AN ANALYSIS OF THE INTERNATIONAL LINKAGES BETWEEN CHINA AND THE US MARKET: A MULTIVARIATE GARCH APPROACH

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PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN FINANCE

In the Master of Science in Finance Program
of the
Faculty
of
Business Administration

SIMON FRASER UNIVERSITY

Fall Term 2018

Approval

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Degree: **Master of Science in Finance**

Title of Project: **An analysis of the international linkages between China and the us market: a multivariate GARCH approach**

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Abstract

This paper attempts to re-examine Li (2007)'s study on the interrelationships among the stock exchanges in mainland China, Hong Kong and the U.S. by applying a four-variable BEKK-GARCH model. After extending the data to a longer and more recent period, we find that global economic recession and financial market integration do affect the correlations among international financial markets. The U.S. market, playing a crucial role in the global markets, directly affects the Chinese stock markets, which is supported by the evidence of unidirectional return and shock spillovers from the stock exchange in the U.S. to those in China. We also find a strong integration of mainland Chinese stock exchanges with Hong Kong market, which is indicated by the bidirectional shock spillovers between the stock exchanges in mainland and that in Hong Kong. These findings differ from Li's conclusions and suggest that international markets have become far more linked than before. Thus, international investors may not benefit as much from the reduction of diversifiable risk by adding mainland Chinese stocks to investment portfolio as before and need to consider more foreign stock market information.

Keywords: multi-variate GARCH; asymmetric response of volatility; stock market linkages; return spillovers; volatility spillovers; shock spillovers

Dedication

We dedicate our dissertation work to our families and friends. A special feeling of gratitude to our loving parents and significant others, who always encourage us to pursue our dreams.

Acknowledgements

We thank our professor Andrey Pavlov from Beedie School of Business, Simon Fraser University who provided insights and expertise that greatly guided our research.

We thank professor Christina Christina Atanasova from Beedie School of Business, Simon Fraser University for evaluating the research and providing valuable feedback as the second reader.

Table of Contents

List of Figures

List of Tables

1. Introduction

With a growing integration of global financial markets and an increasing process of financial liberalization, international financial markets have become more correlated and integrated than ever before. As the leading indicator of the economy, stock index has shown a trend of linkage in recent decades. Especially after the 1987 U.S. October Crash, the linkage of global stock markets has further strengthened, which has attracted the attention of numerous researchers to examine the spillover effects between different equity markets (Huo and Ahmed, 2016). A spillover occurs when the price changes in one market lead to a lagged impact on the other market. The spillover effects include return and volatility spillover and can exist among various countries or among various markets within one country (Huo and Ahmed, 2016). It is important to understand the return and volatility spillover effects across different markets since it allows investors, financial institutions, and governments to gain a better understanding of the dynamic relationships among different financial markets, which can assist in constructing investment portfolios, making asset allocation decisions, and devising market polices.

In this paper, we aim to re-examine Li (2007)'s study on the linkages between the two emerging stock exchanges in mainland China and the established markets in Hong Kong and the United States using data from more recent period of time. We are motivated to do this study since these markets have gone through significant changes and the globalization of capital markets and liberation process can accelerate the co-movement of international financial markets (Roll, 1992). In Li's study, he investigates how and to what extent these four stock exchanges are connected by using sample data from 2000 to 2005 and by applying a four-variable asymmetric GARCH in the form of the BEKK model proposed by Engle and Kroner (1995). We generally confirm his results after replication. His results report unidirectional return and volatility spillovers from Hong Kong to mainland Chinese stock exchanges while no direct linkage between the stock exchanges in mainland China and the US market. Moreover, since the return linkages between the Hong Kong and mainland China stock markets depend on the return linkages between Hong Kong and the US stock markets, Hong Kong has acted as a go-between in the information flow that the information about global economy is transmitted into Chinese market through Hong Kong, but not for the volatility linkages. Nevertheless, the magnitude of the linkages between Hong Kong and Chinese stock markets is small, which suggesting a weak integration of the China stock exchanges with the regional developed market. Therefore, he suggests that adding mainland China stocks in investment portfolios can benefit investors from the reduction of diversifiable risks (Li, 2007).

However, after extending the data to a longer and more recent period, which includes noteworthy events, such as 2008 financial crisis and Chinese stock market liberalization, we find that the U.S. stock market does have a direct impact on Chinese stock markets, which is reflected by both return and shock spillovers from the U.S. market to the other three Chinese markets. Also, both bidirectional return and shock spillovers between Hong Kong and mainland China stock exchanges shows a stronger linkage between Chinese regional markets. These findings are different from Li's conclusion but are in line with Finke and Weigert's study (2016). They found that foreign information has significant predictive ability for future stock returns on a global scale, also suggesting that financial markets are far more linked then previous thought.

