The Global Financial Crisis and the Integration of Emerging Stock Markets in Asia*

Sang Hoon Kang
Professor, Department of Business Administration, Pusan National University
sanghoonkang@pusan.ac.kr

Seong-Min Yoon**
Professor, Department of Economics, Pusan National University
smyoon@pusan.ac.kr

This study investigates the effects of volatility spillovers among five Asian stock markets (China, Hong Kong, Korea, Singapore, and Taiwan) and examines how the global financial crisis of 2008 has influenced volatility transmission among Asian stock markets. The results from a VAR(1)-bivariate GARCH model indicate strong volatility linkages between the Chinese stock market and the four emerging stock markets since the global financial crisis, suggesting the intensification of stock market integration in Asia since the crisis increases the integration of Chinese stock market in Asia. This strong integration of the markets is important in that the intensified linkages can reduce potential gains from the diversification of international equity portfolios.

Keywords: Bivariate GARCH-BEKK model, Global financial crisis, Stock market integration, Stock market linkage, Volatility spillover

JEL Classification: C58, F36, G11, G15

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** Corresponding author
글로벌 금융위기와 아시아 신홍주식시장의 통합

姜 尙 勳
부산대학교 경영학과 교수
sanghoonkang@pusan.ac.kr

尹 盛 民*
부산대학교 경제학부 교수
smyoon@pusan.ac.kr

이 논문은 아시아 주식시장(한국, 중국, 홍콩, 싱가포르, 대만) 사이의 변동성 전이효과를 연구하였다. 그리고 2008년 글로벌 금융위기가 아시아 주식시장 사이의 변동성 전이에 어떻게 영향을 미쳤는지를 검토하였다. VAR(1) 모형과 이변량 GARCH 모형을 이용한 실증분석 결과, 글로벌 금융위기 이후 중국 주식시장과 4개국 신홍 주식시장 사이에 변동성 전이가 강하게 나타난 것을 발견하였다. 이러한 결과는 아시아 주식시장 간의 통합 정도가 강화되었고 또 중국 주식시장이 아시아 신홍주식시장과 동조화 현상을 보이는 것으로 판단된다. 주식시장 사이의 통합이 강화되는 것은 국제적 주식 분산투자를 통한 이익 실현 가능성이 감소될 수 있다는 점에서 중요한 의의를 가진다.

핵심용어: 이변량 GARCH–BEKK 모형, 글로벌 금융위기, 주식시장 통합, 주식시장 연계, 변동성 전이효과
JEL 분류: C58, F36, G11, G15

* 교신저자
I. Introduction

The issue of interdependence among equity markets has attracted increasing attention from researchers, particularly since the October 1987 crash, which brought about correlated stock price movements across stock markets worldwide (Kanas 1998). Early research focused exclusively on the spillover of the first moment of stock prices among major stock markets (Eun & Shim 1989; Jeon & von Furstenberg 1990; Cumby 1990).

Recent studies have investigated the interdependence of equity markets in terms of the conditional second moment of the distribution of returns, which refers to the volatility spillover effect. The existence of volatility spillovers implies that one large shock in a country can increase the volatility of not only equity market in that country but also that in others. Volatility is often related to the rate of information flow (Ross 1989). If information comes in clusters, then asset returns or prices may exhibit volatility even if the market adjusts to the news both perfectly and instantaneously. Thus, examining volatility spillovers can enable a better understanding of how information is transmitted across equity markets.

Early studies typically focused on volatility spillovers among developed stock markets (Hamao, Masulis & Ng 1990; Karolyi 1995; Koutmos & Booth 1995). Recently, however, a number of studies have examined international stock market linkages among developed stock markets and some emerging stock markets in Asia, South America, and emerging Europe (Ng 2000; Edwards & Susmel 2001; Tse, Wu & Young 2003; Kanokwan & Dibooglu 2006; Chuang, Lu & Tswei 2007; Li & Majerowska 2008; Beirne, Schulze-Ghattas & Spagnolo 2010; Wang & Wang 2010). Uncovering the extent of international linkages among emerging stock markets can provide important implications for investors with international equity portfolios. It is clear that stronger international stock market linkages or co-movements can reduce the independence of emerging stock markets from external shocks, thereby reducing the potential
benefits of diversification into emerging stock markets.

