dependent variable: GARCH_KOR

Excluded	Chi-sq	df	Prob.
GARCH_CHN	20.47251	16	0.1997
GARCH_HKG	70.11817	16	0.0000***
GARCH_IDN	110.6895	16	0.0000***
GARCH_IND	21.59801	16	0.1567
GARCH_JPN	20.22453	16	0.2103
GARCH_MYS	14.57950	16	0.5556
GARCH_PHL	22.91466	16	0.1160
GARCH_SGP	96.31333	16	0.0000***
GARCH_THA	32.50695	16	0.0086***
All	514.4078	144	0.0000

Dependent variable: GARCH_MYS

Excluded	Chi-sq	df	Prob.
GARCH_CHN	57.99298	16	0.0000***
GARCH_HKG	26.23557	16	0.0508
GARCH_IDN	49.66178	16	0.0000***
GARCH_IND	15.57535	16	0.4830
GARCH_JPN	18.27057	16	0.3083
GARCH_KOR	40.35230	16	0.0007***
GARCH_PHL	51.53324	16	0.0000***
GARCH_SGP	55.74492	16	0.0000***
GARCH_THA	22.38630	16	0.1312
All	386.9185	144	0.0000

Dependent variable: GARCH_PHL

Excluded	Chi-sq	df	Prob.
GARCH_CHN	48.20486	16	0.0000***
GARCH_HKG	38.41914	16	0.0013***
GARCH_IDN	93.08156	16	0.0000***
GARCH_IND	17.17026	16	0.3747

GARCH_JPN	51.96206	16	0.0000***
GARCH_KOR	52.74039	16	0.0000***
GARCH_MYS	24.72715	16	0.0748
GARCH_SGP	55.72103	16	0.0000***
GARCH_THA	42.23966	16	0.0004***
All	448.5735	144	0.0000

Dependent variable: GARCH_SGP

Excluded	Chi-sq	df	Prob.
GARCH_CHN	25.47306	16	0.0619
GARCH_HKG	41.94614	16	0.0004***
GARCH_IDN	60.56257	16	0.0000***
GARCH_IND	22.65647	16	0.1232
GARCH_JPN	20.86454	16	0.1838
GARCH_KOR	30.07057	16	0.0176**
GARCH_MYS	28.98836	16	0.0240**
GARCH_PHL	54.65520	16	0.0000***
GARCH_THA	28.65076	16	0.0264**
All	336.4836	144	0.0000

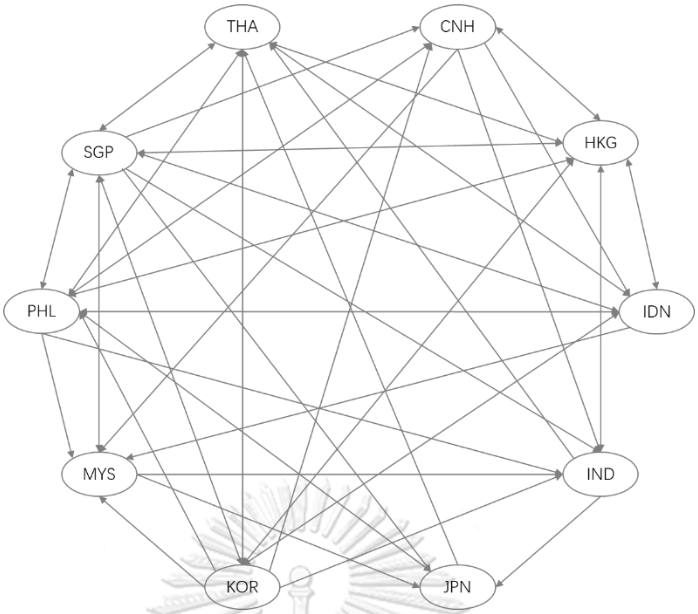
Dependent variable: GARCH_THA

Excluded	Chi-sq	df	Prob.
GARCH_CHN	29.17774	16	0.0228**
GARCH_HKG	54.27995	16	0.0000***
GARCH_IDN	129.7251	16	0.0000***
GARCH_IND	38.70591	16	0.0012***
GARCH_JPN	39.77197	16	0.0008***
GARCH_KOR	60.65217	16	0.0000***
GARCH_MYS	10.79076	16	0.8222
GARCH_PHL	57.83511	16	0.0000***
GARCH_SGP	31.24826	16	0.0125**
All	524.5284	144	0.0000

Note: ** and *** denote the significance at 5%, and 1% level, respectively.

Figure 23 exhibits the significant Granger causality correlations after the 2008 financial crisis, where more connections existing between these country-pairs as well as more bidirectional causality pairs. This phenomenon implies the financial crisis triggered the separate markets to get deeper integration into the whole system, which contribute to the globalization.