Global economic recession and financial market integration and liberalization in the past ten years may cause the discrepancy of the results. During the sample period in Li's study, there was still a direct investment barrier applied to overseas investors that international investors, including overseas Chinese residing in Hong Kong and Macau, can only take part in trading constituent B-shares in the Shanghai and Shenzhen stock exchanges, which segmented Chinese financial markets from the international capital markets. However, during the sample period under our study, these markets have experienced significant changes. The 2008 financial crisis stemmed from the influential U.S. market has pervasive effects on global financial markets, which could cause a fundamental change in the correlations among international markets, for both developed and emerging markets. Cheung, Fung, and Tsai (2010) used data sample from 2003 to 2009 to study the changing interrelationships among the global financial markets before and after the financial crisis and documented enhanced spillover effects from the U.S. markets to other markets in UK, Hong Kong, Japan, Australia, and China. Besides, in order to link the stock markets in mainland China and Hong Kong Exchanges, the Shanghai-Hong Kong Stock connection (SH-HK Stock connect) and Shenzhen-Hong Kong Stock Connection (SZ-HK Stock connect) programs were introduced in 2014 and 2016 respectively, which are tangible progress on Chinese stock market liberalization after the 2008 financial crisis. These two pilot programs allow foreign investors to purchase stocks in Chinese stock markets and also allow domestic investors to purchase foreign shares, which eases the restrictions on both domestic and overseas investors and results in a significant increase in the capitals flows between the mainland China and

Hong Kong stock exchanges in both directions. Accordingly, it is reasonable to expect that the two markets are becoming more integrated.

The rest of the paper is organized as follows. The next section provides some literature review. Section 3 presents descriptive statistics of sample data and introduces the features of four share price indices used in the study. Section 4 presents the econometric methodology, focusing on multivariate asymmetric BEKK-GARCH model. Section 5 reports the empirical results and discusses the implications. Section 6 gives conclusions.

2. Literature Review

Return and volatility spillovers are two main channels of information transmission mechanism, which are important characteristics of financial assets. A spillover occurs when the price changes in one market cause a lagged impact on the other markets (Huo and Ahmed, 2016). Moser (2003) found that international trade, counterparty defaults, and portfolio rebalancing are three leading activities that could lead to spillover effects. Ross (1989) confirmed the positive relation between volatility and rate of information flow, which indicates that the spillovers between financial markets can be used to explain the process of information transmissions and the efficiency of the stock markets. Furthermore, Roll (1992) suggested that the globalization of capital markets and liberation process increase the probabilities that national markets can react promptly to new information from international markets and therefore accelerate the co-movement of international financial markets.

Return and volatility spillover have been studied extensively because understanding spillover effects is helpful in making asset and investment allocation decisions, designing hedging strategies, and devising market policies. Also, there have been numerous applications of multivariate GARCH models to investigate the interrelation between markets. A GARCH model was first used by Eun and Shim in 1989 to study the volatility between stock markets and they found that innovations in the U.S. market are rapidly transmitted to other markets in a clearly recognizable fashion, while the U.S. market movements cannot be effectively explained by any single foreign market. Miyakoshi (2003) used a bivariate EGARCH model to examine how and to what extent the Asian markets are influenced by the regional (Japan) and international (the U.S.) markets. He observed that only the US market can significantly influence the returns of the Asian market, however, the volatility of the Asian market is influenced more by Japanese market then by the U.S. market. Dong and Cao (2009) built a multivariable GARCH model to investigate the volatility spillover between the equity markets in the US, Japan, Hongkong and mainland China. The empirical study shows that there only exists the unidirectional spillover from Hongkong to Shanghai Share A market, and there are no significant spillover effects from both stock markets in the U.S. and Japan to market in Shanghai. However, the Shanghai share A market is indirectly influenced by the U.S. and Japanese stock market through the Hongkong market, which are in line with Li's study.

Since the Global Financial Crisis in 2007, some studies focused on the spillover effects during the financial crisis period. Cheung et al. (2009) explored the effects of 2007-2009 Global financial Crisis on the interdependencies among global stock markets and reported US market's enhanced leadership with respect to the Chinese, Hongkong, Japanese, Australian, Russian, and UK markets. Yilmaz (2010) studied the return and volatility spillovers across ten major East Asian stock markets and the result indicates that return and volatility spillovers behave quite differently during financial crisis and non-crises periods. Likewise, analyzing two datasets which are before and after the financial crisis in the U.S., Chinese, and U.K. stock market, Huang, Kou, and Yang (2012) concluded that the impact of the financial crises on the global financial system affects the transmission mechanism of volatility spillovers in these three markets and the US market is the main source of stock market volatility, especially after the financial crisis.

There are also some studies that have explored the impact of SH-HK and SZ-HK Stock Connect Program as it is a strategic movement of the Chinese capital market opening up to the rest of world. Zhang and Jaffry (2014) looked into the influence of SH-HK Stock Connect on the one-minute intraday high frequency volatility spillover between the two stock markets by applying BEKK-GARCH model. The finding demonstrates that strong bi-volatility spillover exists in the connected period. After, in 2016, Huo and Ahmed also investigated the impact of SH-HK Stock Connect and observed enhanced spillover effects in terms of return and volatility from Shanghai to Hong Kong after the Stock Connect.