A number of previous studies have focused on the impact of financial crises on volatility spillovers and provided support for the hypothesis that financial crises lead to market liberalization, market integration, and volatility transmission. In et al. (2001) found that Hong Kong played an important role in the transmission of volatility to other Asian markets during the Asian financial crisis of 1997. Nam, Yuhn, and Kim (2008) investigated how the Asian financial crisis changed emerging markets in Asia by focusing on volatility spillovers and found that the influence of U.S. innovations on stock prices in Asia increased after the crisis. Saleem (2009) examined the impact of Russia’s 1998 financial crisis on the international linkage of the Russian market and suggested that after the crisis, the Russian market showed a bidirectional connection with the U.S. and Asian markets and a unidirectional relationship with emerging European markets.

Recently, the Chinese stock market has been playing an important role in emerging stock markets in Asia because of its large economic scale and impressive economic growth. In Asian stock markets, Chinese stock market becomes a leading Asian market by market value. In the end of 2009, the value of the China’s A-share market rose 100.88 percent year-on-year to 24.27 trillion yuan (3.57 trillion dollar), overtaking Japan’s 3.53 trillion dollar. In particular, after the global financial crisis of 2008, the Chinese stock market has become one of the largest recipients of external investment in the world, indicating that the investment flow and financial links between the Chinese stock market and other emerging stock markets in Asia have also been rapidly expanding. From this point of view, the present study examines whether the global financial crisis of 2008 has increased the integration of the Chinese stock market with other emerging stock markets in Asia.

This study examines the effects of volatility spillovers among five Asian stock markets (China, Hong Kong, Korea, Singapore, and Taiwan) by using a VAR(1)-bivariate GARCH-BEKK model. In particular, this paper considers the impact of the global financial crisis of 2008 on the volatility transmission.
Previous studies have suggested a weak relationship between the Chinese stock market and other stock markets in Asia (Wang & Firth 2004; Groenewold, Tang & Wu 2004; Johansson & Ljungwall 2009). However, such findings may provide outdated guidance on international portfolio strategies in that they do not reflect recent data.

Because of China’s large economic scale and impressive economic growth, the Chinese stock market has become one of the most important sources of information in Asia. In this context, this study contributes to research on emerging stock markets by focusing on the Chinese stock market’s association, interaction, and integration with other Asian stock markets. The results suggest that stronger international linkages between the Chinese stock market and other stock markets in Asia may limit market independence and reduce potential gains from the diversification of equity portfolios for international investors.

The rest of this paper is organized as follows. Section 2 presents the econometric methodology of the bivariate GARCH-BEKK model. Section 3 provides the descriptive statistics of the sample data. Section 4 discusses the empirical results, and Section 5 concludes.

II. Methodology

Substantial attention has been focused on how news from one market affects the volatility process of another market. The univariate GARCH of Bollerslev (1986) has been extended to the multivariate GARCH model with a cross conditional variance equation. In this study, we analyze the volatility transmission by using a VAR(1)-bivariate GARCH(1,1) model with the BEKK parameterization (Engle & Kroner 1995).