Figure 33: Granger causality relationships during post-crisis period, 4 January 2010 to 30 December 2018



Note: The arrow starts from the Granger cause and the two-way arrow represents there exists bidirectional Granger causality relationship between the two markets. All the causality relationships showed in the graph are statistically significant at 95% confidence level.

5.2.4 Discussion of the volatility spillover effects

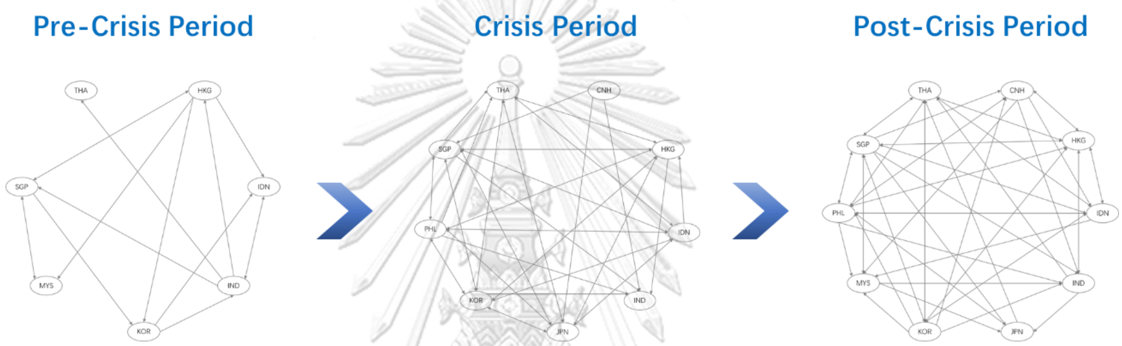
Consequently, the volatility impulse responses of these individual stock markets illustrate different patterns and altered over time, implying the size and the continuity of the effects of unexpected shocks are also quite market specific and time-varying.

Basically, the spillover effects extended a lot during crisis period, compared with non-crisis period. The volatility changes in one stock market are driven by both domestic shocks and abroad shocks. Clearly both the self-volatility spillover and the cross-volatility spillover effects were remarkable during the 2008 financial crisis for all the 10 markets, with larger scale and longer persistence.

Generally, during non-crisis period, in one individual stock market, the volatility spillover of itself is greater than the cross-market volatility spillover almost for all these East Asian stock markets. The relatively low self-volatility spillover in Hong Kong, Singapore and Malaysia reflects higher market efficiency with respect to the local information transfer. On the other hand, Hong Kong always shows relatively higher capability to spill its innovations to Singapore, and Korea.

When looking at the comparison between pre-crisis period and post-crisis period, we would say after the crisis, the individual markets have been more stable in face of information originating in other market, which means it's not easy for these stock markets in East Asia to be affected significantly by the disturbance in other East Asian markets during non-crisis period. Therefore, the East Asian financial system has been more stable after the financial crisis.

Figure 34: The development of the financial system in East Asia based on the Granger causality results



In addition, based on the Granger causality test results in the three phases of crisis, we can observe the development of the financial system in East Asia. As time goes by, these markets are getting increasingly interconnected. Even after the crisis, these financial markets are continuing to integrate further with each other.

To some extent, we could conclude that the 2008 financial crisis might contribute to this integration phenomenon in Asia. However, we should also be careful that the crisis should not be the only power to dominant this change during these years. There might exist other factors to accelerate this process and development. For example, the general development of infrastructure investment, and the advanced information technology could contribute to common information transmission mechanism.

CHAPTER 6
CONCLUSIONS AND LIMITATIONS

6.1 Conclusions

6.1.1 Volatility comovement

In conclusion, the results from the model suggest that generally the volatility comovement degree in East Asian stock markets has strengthened in the past two decades and over, both for developed markets and emerging markets, although the magnitude and time-varying property are quite market specific.

The developed markets in East Asia (Hong Kong, Singapore, Korea and Japan) displayed higher degree of volatility comovement. Specifically, stock markets in Hong Kong and Singapore are relatively strongly correlated with other stock markets in Asia. At the same time, emerging markets are getting increasingly related to the external financial markets over time, despite still at a low level. In addition, the results reflect that the ASEAN counties illustrate slightly closer correlations between each other and shows similar volatility comovement tendency. On the other hand, Chinese stock market and Philippine stock market typically exhibits the lowest correlations with the rest of the countries.