Besides, volatility has been believed to be larger in a bear market than in a bull market. The asymmetric phenomenon was explained by Black (1976) and Christie (1982) with leverage effect, suggesting that upsurge in financial leverage due to falling stock prices might increase volatility. Yarovaya, Brzeszczynski, and Lau (2016) investigated the channels of volatility transmission across stock index futures in six major developed and emerging markets in Asia. The results show that the signal receiving markets are sensitive to both positive and negative volatility shocks, which discloses the asymmetric nature of volatility transmission channels.

3. Data and Statistics Summary

In this paper, we used same stock indices as Li used in his study but with a more recent sample period. The raw data are the daily closing adjusted prices of Shanghai Stock Exchange Composite Index (SSEC), the Shenzhen Stock Exchange Component Index (SZSE), the Hong Kong Hang Seng Index (HSI), and the Standard & Poor's 500 (S&P 500) from 1 January 2007 to 31 July 2018[1]. The period under study experienced the financial crisis in 2008, the Shanghai-Hong Kong Stock Connect in 2014, and the Shenzhen-Hong Kong Stock Connect in 2016 and some other influential events. Data are downloaded from Yahoo Finance, and data with days when any of these stock markets is closed are remove, which yields 2642 observations for each series.

The indices under study are four widely accepted and representative benchmark indices for the four stock exchange markets and are all value weighted arithmetic indices. Shanghai and Shenzhen Stock Exchanges are the only existing ones in mainland China. The SSE Composite index is used to record and monitor the daily price changes of all listed stocks in the Shanghai stock exchanges, including A shares and B shares. Most of companies listed in Shanghai stock market are state-owned enterprises that control the lifeline of national economy. The constituent stocks are large-cap blue-chip stocks with stable operations, stable dividends, and low P/E ratios. On the other hand, the SZSE

[1] There is a 12-hour time difference between the closing time of the U.S. stock exchange and the China one. This is a limitation to our study as we did not factor this into our model.

Component index is an index of 500 stocks that are traded at the Shenzhen stock exchange. Compared with the constituent companies in SSEC, these listed companies are mostly private enterprises which come from different industries with relatively greater fluctuations in operations and P/E ratios are significantly higher than those of SSEC listed companies. The HSI, which is the main indicator of the overall stock market performance in Hong Kong, includes 50 constituent companies representing about 58% of the capitalization for the stock exchange of Hong Kong (‘Hang Seng Index’, n.d.). The S&P 500 is included to represent the global financial centre. The index is considered as the most accurate reflection of the US stock market as it is based on the market capitalization of 500 large companies in leading industries and service having common stock listed on the NYSE and NASDAQ (Li, 2007).