Firstly, we consider the bivariate conditional mean model, namely VAR(1) process:
\[
\begin{bmatrix}
R_{i,t} \\
R_{j,t}
\end{bmatrix} = \begin{bmatrix}
\beta_{i0} \\
\beta_{j0}
\end{bmatrix} + \begin{bmatrix}
\beta_{ii} & \beta_{ij} \\
\beta_{ji} & \beta_{jj}
\end{bmatrix}\begin{bmatrix}
R_{i,t-1} \\
R_{j,t-1}
\end{bmatrix} + \begin{bmatrix}
\varepsilon_{i,t} \\
\varepsilon_{j,t}
\end{bmatrix},
\]
\[\Omega_{t-1} \sim N(0, H_t), \tag{1}\]

where \( R_{i,t} \) and \( R_{j,t} \) are a continuously compounded percentage return series for countries \( i \) and \( j \). \( H_t \) is a 2×2 corresponding conditional variance-covariance matrix. The market information available at time \( t-1 \) is represented by the information \( \Omega_{t-1} \). The parameter \( \beta_{ij} (\beta_{ji}) \) implies the mean spillover effect between Asian countries.

The standard BEKK parameterization for the bivariate GARCH(1,1) model is written as:

\[
H_t = C' C + A' \varepsilon_{t-1} \varepsilon_{t-1}' A + B' H_{t-1} B,
\tag{2}
\]

\[
H_t = \begin{bmatrix}
h_{11,t} & h_{12,t} \\
h_{21,t} & h_{22,t}
\end{bmatrix} = \begin{bmatrix}
c_{11} & c_{12} \\
c_{21} & c_{22}
\end{bmatrix}' \begin{bmatrix}
c_{11} \\
c_{21} & c_{22}
\end{bmatrix}
\]

\[
+ \begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{bmatrix}' \begin{bmatrix}
\varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1} \varepsilon_{2,t-1} \\
\varepsilon_{1,t-1} \varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2
\end{bmatrix} \begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{bmatrix}
\]

\[
+ \begin{bmatrix}
b_{11} & b_{12} \\
b_{21} & b_{22}
\end{bmatrix}' \begin{bmatrix}
h_{11,t-1} & h_{12,t-1} \\
h_{21,t-1} & h_{22,t-1}
\end{bmatrix} \begin{bmatrix}
b_{11} & b_{12} \\
b_{21} & b_{22}
\end{bmatrix}, \tag{3}
\]

where \( H_t \) is a 2×2 conditional variance-covariance matrix at time \( t \); \( C \) is a 2×2 lower triangular matrix with three parameters; \( A \) is a 2×2 square matrix of parameters and measures the extent to which conditional variances are correlated past squared errors; and \( B \) is a 2×2 squared matrix of parameters and shows the extent to which current levels of conditional variances are related to past conditional variances.
The conditional variance of the bivariate GARCH(1,1) model can be expressed as

\[ h_{11, t} = c_{11}^2 + c_{21}^2 + a_{11}^2 \epsilon_{1, t-1}^2 + 2a_{11}a_{21} \epsilon_{1, t-1} \epsilon_{2, t-1} + a_{21}^2 \epsilon_{2, t-1}^2 + b_{11}^2 h_{11, t-1} + 2b_{11}b_{21} h_{12, t-1} + b_{21}^2 h_{22, t-1}, \]

(4)

\[ h_{22, t} = c_{22}^2 + a_{12}^2 \epsilon_{1, t-1}^2 + 2a_{12}a_{22} \epsilon_{1, t-1} \epsilon_{2, t-1} + a_{22}^2 \epsilon_{2, t-1}^2 + b_{12}^2 h_{11, t-1} + 2b_{12}b_{22} h_{12, t-1} + b_{22}^2 h_{22, t-1}, \]

(5)

where the parameters \( a_{12}, a_{21}, b_{12}, b_{21} \) of Equations (4) and (5) reveal how shocks and volatility are transmitted over time and across equity markets. The off-diagonal elements of matrices \( A \) and \( B \) capture cross-market effects such as shock spillovers \( (a_{12} \text{ and } a_{21}) \) and volatility spillovers \( (b_{12} \text{ and } b_{21}) \).