We could also observe that sever financial crises have positive and significant impacts on the volatility comovement in East Asian financial markets. During the 1997 Asian Financial Crisis, most of the stock markets in East Asia were affected to a large scale, whereas Chinese and Japanese stock markets were more stable to escape from a huge damage. The 2008 Global Financial Crisis and the following Global Recession, from 2007 to 2013, caused even greater turbulence and impacts in all cases than 1997 Asian Crisis, in terms of both size and persistence. These findings imply that it’s more difficult to reduce the risk exposure of international asset portfolio by diversification of East Asian financial assets when financial crisis occurs. We could also expect another common peak time of volatility comovement in the near future due to the trade war between America and China.

6.1.2 Volatility spillover effects

The impulse response of these markets and the Granger causality test results display that the overall degree of volatility spillover effects as well as the Granger causality relationships in the financial system of East Asia altered clearly in different phases of the financial crisis.

The range of spillover effects extended a lot in crisis period, compared with both pre-crisis period and post-crisis period. The size of the spillover effects nowadays was even lower than that before the financial crisis occurred. Moreover, the persistence of the effects was also much longer in financial crisis than before and after crisis. Basically, innovations from abroad could be modified within 30 days during pre-crisis and post-crisis period, whereas it needs about 80-90 days to fade the effects of the cross-border spillover during the financial crisis. These phenomena imply that the main East Asian financial system was kind of fragile under financial crisis as the markets could be affected easily and it's harder to recover to the normal states.

The volatility spillover results also give us some hints that severe financial crisis sort of triggers higher degree of systematic integration and stationarity, although it causes huge turmoil. After the financial crisis, the East Asian financial system seems like being more stable to defend the unpredictable shocks. This displays in two aspects. Firstly, the disturbance causes less impacts on the internal and external stock markets. Second, it takes less time to restore from the uncertainty. For now, the financial system in East Asia has become more interconnected and complex, and no market is totally independent. Even though a tiny innovation would be spread to everywhere and we will never know how much it would cost until it happens. It's necessary for policymakers to take all the international relationships into consideration, and to enhance their regulatory system to prevent a disaster in the future.

6.1.3 Some lessons of this research

This study gives much evidence about volatility comovement of stock market returns in Asian financial markets, which contributes to better and deeper understanding on this financial system, as well as some reference significance.

Based on the research and analysis above, I would say, the financial integration has become an unstoppable tendency in East Asia. In this kind of environment, both investors and policy makers have to be more cautious and consider more to avoid huge destructions.

For investors, they should keep close eye on information in international financial centers like Hong Kong and Singapore stock markets which partially constitutes the systematic risk of their international asset portfolios. On the other hand, there are still opportunity for them to reduce risk exposure by diversification, despite smaller room than before. Especially, markets that show low volatility correlation levels would show more power to hedge risk, such as Philippines, Malaysia, and India. Chinese stock market showed quite risk independent before 2007, but in the future, it would have high potential to surge dramatically due to the Trade War.

As to policy makers, they should also pay more attention to information in financial centers as well as markets that are strongly correlated with them. Another consideration for them is that when they making policies regarding financial liberalization or financial openness, they should really be careful to ensure their markets are able to react and deal with shocks from common information as well as market-specific information spillover. Otherwise, they may have to control their speed to open up the financial markets step by step.

6.2 Limitations

The aim of this study is mainly to investigate the empirical results of volatility comovement and spillover effects. Hence, it only tested some commonly believed variables that might contribute to the phenomenon, without digging quite deeply into the specific factors to make an interpretation in depth. The future research could pay some attention into this issue to investigate valuable insights.

Another shortage is these findings leave the asymmetric effects of good or bad innovations out of consideration. In reality, however, the asymmetry is the general state. If we could understand the nature and core of that, we would be able to get along well with the financial system and maintain the financial environment stable by protecting the system from huge turmoil. Therefore, it is meaningful to pursue further research regarding this issue.

REFERENCES

Aamir, M., & Ali Shah, S. (2018). Determinants of Stock Market Co-Movements between Pakistan and Asian Emerging Economies. *Journal of Risk and Financial Management, 11*(3), 32.

Anderson, J. E. (2011). The gravity model. *Annu. Rev. Econ., 3*(1), 133-160.

Balasubramanyan, L. (2004). Do Time-Varying Covariances, Volatility Comovement and Spillover Matter? *, 1*(2).

Bauwens, L., Laurent, S., & Rombouts, J. V. K. (2006). Multivariate GARCH models: a survey. *Journal of Applied Econometrics, 21*(1), 79-109. doi:10.1002/jae.842

Bikhchandani, S., & Sharma, S. (2000). Herd behavior in financial markets. *IMF Staff papers, 47*(3), 279-310.

Chen, J., Kobayashi, M., & McAleer, M. (2017). Testing for volatility co-movement in bivariate stochastic volatility models. *47*(1), 13-36.