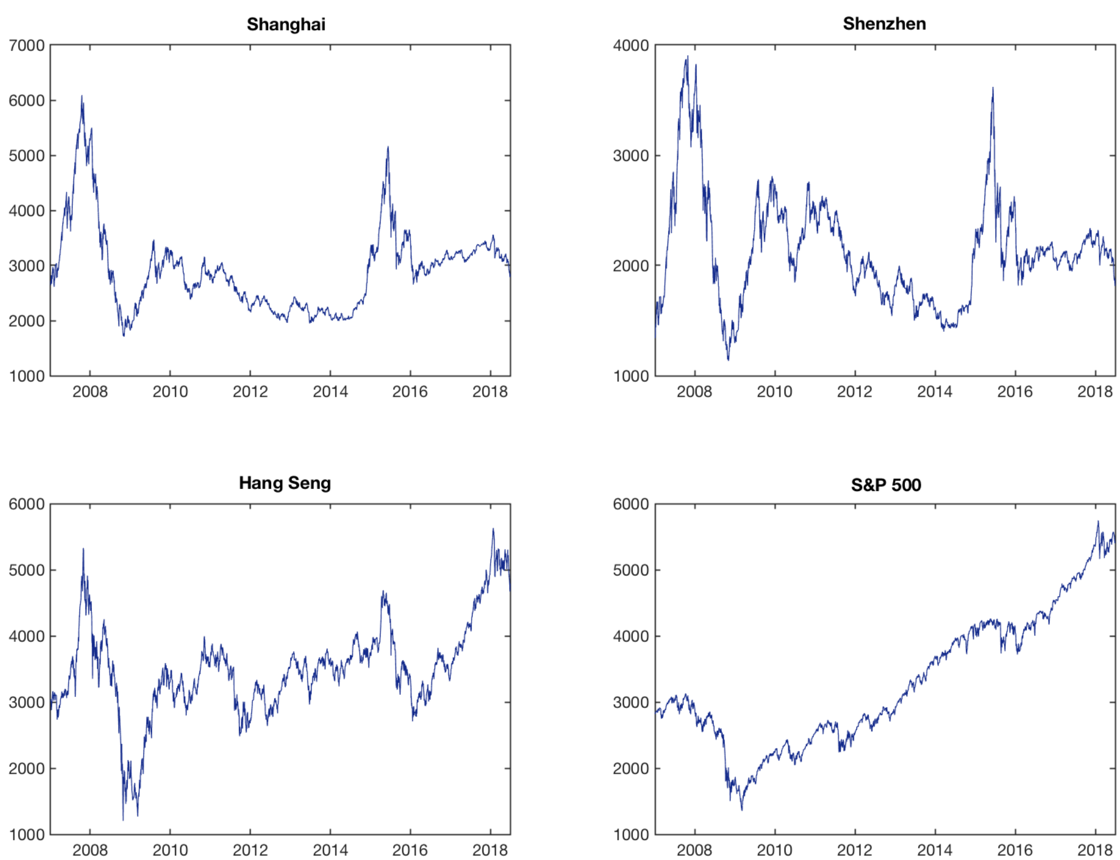

Figure 1: Share Price Indices

Fig.1 presents an overview of the four indices' daily stock price movements during the sample period. Apparently, share price of the two mainland Chinese indices and Hang Seng index followed a similar trend in the last decade, especially during the 2007 Chinese stock bubble and 2015 Chinese stock market turbulence, but the movement of S&P 500 was quite different from the others except for the financial crises period. All the series started to turn downwards since the middle of 2008 and reached the bottom at the end of the year. After the 2008 financial crisis, S&P 500 showed a continuous upward trend towards the end of period under study. The Hang Seng index seemed to follow the same increasing trend as S&P 500 had after 2015, while the SSEC and SZSE were just fluctuating around certain stock price level. The corresponding return series of the four indices are shown in Fig.2. We can observe that the returns of share price indices exhibit volatility clustering. That is once a high volatility occurs, it persists for a while. Such feature confirms the appropriateness of applying the GARCH model in the study. Furthermore, the clusters between Shanghai and Shenzhen stock indices and between Hang Seng index and S&P 500 tend to appear concurrently during the sample period, which indicates that volatility should be modelled systematically.

A brief summary of descriptive statistics for the return series are provided in Table 1. For the last ten years, all the mean returns for the indices are positive and close to zero. The S&P 500 has highest average daily return while SSEC has the lowest one. The standard deviation estimates indicate that S&P 500 is relatively stable compared with the other Chinese indices, and Shenzhen stock exchange has the highest volatility with a standard deviation of 2%. The return series of all these indices are skewed to the left, implying that investors have a greater chance of receiving frequent small losses and a few extreme gains. Moreover, all the return series display excess kurtosis (larger than 3), indicating that they are all leptokurtic and have both fatter tails and higher peaks. Specifically, the kurtosis of S&P500 and Hang Seng index are all higher than 11 and are comparatively higher than those of the other two Chinese markets, meaning that the investors of these two stock markets are more likely to experience occasional extreme returns (either positive or negative). The results of the Jarque-Bera test also reject the null hypothesis that the returns of the four indices are normally distributed, which justifies the use of student-t distribution in this study.