The parameters of the bivariate GARCH model can be estimated by the maximum likelihood estimation method optimized with the Berndt, Hall, Hall, and Hausman (BHHH) algorithm. The conditional log-likelihood function \( L(\theta) \) is expressed as

\[ L(\theta) = -T \log 2\pi - 0.5 \sum_{t=1}^{T} \log \left| H_t(\theta) \right| - 0.5 \sum_{t=1}^{T} \epsilon_t(\theta)' H_t^{-1} \epsilon_t(\theta), \]

(6)

where \( T \) is number of observations and \( \theta \) denotes the vector of all unknown parameters. Due to the non-linear structure of the BEKK model, the covariance dynamics are governed by eleven parameters in our application. Under the assumption of other distribution errors, such as Student-t, it lacks parameter

1) This study considers only the first order lag of simple GARCH (1,1) model as increasing in the order lag of GARCH model produces too many covariance parameters.
parsimony. In this context, we consider only the assumption of normal distribution error in our study.

III. Data and Descriptive Statistics

We considered the Morgan Stanley Capital International (MSCI) indices for five emerging stock markets in Asia: China, Hong Kong, Korea, Taiwan, and Singapore. The sample covered daily price index data from January 2, 2006, to January 31, 2011, which were drawn from the New Informax database. All daily price series were converted into the logarithmic return series, that is, 

\[
R_{i,t} = \ln \left( \frac{P_{i,t}}{P_{i,t-1}} \right) \times 100,
\]

where \( R_{i,t} \) denotes the continuously compounded percentage returns for countries \( i \) at time \( t \) and \( P_{i,t} \) denotes the price level of countries \( i \) at time \( t \).

| Statistic                  | Chow breakpoint test | P-value |
|----------------------------|----------------------|---------|
| F-statistic                | 4.8638               | 0.0001  |
| Log likelihood ratio       | 29.127               | 0.0001  |
| Wald statistic             | 29.902               | 0.0001  |

Table 1. Results of the Chow Known Breakpoint Test

| Statistic                  | Value | Prob.  |
|----------------------------|-------|--------|
| Maximum LR F-statistic (10/31/2008) | 13.53 | 0.222  |
| Maximum Wald F-statistic (10/31/2008) | 13.53 | 0.222  |
| Exp LR F-statistic         | 3.179 | 0.434  |
| Exp Wald F-statistic       | 3.179 | 0.434  |
| Ave LR F-statistic         | 3.718 | 0.698  |
| Ave Wald F-statistic       | 3.718 | 0.698  |

Table 2. Results of the Hansen Unknown Breakpoint Test

Note: Probabilities are calculated using Hansen’s (1997) method.

2) The dynamic conditional correlation (DCC) model of Engle (2002) overcomes this limitation of BEEK model. Nevertheless, we consider the BEKK model which is useful to interpret the cross market effect in financial time series.
To analyze the impact of the global financial crisis of 2008, we divided the whole sample into two groups using the Chow known breakpoint test and the Hansen unknown breakpoint test. The Chow test was implemented with the consideration of the global crisis, which became evident on September 15, 2008 (when Lehman Brothers declared bankruptcy) as a known breakpoint. The results of the Chow test are shown in Table 1. The null hypothesis of no break at the specified breakpoint was strongly rejected by all three test statistics. For a comparison purpose, we also implemented the Hansen break point test which has the null hypothesis of no breakpoints. Table 2 displays the results of Hansen breakpoint test. The Hansen test indicates an unknown breakpoint.

Figure 1. Dynamics of Squared Return Series from January 2, 2006 to January 31, 2011
October 31, 2008, but all the three of the summary statistic measures fail to reject the null hypothesis of no breakpoint. Thus, we set September 15, 2008, as the cut-off date and divided the data into two subperiods: the pre-crisis period (January 2, 2006-September 12, 2008: 703 observations) and the post-crisis period (September 15, 2008-January 31, 2011: 617 observations).