Chow, H. K. (2017). Volatility Spillovers and Linkages in Asian Stock Markets. *Emerging Markets Finance and Trade, 53*(12), 2770-2781. doi:10.1080/1540496x.2017.1314960

Dajcman, S., Festic, M., & Kavkler, A. (2012). European stock market comovement dynamics during some major financial market turmoils in the period 1997 to 2010 – a comparative DCC-GARCH and wavelet correlation analysis. *Applied Economics Letters, 19*(13), 1249-1256. doi:10.1080/13504851.2011.619481

Diebold, F. X., & Yilmaz, K. (2009). Measuring financial asset return and volatility spillovers, with application to global equity markets. *119*(534), 158-171.

Drakos, K., & Kutan, A. M. (2005). Why Do Financial Markets Move Together?: An Investigation of Greek and Turkish Markets. *Eastern European Economics, 43*(4), 5-26.

Engle, R. (2002). Dynamic Conditional Correlation. *Journal of Business & Economic Statistics, 20*(3), 339-350. doi:10.1198/073500102288618487

Engle, R. F., & Sheppard, K. (2001). *Theoretical and empirical properties of dynamic conditional correlation multivariate GARCH*. Retrieved from

Engle, R. F., & Susmel, R. (1993). Common volatility in international equity markets. *11*(2), 167-176.

Fleming, J., Kirby, C., & Ostdiek, B. (1998). Information and volatility linkages in the stock, bond, and money markets. *Journal of financial economics, 49*(1), 111-137.

Hansen, P. R., & Lunde, A. (2005). A forecast comparison of volatility models: does anything beat a GARCH (1, 1)? *Journal of Applied Econometrics, 20*(7), 873-889.

Horvath, R., & Poldauf, P. (2012). International stock market comovements: what happened during the financial crisis? *, 12*(1).

IMF. (2019). *World Economic Outlook: Growth Slowdown, Precarious Recovery*. Retrieved from Washington, DC:

Jin, X. (2015). Volatility transmission and volatility impulse response functions among the Greater China stock markets. *Journal of Asian Economics, 39*, 43-58.

Johnson, R., & Soenen, L. (2002). Asian economic integration and stock market comovement. *25*(1), 141-157.

Johnson, R., & Soenen, L. (2003). Economic integration and stock market comovement in the Americas. *13*(1), 85-100.

Kwon, E. (2004). Financial Liberalization in South Korea. *Journal of Contemporary Asia, 34*(1), 70-101.

Lee, J. K.-Y., & Wong, A. Y.-T. (2012). Impact of financial liberalisation on stock market liquidity: experience of China. *Journal of Chinese Economic and Foreign Trade Studies, 5*(1), 4-19.

Morana, C., & Beltratti, A. (2008). Comovements in international stock markets. *18*(1), 31-45.

Orskaug, E. (2009). *Multivariate dcc-garch model:-with various error distributions.* Institutt for matematiske fag,

Shen, Y. (2018). International risk transmission of stock market movements. *Economic Modelling, 69*, 220-236.

Walti, S. (2005). The macroeconomic determinants of stock market synchronization. *Journal of International Banking Law, 11*(10), 436-441.

Yilmaz, K. (2010). Return and volatility spillovers among the East Asian equity markets. *Journal of Asian Economics, 21*(3), 304-313.

APPENDICES

Appendix 1:

Table 8: Estimation result of DCC-MGARCH model

```
*---------------------------------------------*
*        DCC GARCH Fit        *
*---------------------------------------------*

Distribution        :  mvnorm
Model               :  DCC(1,1)
No. Parameters      :  97
[VAR GARCH DCC UncQ] : [0+50+2+45]
No. Series          :  10
No. Obs.            :  6485
Log-Likelihood      :  208690.5
Av.Log-Likelihood   :  32.18

Optimal Parameters
-----------------------------------
```