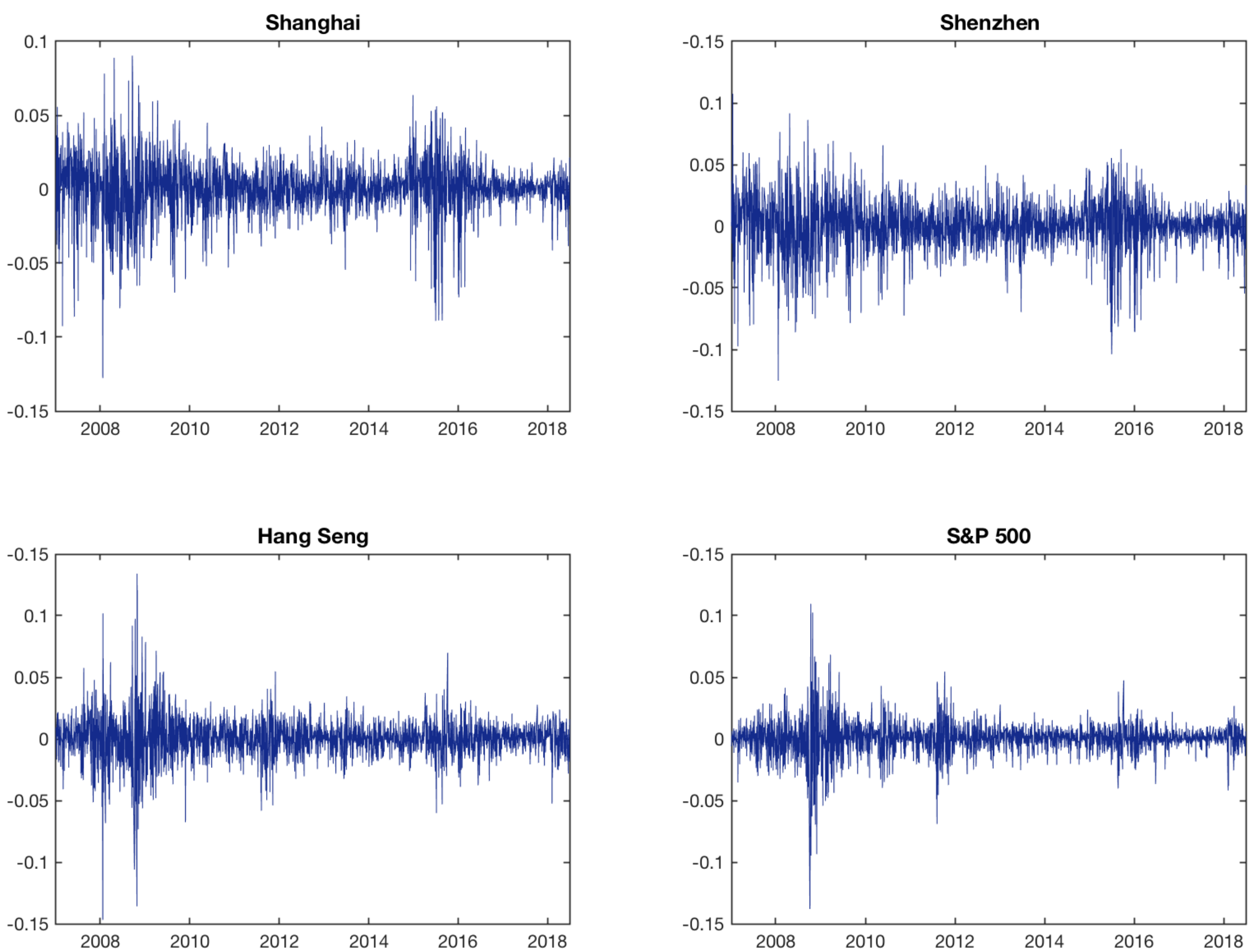

Figure 2: Returns of the share price indices

Table 1: Descriptive statistics of sample returns

	Shanghai	Shenzhen	Hang Seng	S&P 500
Mean	0.000018	0.000127	0.000140	0.000246
Median	0.000760	0.000587	0.000551	0.000685
Maximum	0.090345	0.107526	0.134068	0.109572
Minimum	(0.127636)	(0.125315)	(0.146954)	(0.137989)
Standard Deviation	0.017692	0.020255	0.016364	0.013092
Skewness	(0.687546)	(0.546601)	(0.233463)	(0.607567)
Kurtosis (excess)	4.972582	3.556000	11.007381	13.767011
Jarque-Bera	2931.2463	1524.1549	13367.0228	21034.6610
Probability	0.000000	0.000000	0.000000	0.000000

4. Methodology

The daily returns of four indices are the variables of interest in this study. The returns are calculated as first differences of natural logarithm of the share prices of each index. A multivariate GARCH model considers both mean returns and return volatility and thus provides a proper methodology to explore both return linkages and volatility spillovers (Huang & Kuo, 2013). More specifically, the mean equations are formulated to explore the return linkages, and their time-varying variance-covariance equations are estimated to investigate the volatility spillovers, shock spillovers, and negative shock spillovers.

4.1 Mean Equation: VAR(1)

The mean equations of the model can be estimated to explore return relationships among SSEC, SZSE, HSI, and S&P500. It is specified as follows:

Equation 1: $Rt = \alpha + \Gamma Rt\text{-}1 + \varepsilon t, \varepsilon t|It\text{-}1 \sim N (0, Ht)$

Where R_t is a 4 × 1 vector of daily returns at time t and Γ is a 4 × 4 matrix of parameters associated with the lagged returns. The diagonal elements γ_{ii} in matrix Γ measure each index's own past returns effect, while the off-diagonal elements γ_{ij} capture the return linkages between index returns. ε_t is a 4 × 1 vector of random errors at time t, which are assumed to follow a normal distribution conditional on the information set I_{t-1}. H_t is the 4 × 4 conditional variance-covariance matrix of the random errors.

4.2 Variance-Covariance Equation: BEKK(1,1)

The VEC-GARCH model proposed by Bollerslev et al. (1988) is a generalization of the univariate GARCH model. Every conditional variance and covariance (H_t) is a function of the lagged squared errors and cross products of errors and lagged conditional variances and covariances. It is specified as follows:

Equation 2: $$\mathrm{vech}(\boldsymbol{H}_t) = \boldsymbol{c} + \sum_{j=1}^{q} \boldsymbol{A}_j \mathrm{vech}(\boldsymbol{r}_{t-j}\boldsymbol{r}'_{t-j}) + \sum_{j=1}^{p} \boldsymbol{B}_j \mathrm{vech}(\boldsymbol{H}_{t-j})$$

Where vech is an operator that stacks the columns of the lower triangular part of its argument square matrix (Silvennoine & Terasvirta, 2009).