Figure 1 displays the dynamics of all sample squared returns. After September 15, 2008, all sample returns exhibited volatile movements or volatility clustering, that is, “large changes tend to be followed by large changes, of either sign, and small changes tend to be followed by small changes” (Mandelbrot 1963).

Table 3 shows the descriptive statistics and the results of the unit root tests for all sample returns in both subperiods. As shown in Panel A of Table 3, the range between the maximum and the minimum indicates that the return series for the post-crisis period was more volatile than that for the pre-crisis period and that all standard deviations for the post-crisis period were higher than those for the pre-crisis period because of the impact of the global financial crisis. All skewness and kurtosis values were high, and the calculated values of J-B test statistic were highly significant at the 1% level, indicating that all the returns were not normally distributed.

We also examined the null hypothesis of a white-noise process for sample returns by using the Ljung-Box test statistic of the returns ($Q^{(32)}$) and the squared returns ($Q^{(32)}_s$), respectively. According to the $Q^{(32)}$ statistics, the null hypothesis of no serial correlation is significantly rejected in the post-crisis period, but not in the pre-crisis period. It appears that there is significant evidence of serial dependence in the level of return series after the crisis.

Likewise, the $Q^{(32)}_s$ statistics for squared return series suggest that there is significant evidence of serial correlation for both in the pre-and post crisis periods. In other words, the distribution of the next squared return depends not only on the current squared return but also on several previous squared returns, which results in volatility clustering. Thus, these results favor a model incorporating ARCH/GARCH features.
| Periods                  | Pre-crisis Period (January 2, 2006-September 12, 2008) | Post-crisis period (September 15, 2008-January 31, 2011) |
|-------------------------|--------------------------------------------------------|----------------------------------------------------------|
| Series                  | China | Hong Kong | Korea | Singapore | Taiwan | China | Hong Kong | Korea | Singapore | Taiwan |
| **Panel A: Descriptive statistics** |                   |                   |       |           |        |       |           |       |           |        |
| Mean                    | 0.073 | 0.021      | -0.006| 0.039      | -0.012 | 0.047 | 0.047      | 0.059 | 0.046      | 0.064  |
| Min                     | -10.77 | -6.603     | -8.125| -7.175     | -7.166 | -12.83 | -12.56     | -20.68 | -9.801     | -6.474 |
| Max                     | 9.638 | 7.418      | 8.874 | 6.242      | 6.114  | 14.04 | 10.45      | 24.99 | 8.563      | 8.231  |
| Std. Dev.               | 2.045 | 1.384      | 1.629 | 1.395      | 1.529  | 2.415 | 1.858      | 2.880 | 1.940      | 1.771  |
| Skewness                | -0.238 | -0.181     | -0.253| -0.352     | -0.411 | 0.144 | -0.152     | -0.129 | -0.182     | -0.146 |
| Kurtosis                | 5.982 | 6.229      | 5.721 | 5.334      | 5.013  | 9.577 | 10.25      | 18.08 | 6.942      | 5.746  |
| J-B                     | 267.1** | 309.2***   | 224.1***| 174.0***   | 138.2***| 1116***| 1357***   | 5857***| 403.7***   | 196.3***|
| Q (32)                  | 30.44 | 41.93      | 18.22 | 37.50      | 49.32  | 70.92 ***| 62.79***  | 51.46***| 69.54***   | 51.57***|
| Q_s(32)                 | 317.7***| 451.2***   | 86.41***| 215.3***   | 147.3***| 1143***| 857.1***  | 391.1***| 1003***    | 456.8***|
| **Panel B: Unit root tests** |                   |                   |       |           |        |       |           |       |           |        |
| ADF                     | -26.03*** | -26.86*** | -26.04***| -26.72*** | -27.06***| -24.65***| -25.31*** | -24.20***| -24.53*** | -22.77***|
| PP                      | -26.03*** | -26.91*** | -26.04***| -26.79*** | -27.07***| 24.85***| -25.31*** | -24.21***| 24.57***   | -22.76***|