	Estimate	Std. Error	t value	Pr(>|t|)
[RCHN].mu	0.000249	0.000183	1.3592e+00	0.174073
[RCHN].ar1	0.023449	0.015318	1.5309e+00	0.125806
[RCHN].omega	0.000001	0.000007	1.4805e-01	0.882304
[RCHN].alpha1	0.053476	0.063682	8.3975e-01	0.401050
[RCHN].beta1	0.945520	0.061651	1.5337e+01	0.000000
[RHKG].mu	0.000539	0.000264	2.0427e+00	0.041083
[RHKG].ar1	0.066237	0.028593	2.3165e+00	0.020530
[RHKG].omega	0.000001	0.000015	9.9207e-02	0.920974
[RHKG].alpha1	0.068780	0.157674	4.3622e-01	0.662679
[RHKG].beta1	0.924187	0.166164	5.5619e+00	0.000000
[RIDN].mu	0.000701	0.000138	5.0743e+00	0.000000
[RIDN].ar1	0.142952	0.015543	9.1971e+00	0.000000
[RIDN].omega	0.000002	0.000005	3.3839e-01	0.735069
[RIDN].alpha1	0.100565	0.076325	1.3176e+00	0.187641
[RIDN].beta1	0.895304	0.075456	1.1865e+01	0.000000
[RIND].mu	0.000724	0.000157	4.6014e+00	0.000004
[RIND].ar1	0.119967	0.014478	8.2864e+00	0.000000
[RIND].omega	0.000003	0.000002	1.3020e+00	0.192927
[RIND].alpha1	0.110315	0.026341	4.1880e+00	0.000028
[RIND].beta1	0.879664	0.027813	3.1628e+01	0.000000
[RJPN].mu	0.000156	0.000148	1.0547e+00	0.291583
[RJPN].ar1	0.019974	0.013952	1.4316e+00	0.152247
[RJPN].omega	0.000005	0.000006	8.1694e-01	0.413962
[RJPN].alpha1	0.111080	0.011661	9.5261e+00	0.000000
[RJPN].beta1	0.867822	0.026893	3.2269e+01	0.000000
[RKOR].mu	0.000372	0.000131	2.8479e+00	0.004401
[RKOR].ar1	0.059109	0.013060	4.5259e+00	0.000006
[RKOR].omega	0.000001	0.000001	6.5317e-01	0.513646
[RKOR].alpha1	0.067146	0.013976	4.8042e+00	0.000002
[RKOR].beta1	0.931553	0.013826	6.7379e+01	0.000000
[RMYS].mu	0.000304	0.000104	2.9192e+00	0.003510
[RMYS].ar1	0.160187	0.014958	1.0709e+01	0.000000
[RMYS].omega	0.000001	0.000003	2.9211e-01	0.770203

[RMYS].alpha1	0.116498	0.068791	1.6935e+00	0.090358
[RMYS].beta1	0.881954	0.060083	1.4679e+01	0.000000
[RPHL].mu	0.000421	0.000142	2.9689e+00	0.002989
[RPHL].ar1	0.156172	0.014518	1.0757e+01	0.000000
[RPHL].omega	0.000005	0.000005	9.2162e-01	0.356726
[RPHL].alpha1	0.145625	0.014220	1.0241e+01	0.000000
[RPHL].beta1	0.829498	0.039467	2.1017e+01	0.000000
[RSGP].mu	0.000296	0.000116	2.5583e+00	0.010519
[RSGP].ar1	0.082664	0.014624	5.6526e+00	0.000000
[RSGP].omega	0.000001	0.000005	1.7201e-01	0.863427
[RSGP].alpha1	0.098946	0.103254	9.5827e-01	0.337926
[RSGP].beta1	0.897740	0.096442	9.3086e+00	0.000000
[RTHA].mu	0.000644	0.000178	3.6149e+00	0.000300
[RTHA].ar1	0.124166	0.019579	6.3417e+00	0.000000
[RTHA].omega	0.000003	0.000004	7.6383e-01	0.444967
[RTHA].alpha1	0.115510	0.013539	8.5316e+00	0.000000
[RTHA].beta1	0.876979	0.015614	5.6165e+01	0.000000
[Joint]dcca1	**0.003993**	**0.000547**	**7.3025e+00**	**0.000000**
[Joint]dccb1	**0.994998**	**0.000869**	**1.1452e+03**	**0.000000**

Information Criteria

Akaike -64.331
Bayes -64.230
Shibata -64.331
Hannan-Quinn -64.296

Appendix 2:

Table 9: Estimation Results of Panel Data Model (Period Fixed Effects & Cross-section Fixed Effects)

Dependent Variable: DCC?
Method: Pooled Least Squares
Date: 03/18/19 Time: 19:57
Sample: 1995 2017
Included observations: 23
Cross-sections included: 90
Total pool (balanced) observations: 2070