However, major disadvantages of this model are that the number of parameters to be estimated is large and the covariance matrices need to be positive definiteness. Both problems are computationally demanding. Therefore, the BEKK model, proposed by Engle and Kroner (1995) is preferred since the conditional covariance matrices are positive definite by construction. It has the following form:

Equation 3: $Ht = C'C + A' \varepsilon't\text{-}1\ \varepsilon t\text{-}1A + B'Ht\text{-}1B$

Where C is a 4 × 4 lower triangular matrix of constants, while A and B are 4 × 4 matrices. The diagonal parameters A_{ii} in matrix A measure the response of market i to its own past shocks, while the diagonal parameters B_{ii} in matrix B measure the response of market i to its own past volatilities. The off-diagonal parameters A_{ij} and B_{ij} measure the cross-market effects of shocks and volatilities, respectively.

4.3 Asymmetric effects

Kroner and Ng (1988) proposed an extended model to the BEKK one to capture the asymmetric response of volatility. For example, stock volatility tends to rise more in response to negative shocks (bad news) than positive ones. The equation is as follows:

Equation 4: $H_t = C'C + A'\ \varepsilon'_{t-1}\ \varepsilon_{t-1}A + B'H_{t-1}B + D\ \xi'_{t-1}\ \xi_{t-1}D$

Where ξ_t is defined as ε_t if ε_t is negative and zero otherwise. D is a 4 × 4 matrix where the diagonal parameters D_{ii} measure the response of market i to its own past negative shocks, and the off-diagonal parameters D_{ij} measure the response of market j to negative shocks from market I, namely the cross-market effects of negative shocks.

4.4 Estimation method

The Berndt, Hall, Hall and Hausman (BHHH) algorithm is used to maximize the log-likelihood function. The conditional log-likelihood function L with T observations can be expressed as follows:

Equation 5: $$L = -0.5\sum_{t=1}^{T}\left(n\log(2\pi) + \log|H_t| + \log\left(\varepsilon_t' H_t^{-1}\varepsilon_t\right)\right)$$

5. Empirical Results

The VAR (1)-BEKK (1,1) model is applied using student-t distribution and BHHH estimation method so that the mean equation (1) and the time-varying variance-covariance equation with asymmetric effects (4) are estimated simultaneously. SSEC, SZSE, HSI, and S&P500 are indexed as 1, 2, 3, and 4, respectively. The model converges after 46 iterations and the results are reported in Table 2. We also carry out the Ljung-Box Q-test for the standardized residuals from the model and for the squared standardized residuals to test if there is series dependence in both residual series.

Table 2: Estimated coefficient for the four-variable asymmetric GARCH model

	SSE (i = 1）		SZSE (i = 2)		HSI (i = 3)		S&P500 (i = 4)	
γ_{1i}	-0.006221826	（0.037835663）	-0.019202354	（0.044533231）	-0.079238287 **	（0.031246547）	0.012026933	（0.018725617）
γ_{2i}	0.01797773	（0.029287025）	0.04452732	（0.036197926）	0.014850191	（0.026003757）	-0.01128005	（0.015615893）
γ_{3i}	-0.037887549 *	（0.020365729）	-0.047976925 *	（0.024855050）	-0.062610743 ***	（0.019699017）	-0.001790758	（0.013561448）
γ_{4i}	0.217291375 ***	（0.021955056）	0.221980527 ***	（0.026119583）	0.529982099 ***	（0.021144847）	-0.062402411 ***	（0.020373427）
a1i	0.258932998 ***	（0.028741611）	-0.083244757 ***	（0.031608674）	0.201516365 ***	（0.025140520）	-0.006923665	（0.019905420）
a2i	-0.068138282 ***	（0.022553338）	0.206067808 ***	（0.025788339）	-0.090449532 ***	（0.020984024）	0.004750000	（0.015542253）
a3i	-0.053762939 ***	（0.019803218）	-0.039217881 *	（0.023941908）	-0.155577647 ***	（0.023578694）	0.002165243	（0.019924811）
a4i	-0.113292615 ***	（0.017500818）	-0.095453966 ***	（0.021114403）	-0.138091525 ***	（0.019292868）	-0.001499347	（0.032270581）
b1i	0.955699415 ***	（0.010218446）	0.032789356 ***	（0.011711905）	-0.046644373 ***	（0.009117611）	-0.002648785	（0.007052648）
b2i	0.01924142 **	（0.009157798）	0.95279828 ***	（0.010441358）	0.040422507 ***	（0.008537445）	-0.002222834	（0.006891289）
b3i	-0.008036645	（0.007211933）	-0.00788515	（0.008146868）	0.957680006 ***	（0.006320873）	-0.002342058	（0.006278701）
b4i	0.001381813	（0.007292512）	0.001826522	（0.008435096）	0.015080316 *	（0.008626878）	0.940894321 ***	（0.005440246）
d1i	0.234380508 ***	（0.046162284）	0.247343395 ***	（0.048358508）	-0.019752978	（0.048920503）	0.051186577 **	（0.022605168）
d2i	-0.094831889 ***	（0.033898641）	-0.049434618	（0.040610569）	-0.012239788	（0.040999492）	-0.047927927 ***	（0.017958780）
d3i	0.029833594	（0.031567452）	0.038979207	（0.037674987）	0.212702997 ***	（0.031653843）	-0.010646511	（0.024474261）
d4i	-0.004257323	（0.029348094）	-0.02459564	（0.035323518）	-0.012399543	（0.030743218）	0.45002921 ***	（0.025903826）
LB-Q(12)	18.4553		9.6068		8.6069		12.3234	
LB-Q(24)	24.5244		15.5903		20.9681		35.2412	
LB-Qs(12)	15.5687		21.7505		26.603		5.7448	
LB-Qs(24)	21.4084		31.953		39.218		27.3942	
LLR	34221.5569							