Note: J-B is the test statistic for the null hypothesis of normality in the distribution of sample returns. The Ljung-Box statistic, Q(32), is used to check for serial correlation in the returns and the squared returns up to 32th order. MacKinnon's (1991) 1% critical value was -3.435 for the ADF and PP tests. *** indicates the rejection of the null hypothesis at the 1% level of significance.
Panel B of Table 3 provides the results of two types of unit root tests for each of the sample returns: the augmented Dickey-Fuller (ADF) and Phillips-Peron (PP) tests. The large negative values of the ADF and PP test statistics rejected the null hypothesis of a unit root at the 1% significance level, implying that all sample return series were stationary processes for both subperiods.

Table 4 shows correlations for sample stock returns. Overall, the returns are positively correlated with each other because the values of correlation coefficient are over 0.5 in the both periods. The degree of correlation coefficient becomes stronger due to the impact of financial crisis.

### IV. Empirical Results

To assess the impact of the global financial crisis on the volatility spillover effect, we examined the direction of volatility spillovers and then compared the
estimation results from the VAR(1)-GARCH-BEKK model for the pre-crisis period with those for the post-crisis period. Tables 5 and 6 show the estimation results from the VAR(1)-bivariate GARCH model for the pre- and post-crisis periods, respectively. The modeled pairs were China-Hong Kong, China-Korea, China-Taiwan, China-Singapore, Korea-Singapore, Korea-Taiwan and Singapore-Taiwan. Note that the Ljung-Box $Q$-statistic for standardized residuals and squared standardized residuals, $Q_i(32)$ and $Q_i^2(32)$, are reported at the bottom of Tables 5 and 6. From the calculated values of this statistic, we found that there is no serial correlation in the both standard residuals and squared standardized residuals, indicating the appropriateness of the bivariate GARCH (1,1) model.

1. Volatility Spillovers in the Pre-crisis Period

For the analysis of the effects of volatility spillovers in the pre-crisis period, Table 5 reports the estimation results from the VAR(1)-bivariate GARCH(1,1) model for volatility spillovers among the Asian stock markets. We first consider the return spillover effect among Asian stock market. Due to the significance of $\beta_{12}$ and $\beta_{21}$, we conclude that there is uni-directional mean spillover effect from China to Korea and Singapore, from Hong Kong to China and Taiwan to Korea.