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.684097	2.298833	-0.297585	0.7661
_CHNHKG--LGDP_CHNHKG	0.089714	0.452518	0.198254	0.8429
_CHNIDN--LGDP_CHNIDN	-0.002572	0.452518	-0.005683	0.9955
_CHNIND--LGDP_CHNIND	-0.017905	0.452518	-0.039567	0.9684
_CHNJPN--LGDP_CHNJPN	0.005001	0.452518	0.011052	0.9912
_CHNKOR--LGDP_CHNKOR	0.020391	0.452518	0.045062	0.9641
_CHNMYS--LGDP_CHNMYS	-0.005033	0.452518	-0.011122	0.9911
_CHNPHL--LGDP_CHNPHL	14.41905	0.452518	31.86407	0.0000
_CHNSGP--LGDP_CHNSGP	0.022750	0.452518	0.050275	0.9599
_CHNTHA--LGDP_CHNTHA	-0.016712	0.452518	-0.036931	0.9705
_HKGCHN--LGDP_HKGCHN	0.415603	1.702353	0.244134	0.8072
_HKGIDN--LGDP_HKGIDN	-0.019980	1.702353	-0.011736	0.9906
_HKGIND--LGDP_HKGIND	0.121829	1.702353	0.071565	0.9430
_HKGJPN--LGDP_HKGJPN	-0.081092	1.702353	-0.047635	0.9620
_HKGKOR--LGDP_HKGKOR	0.081428	1.702353	0.047832	0.9619
_HKGMYS--LGDP_HKGMYS	-0.078216	1.702353	-0.045946	0.9634
_HKGPHL--LGDP_HKGPHL	-0.061124	1.702353	-0.035906	0.9714
_HKGSGP--LGDP_HKGSGP	-0.115451	1.702353	-0.067819	0.9459
_HKGTHA--LGDP_HKGTHA	-0.086407	1.702353	-0.050757	0.9595
_IDNCHN--LGDP_IDNCHN	-0.004007	0.587825	-0.006817	0.9946
_IDNHKG--LGDP_IDNHKG	-0.022940	0.587825	-0.039025	0.9689
_IDNIND--LGDP_IDNIND	-0.005978	0.587825	-0.010170	0.9919
_IDNJPN--LGDP_IDNJPN	-0.024516	0.587825	-0.041707	0.9667
_IDNKOR--LGDP_IDNKOR	0.017194	0.587825	0.029250	0.9767
_IDNMYS--LGDP_IDNMYS	-0.015435	0.587825	-0.026257	0.9791
_IDNPHL--LGDP_IDNPHL	-0.058149	0.587825	-0.098923	0.9212
_IDNSGP--LGDP_IDNSGP	-0.037438	0.587825	-0.063689	0.9492
_IDNTHA--LGDP_IDNTHA	-0.048519	0.587825	-0.082540	0.9342
_INDCHN--LGDP_INDCHN	-0.019124	0.646462	-0.029582	0.9764
_INDHKG--LGDP_INDHKG	0.013833	0.587825	0.023532	0.9812
_INDIDN--LGDP_INDIDN	0.007670	0.646462	0.011865	0.9905
_INDJPN--LGDP_INDJPN	-0.001468	0.646462	-0.002271	0.9982
_INDKOR--LGDP_INDKOR	-0.014627	0.646462	-0.022626	0.9820
_INDMYS--LGDP_INDMYS	-0.003285	0.646462	-0.005082	0.9959
_INDPHL--LGDP_INDPHL	-0.032710	0.646462	-0.050598	0.9597
_INDSGP--LGDP_INDSGP	0.035811	0.646462	0.055395	0.9558
_INDTHA--LGDP_INDTHA	0.028107	0.646462	0.043479	0.9653
_JPNCHN--LGDP_JPNCHN	-1.080227	3.761414	-0.287186	0.7740
_JPNHKG--LGDP_JPNHKG	-1.367684	3.761414	-0.363609	0.7162
_JPNIDN--LGDP_JPNIDN	-1.126495	3.761414	-0.299487	0.7646
_JPNIND--LGDP_JPNIND	-1.434511	3.761414	-0.381375	0.7030
_JPNKOR--LGDP_JPNKOR	-1.101335	3.761414	-0.292798	0.7697
_JPNMYS--LGDP_JPNMYS	-1.253287	3.761414	-0.333196	0.7390
_JPNPHL--LGDP_JPNPHL	-1.212398	3.761414	-0.322325	0.7472
_JPNSGP--LGDP_JPNSGP	-1.308596	3.761414	-0.347900	0.7280
_JPNTHA--LGDP_JPNTHA	-1.362714	3.761414	-0.362288	0.7172
_KORCHN--LGDP_KORCHN	0.167599	1.062673	0.157715	0.8747
_KORHKG--LGDP_KORHKG	0.173780	1.062673	0.163531	0.8701