Notes: Constants are not presented in the above table to save space. Value in the first column for each series is the estimated coefficient, and values in bracket are standard errors. ***, **, and * represents significance level of 1%, 5%, and 10%, respectively. All coefficients γ_{ij}, a_{ij}, b_{ij}, and d_{ij} represent the effect of residual i on variable j. LB-Q (12) and LB-Q (24) are Ljung-Box Q-statistic for the standardized residuals up to 12 and 24 lags. LB-Qs (12) and LB-Qs (24) are Ljung-Box Q-statistic for the squared standardized residuals up to 12 and 24 lags. LLR represents the log likelihood ratio.

5.1 Return Spillover

The Ljung-Box Q-statistics for standardized residual, as shown in Table 2, does not exceed the critical value of 21.0261 and 36.4150 for 12 and 24 lags, respectively. This implies that we cannot reject the null hypothesis that the residual series has no autocorrelation, which further indicates the appropriate specification of the mean equations.

The returns interrelationship across the four indices can be interpreted from matrix Γ in the mean equation (Equation 1). Conventionally speaking, returns tend to spill over from a developed market to a less developed market or a developing market. From our model, we find unidirectional return spillover effects from the stock exchange in the U.S. to those in Shanghai, Shenzhen, and Hong Kong and also from stock exchange in Hong Kong to that in Shenzhen. This is evidenced by the statistically significant off-diagonal parameters, γ_{41}, γ_{42}, γ_{43}, and γ_{32}, and the statistically insignificant off-diagonal parameters, γ_{14}, γ_{24}, γ_{34}, and γ_{23}. The results seem to coincide with the conventional expectation that returns tend to spill over from the U.S. market (a developed one) to the China market (a less developed one). The magnitude of the linkages is large, as a 1% increase in the returns of the S&P 500 index will result in 22%, 22% and 53% increase in the three Chinese indices.

In comparison, Li (2007) found that there were no direct return linkages between stock exchanges in mainland China and the U.S., and that Hong Kong market acted as a go-between information flow for these two markets. Our results, on the other hand, show that the U.S. market plays a major role in the transmission of news, impacting the returns of the Chinese market and confirm an enhanced leadership of U.S. market among the four financial markets under study. This founding is consistent with the conclusions drawn by Cheung et al. (2009).

Also, there is bidirectional relationship between stock exchange in Shanghai and Hong Kong. The coefficients, γ_{13} and γ_{31}, are both statistically significant, which shows return linkages between the SSEC and the HSI. Such bidirectional return relationship between these two markets strengthens Hong Li's finding (2007) and verifies the impact of increased interactions between these two markets, for example, the Shanghai-Hong Kong Stock Connect program in 2014.

5.2 Shock spillover

The suitability of the variance-covariance equations as estimated by the four-variable asymmetric BEKK model can be reflected by the Ljung-Box Q-statistics for the squared standardized residuals. As shown in Table 2, we can conclude that there is no autocorrelation in the squared standardized residuals.

The diagonal elements in the matrix A capture the own ARCH effect, and the diagonal parameters in the matrix B measure the own GARCH effect. Similar to the results found by Li, the estimated diagonal parameters in matrix A (a_{11}, a_{22}, and a_{33}) and in matrix B (b_{11}, b_{22}, and b_{33}, b_{44}) are all significant, which indicates a strong GARCH (1,1) process driving the conditional variances of the three Chinese indices. The conditional variance of the three Chinese indices are affected by their own past shocks and volatilities, while the conditional variance of the S&P500 is affected only by its own past volatilities.

The off-diagonal elements of matrix A measure the shock spillover effects across four stock exchanges. Using the data of a longer and more recent period of time, we find similar results as Li did. There are bidirectional shock spillovers between the stock exchange in Shanghai and Shenzhen, which is evidenced by statistically significant coefficients a_{12} and a_{21}. Unexpected shocks in Shanghai stock exchange will affect the volatility of Shenzhen stock exchange, and vice versa. Such result is not unexpected. As the only two stock exchanges in mainland China, shock or bad news in one stock exchange will negatively impact the decision making of all investors in the mainland China market. We also observe bidirectional shock spillovers between the stock exchange in Shanghai and Hong Kong and between the stock exchange in Shenzhen and Hong Kong, as the coefficients, a_{13} and a_{31}, and a_{23} and a_{32} are statistically significant. The result is also anticipated due to the close trading relationship between mainland China and Hong Kong as well as due to the progress in Chinese stock market liberalization. In 2016, the largest export from Hong Kong was to mainland China, and Hong Kong was the second largest export destination of China (OEC, 2016).