As mentioned earlier, the diagonal elements of matrix $A$ capture the own past shock effect, whereas those of matrix $B$ measure the own past volatility effect. As shown in Table 5, the estimated values of the diagonal parameters ($b_{11}$ and $b_{22}$) of matrix $B$ were statistically significant, indicating that there were strong GARCH effects, that is, the own past volatility impacted the conditional variance of both markets. Furthermore, the diagonal parameters ($a_{11}$ and $a_{22}$) were significant, implying there were ARCH effects for all the markets.
|                        | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
|------------------------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| **VAR(1) Mean Equation** |       |      |       |      |       |      |       |      |       |      |       |      |
| \( \beta_0 \)       | 0.166** | (0.054) | 0.175** | (0.056) | 0.172** | (0.056) | 0.204** | (0.056) | 0.051 | (0.046) | 0.075 | (0.050) | 0.051 | (0.045) |
| \( \beta_1 \)       | 0.083** | (0.034) | 0.046** | (0.053) | 0.075 | (0.040) | 0.069** | (0.046) | 0.114** | (0.038) | 0.067 | (0.044) | 0.113 | (0.038) |
| \( \beta_2 \)       | 0.055 | (0.064) | -0.018 | (0.049) | -0.060 | (0.052) | 0.041** | (0.044) | 0.003 | (0.042) | 0.097** | (0.047) | 0.003 | (0.042) |
| \( \beta_3 \)       | 0.061 | (1.000) | 0.101** | (0.050) | 0.287** | (0.069) | 0.011 | (0.049) | 0.099 | (0.045) | -0.061 | (0.053) | 0.099 | (0.046) |
| \( \beta_4 \)       | -0.087** | (0.034) | 0.034 | (0.043) | -0.081** | (0.032) | 0.021 | (0.032) | 0.008 | (0.034) | 0.135** | (0.044) | 0.008 | (0.033) |
| \( \beta_5 \)       | 0.150** | (0.067) | 0.018 | (0.047) | 0.110** | (0.050) | -0.021 | (0.041) | -0.025 | (0.043) | -0.065 | (0.051) | -0.025 | (0.043) |
| **Bivariate GARCH(1,1) Model** |       |      |       |      |       |      |       |      |       |      |       |      |
| \( c_{11} \)       | 0.424** | (0.097) | -0.279** | (0.095) | 0.468** | (0.091) | 0.316** | (0.074) | 0.056 | (0.058) | -0.299** | (0.044) | 0.056 | (0.057) |
| \( c_{21} \)       | 0.154** | (0.044) | 0.062 | (0.100) | -0.131 | (0.076) | 0.066 | (0.056) | 0.176** | (0.045) | -0.130 | (0.087) | 0.176** | (0.045) |
| \( c_{22} \)       | -0.073** | (0.023) | 0.000 | (0.141) | 0.000 | (0.364) | -0.140** | (0.035) | 0.000 | (0.837) | 0.000 | (0.106) | 0.000 | (0.837) |
| \( a_{11} \)       | 0.151 | (0.084) | 0.410** | (0.051) | 0.435** | (0.049) | 0.367** | (0.041) | 0.142** | (0.042) | -0.148** | (0.047) | 0.143** | (0.042) |
| \( a_{12} \)       | -0.062 | (0.044) | 0.170** | (0.051) | 0.049 | (0.032) | 0.041 | (0.035) | -0.077** | (0.023) | -0.151** | (0.053) | -0.077** | (0.023) |

Table 5. The Estimation Results of VAR(1)–Bivariate GARCH(1,1) Model for the Pre-crisis Period
Table 5. Continued

| Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| $a_{21}$ | 0.349** | (0.110) | -0.154** | (0.065) | -0.306** | (0.091) | 0.009 | (0.049) | 0.204** | (0.055) | 0.401** | (0.061) | 0.204** | (0.056) |
| $a_{22}$ | 0.392** | (0.054) | 0.140** | (0.055) | 0.273** | (0.048) | 0.186** | (0.035) | 0.425** | (0.046) | 0.502** | (0.068) | 0.425** | (0.046) |
| $b_{11}$ | 0.904** | (0.061) | 0.797** | (0.022) | 0.752** | (0.051) | 0.927** | (0.019) | 0.998** | (0.007) | 0.879** | (0.014) | 0.998** | (0.007) |
| $b_{12}$ | -0.009 | (0.031) | -0.168** | (0.021) | -0.030 | (0.026) | 0.007 | (0.012) | 0.026** | (0.010) | -0.133** | (0.014) | 0.026** | (0.010) |
| $b_{21}$ | 0.002 | (0.075) | 0.235** | (0.027) | 0.306** | (0.063) | -0.014 | (0.017) | -0.066** | (0.016) | 0.092** | (0.032) | -0.066** | (0.016) |
| $b_{22}$ | 0.954 | (0.036) | 1.069** | (0.016) | 0.977** | (0.033) | 0.966** | (0.010) | 0.907** | (0.016) | 1.010** | (0.023) | 0.907** | (0.016) |