_KORIDN--LGDP_KORIDN	0.178398	1.062673	0.167877	0.8667
_KORIND--LGDP_KORIND	0.102066	1.062673	0.096046	0.9235
_KORJPN--LGDP_KORJPN	0.210619	1.062673	0.198197	0.8429
_KORMYS--LGDP_KORMYS	0.153203	1.062673	0.144167	0.8854
_KORPHL--LGDP_KORPHL	0.113183	1.062673	0.106508	0.9152
_KORSGP--LGDP_KORSGP	0.132078	1.062673	0.124288	0.9011
_KORTHA--LGDP_KORTHA	0.018746	1.062673	0.017641	0.9859
_MYSCHN--LGDP_MYSCHN	-0.010530	0.813808	-0.012939	0.9897
_MYSHKG--LGDP_MYSHKG	-0.092723	0.813808	-0.113937	0.9093
_MYSIDN--LGDP_MYSIDN	-0.024439	0.813808	-0.030030	0.9760
_MYSIND--LGDP_MYSIND	-0.028074	0.813808	-0.034497	0.9725
_MYSJPN--LGDP_MYSJPN	-0.051836	0.813808	-0.063695	0.9492
_MYSKOR--LGDP_MYSKOR	0.009051	0.813808	0.011122	0.9911
_MYSPHL--LGDP_MYSPHL	-0.049987	0.813808	-0.061423	0.9510
_MYSSGP--LGDP_MYSSGP	-0.132841	0.813808	-0.163234	0.8704
_MYSTHA--LGDP_MYSTHA	-0.122130	0.813808	-0.150072	0.8807
_PHLCHN--LGDP_PHLCHN	25.83825	0.798987	32.33877	0.0000
_PHLHKG--LGDP_PHLHKG	-0.081504	0.798987	-0.102010	0.9188
_PHLIDN--LGDP_PHLIDN	-0.072257	0.798987	-0.090436	0.9280
_PHLIND--LGDP_PHLIND	-0.057746	0.798987	-0.072274	0.9424
_PHLJPN--LGDP_PHLJPN	-0.035261	0.798987	-0.044132	0.9648
_PHLKOR--LGDP_PHLKOR	-0.018635	0.798987	-0.023323	0.9814
_PHLMYS--LGDP_PHLMYS	-0.042584	0.798987	-0.053298	0.9575
_PHLSGP--LGDP_PHLSGP	-0.105877	0.798987	-0.132514	0.8946
_PHLTHA--LGDP_PHLTHA	-0.098580	0.798987	-0.123382	0.9018
_SGPCHN--LGDP_SGPCHN	0.036099	0.842808	0.042832	0.9658
_SGPHKG--LGDP_SGPHKG	-0.105737	0.842808	-0.125458	0.9002
_SGPIDN--LGDP_SGPIDN	-0.054191	0.842808	-0.064298	0.9487
_SGPIND--LGDP_SGPIND	0.015722	0.842808	0.018654	0.9851
_SGPJPN--LGDP_SGPJPN	-0.052680	0.842808	-0.062505	0.9502
_SGPKOR--LGDP_SGPKOR	-0.028240	0.842808	-0.033507	0.9733
_SGPMYS--LGDP_SGPMYS	-0.131968	0.842808	-0.156582	0.8756
_SGPPHL--LGDP_SGPPHL	-0.120009	0.842808	-0.142391	0.8868
_SGPTHA--LGDP_SGPTHA	-0.105452	0.842808	-0.125120	0.9004
_THACHN--LGDP_THACHN	-0.053644	0.911666	-0.058842	0.9531
_THAHKG--LGDP_THAHKG	-0.096265	0.911666	-0.105593	0.9159
_THAIDN--LGDP_THAIDN	-0.070106	0.911666	-0.076898	0.9387
_THAIND--LGDP_THAIND	0.012325	0.911666	0.013519	0.9892
_THAJPN--LGDP_THAJPN	-0.113256	0.911666	-0.124230	0.9011
_THAKOR--LGDP_THAKOR	-0.116524	0.911666	-0.127815	0.8983
_THAMYS--LGDP_THAMYS	-0.132677	0.911666	-0.145533	0.8843
_THAPHL--LGDP_THAPHL	-0.122194	0.911666	-0.134034	0.8934
_THASGP--LGDP_THASGP	-0.112143	0.911666	-0.123009	0.9021
Fixed Effects (Cross)				
_CHNHKG--C	0.240066			
_CHNIDN--C	0.835535			
_CHNIND--C	0.964727			
_CHNJPN--C	0.792277			
_CHNKOR--C	0.684798			
_CHNMYS--C	0.852738			
_CHNPHL--C	-87.65224			
_CHNSGP--C	0.668895			
_CHNTHA--C	0.942498			
_HKGCHN--C	-1.258371			
_HKGIDN--C	1.192207			
_HKGIND--C	0.396019			
_HKGJPN--C	1.598846			
_HKGKOR--C	0.738774			
_HKGMYS--C	1.514272			
_HKGPHL--C	1.327713			
_HKGSGP--C	1.920080			
_HKGTHA--C	1.535485			
_IDNCHN--C	0.838679			
_IDNHKG--C	1.221772			
_IDNIND--C	1.003255			
_IDNJPN--C	1.121265			
_IDNKOR--C	0.899851			