Furthermore, we find that unexpected shocks of the U.S. market affect the volatility of the three stock exchanges in China since the coefficient, a_{41}, a_{42}, and a_{43}, are all statistically significant. The result is different from what Li observed in his paper using the earlier and shorter sample data. Such discrepancy could be explained by the integration of the international financial markets in recent years. The result, however, is consistent with the finding of Huang et al. (2012) that the U.S. market is the major source of stock market volatility, especially after the 2008 financial crisis. China market is one of the most fast-developing markets, and its volatility is affected not only by its own past shocks, but also by unexpected shocks from a more developed market, such as the U.S. market.

5.3 Volatility spillover

The volatility linkages among four markets are captured in the matrix B. First, we find that all diagonal parameters, b_{11}, b_{22}, b_{33}, and b_{44}, are significant, indicating that the conditional variance of all four stock indices are affected by their own past volatilities. Then, we observe bidirectional volatility linkages between the two mainland China stock exchanges. The evidence is that coefficient b_{12} and b_{21} are both significant. This finding further supports a strong connection between the two stock exchanges, which was not found by Hong Li. Moreover, we find that there is a unidirectional volatility spillover effects from the stock exchange in two mainland China markets as well as the U.S. market to the stock exchange in Hong Kong. The evidence is that the off-diagonal parameters, b_{13}, b_{23}, and b_{43} are significant, whereas their counterparts b_{31}, b_{32}, and b_{34} are insignificant. This finding is also different from the results observed by Li (2007) who only found unidirectional volatility spillovers from Hong Kong to the two mainland China stock markets. Nevertheless, both Hong Li and us found that the magnitude of the squared coefficients is small, indicating a weak volatility linkage among the stock changes in mainland China, the U.S., and the stock exchange in Hong Kong.

5.4 Negative shock spillover

The statistic from the log-likelihood test for the four-variable asymmetric GARCH model vs. the four-variable symmetric GARCH model is 378.15, indicating that we can reject the null hypothesis that the restricted model (with the coefficients in matrix D equalling zero simultaneously) is better than the unrestricted one.

The negative shock effects can be illustrated by the matrix D. The diagonal parameters, d_{11}, d_{33}, and d_{44}, are all statistically significant, suggesting that all the markets, except the Shenzhen stock exchange, have asymmetric response to negative shocks of their own stock market. Also, it is not beyond our expectation that bidirectional negative shock spillover effects exist between the stock exchange in Shanghai and Shenzhen. The volatility in the Shanghai stock exchange is affected by the negative shock in the Shenzhen stock exchange, and vice versa. Furthermore, after comparing the coefficients, a_{12} and d_{12}, and a_{21} and d_{21}, we find that the negative shock spillover effects from the Shanghai market to Shenzhen market are greater than the positive shock spillover effects. This conclusion also holds for the other direction, from Shenzhen market to Shanghai market.

6. Conclusion

Using the daily return data of the SSE Composite index, SZSE Composite index, Hang Seng index, and the S&P 500 index from January 2007 to July 2018, we have found some important international linkages among the four stock exchanges under study.

First, we found return and shock spillovers from the stock exchange in the U.S. to the three stock exchanges in China. As the center of the news transmission, the U.S. market does have an impact on the China market. The returns of the China market will be affected by the returns of the U.S. market, and the volatility of the China market is affected by the positive shocks in the U.S. market as well. Moreover, we conclude that there have been more integrations between the mainland China stock exchanges and the Hong Kong one. We find bidirectional shock spillovers between the stock exchange in Shanghai and Hong Kong and between Shenzhen and Hong Kong. This finding coincides with the increased interactions between these two markets, for example, the Shanghai-Hong Kong and Shenzhen-Hong Kong Stock Connect program. We also find bidirectional return spillovers between Shanghai and Hong Kong market. In addition, there are unidirectional volatility spillovers from the two stock exchanges in mainland China and the one in U.S. to the stock exchange in Hong Kong. The magnitude of the coefficients implies small volatility linkages among the markets. Despite the small linkages, the effect of return and shock spillovers from the U.S. market to the China market is significant, which suggests that the return on investment in the Chinese stock exchange would not only be affected by the country's exposure to firm-specific and country-specific risk factors, but also returns and shocks in the U.S. market

Our study also finds evidence that there is bidirectional shock and volatility spillover between the two mainland China stock exchanges. The conditional variance is not only affected by their own past shocks and volatilities, but also affected by the other stock market, indicating the integration of these two stock exchanges in terms of volatility. The risk information within the country is important for the volatility of the mainland share price indices.

Li (2007) suggested in his study that adding the emerging Chinese stocks to overseas investors' portfolio may benefit them by reducing the diversified risks. However, based on our findings, the international financial market seems to have become more integrated and linked than before, and thus such diversification benefits have been weakened. Investors should consider more foreign information for their investment decisions as indicated by our results and findings of Finke and Weigert (2016).

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