_IDNMYS--C	1.152068
_IDNPHL--C	1.357750
_IDNSGP--C	1.340312
_IDNTHA--C	1.321817
_INDCHN--C	0.951615
_INDHKG--C	0.964337
_INDIDN--C	0.915331
_INDJPN--C	0.934477
_INDKOR--C	1.089620
_INDMYS--C	0.933809
_INDPHL--C	1.082854
_INDSGP--C	0.787585
_INDTHA--C	0.769707
_JPNCHN--C	9.999620
_JPNHKG--C	12.77252
_JPNIDN--C	10.53548
_JPNIND--C	13.09820
_JPNKOR--C	10.50079
_JPNMYS--C	11.64531
_JPNPHL--C	11.25766
_JPNSGP--C	12.23738
_JPNTHA--C	12.51890
_KORCHN--C	-0.282613
_KORHKG--C	0.000630
_KORIDN--C	-0.202106
_KORIND--C	0.300783
_KORJPN--C	-0.267056
_KORMYS--C	-0.021445
_KORPHL--C	0.202139
_KORSGP--C	0.240004
_KORTHA--C	0.861833
_MYSCHN--C	0.866050
_MYSHKG--C	1.569836
_MYSIDN--C	1.185115
_MYSIND--C	1.054623
_MYSJPN--C	1.274010
_MYSKOR--C	0.966386
_MYSPHL--C	1.252140
_MYSSGP--C	1.818997
_MYSTHA--C	1.629511
_PHLCHN--C	-99.09294
_PHLHKG--C	1.402758
_PHLIDN--C	1.368261
_PHLIND--C	1.143707
_PHLJPN--C	1.142491
_PHLKOR--C	1.057829
_PHLMYS--C	1.206775
_PHLSGP--C	1.532312
_PHLTHA--C	1.421115
_SGPCHN--C	0.668839
_SGPHKG--C	1.839032
_SGPIDN--C	1.392349
_SGPIND--C	0.952710
_SGPJPN--C	1.398914
_SGPKOR--C	1.274429
_SGPMYS--C	1.809283
_SGPPHL--C	1.618511
_SGPTHA--C	1.632288
_THACHN--C	1.100024
_THAHKG--C	1.597693
_THAIDN--C	1.414941
_THAIND--C	0.894760
_THAJPN--C	1.570403
_THAKOR--C	1.622092
_THAMYS--C	1.727854
_THAPHL--C	1.600189
_THASGP--C	1.708265

Fixed Effects (Period)	
1995--C	0.142334
1996--C	-0.330000
1997--C	-0.060044
1998--C	0.234623
1999--C	-0.042251
2000--C	-0.114349
2001--C	-0.183134
2002--C	-0.164031
2003--C	-0.074838
2004--C	-0.287763
2005--C	-0.481111
2006--C	-0.383471
2007--C	-0.200053
2008--C	0.641980
2009--C	0.677776
2010--C	0.409323
2011--C	0.249810
2012--C	0.575707
2013--C	0.127529
2014--C	-0.143668
2015--C	-0.482050
2016--C	0.150664
2017--C	-0.262986

Effects Specification

Cross-section fixed (dummy variables)
Period fixed (dummy variables)

R-squared	0.854572	Mean dependent var	0.920570
Adjusted R-squared	0.838923	S.D. dependent var	4.892596
S.E. of regression	1.963613	Akaike info criterion	4.279938
Sum squared resid	7202.590	Schwarz criterion	4.829857
Log likelihood	-4227.736	Hannan-Quinn criter.	4.481505
F-statistic	54.61096	Durbin-Watson stat	1.156949
Prob(F-statistic)	0.000000		

Redundant Fixed Effects Tests
Pool: DCC
Test cross-section and period fixed effects

Effects Test	Statistic	d.f.	Prob.
Cross-section F	14.767331	(89,1868)	0.0000
Cross-section Chi-square	1102.758358	89	0.0000
Period F	2.515239	(22,1868)	0.0001
Period Chi-square	60.428370	22	0.0000
Cross-Section/Period F	12.350452	(111,1868)	0.0000
Cross-Section/Period Chi-square	1139.256529	111	0.0000

VITA

NAME	Weijie YU
DATE OF BIRTH	9 Feb 1992
PLACE OF BIRTH	Datong City, Shanxi Province, China
INSTITUTIONS ATTENDED	Peking University Minzu University of China
HOME ADDRESS	Zuoyunzonghejishu School, Datong City, Shanxi Province, China
AWARD RECEIVED	MAIEF Scholarship Awards