| Diagnostic tests | Log($L$) | $Q_1^{(32)}$ | $Q_2^{(32)}$ | $Q_1^{(32)}$ | $Q_2^{(32)}$ |
|------------------|------|-------------|-------------|-------------|-------------|
|                  | -2029.49 | 43.11[0.091] | 53.50[0.010] | 24.34[0.831] | 26.23[0.753] |
|                  | -2522.14 | 37.55[0.230] | 19.68[0.956] | 21.21[0.927] | 29.52[0.592] |
|                  | -2331.65 | 41.34[0.125] | 37.75[0.222] | 29.10[0.613] | 26.52[0.739] |
|                  | -2510.25 | 40.74[0.138] | 38.72[0.192] | 24.59[0.822] | 38.95[0.185] |
|                  | -2249.46 | 20.75[0.937] | 37.91[0.217] | 28.56[0.641] | 24.92[0.809] |
|                  | -2299.01 | 19.74[0.955] | 33.42[0.398] | 38.73[0.192] | 43.89[0.078] |
|                  | -2249.46 | 20.75[0.937] | 37.91[0.217] | 28.56[0.641] | 24.92[0.809] |

Note: Values in brackets and parentheses are p-values and standard errors, respectively. ** indicates significance at the 5% level.
Table 6. The Estimation Results of VAR(1)-Bivariate GARCH(1,1) Model for the Post-crisis Period

|                                | China-Hong Kong | China-Korea | China-Singapore | China-Taiwan | Korea-Singapore | Korea-Taiwan | Singapore-Taiwan |
|--------------------------------|-----------------|-------------|-----------------|--------------|-----------------|--------------|-----------------|
| **Coef.**                      | Coef. S.E.      | Coef. S.E.  | Coef. S.E.      | Coef. S.E.   | Coef. S.E.      | Coef. S.E.   | Coef. S.E.      |
| **VAR(1) Mean Equation**       |                 |             |                 |              |                 |              |                 |
| \( \beta_{00} \)               | 0.085 (0.057)   | 0.094 (0.056) | 0.055 (0.055)   | 0.064 (0.059) | 0.147** (0.062) | 0.128** (0.063) | 0.113** (0.043) |
| \( \beta_{20} \)               | 0.085 (0.046)   | 0.154** (0.069) | 0.103** (0.046) | 0.104 (0.052) | 0.150** (0.045) | 0.083** (0.050) | 0.106** (0.048) |
| \( \beta_{01} \)               | 0.092 (0.078)   | 0.062 (0.052) | -0.121** (0.051) | 0.091 (0.049) | -0.194** (0.042) | -0.059 (0.051) | 0.052 (0.048) |
| \( \beta_{12} \)               | -0.072 (0.094)  | -0.021 (0.042) | 0.239** (0.054) | -0.103 (0.054) | 0.432** (0.061) | 0.117 (0.063) | -0.093** (0.044) |
| \( \beta_{21} \)               | 0.020 (0.060)   | 0.205** (0.062) | -0.025 (0.045)  | 0.132** (0.039) | -0.097** (0.024) | 0.049 (0.030) | 0.279** (0.044) |
| \( \beta_{22} \)               | 0.034 (0.072)   | -0.113** (0.050) | 0.018 (0.052)   | -0.036 (0.049) | 0.089** (0.045) | 0.035 (0.046) | -0.098** (0.042) |
| **Bivariate GARCH(1,1) Model** |                 |             |                 |              |                 |              |                 |
| \( c_{11} \)                   | 0.120** (0.054) | -0.088 (0.077) | 0.173** (0.038) | 0.204** (0.043) | 0.232** (0.043) | 0.297** (0.046) | -0.172** (0.040) |
| \( c_{21} \)                   | 0.036 (0.051)   | 0.068 (0.102) | 0.111 (0.062)   | 0.170** (0.067) | 0.099** (0.048) | 0.107** (0.012) | -0.259** (0.036) |
| \( c_{22} \)                   | 0.000 (0.156)   | 0.000 (0.300) | -0.086** (0.041) | 0.106 (0.075) | 0.076 (0.054)   | -0.015 (0.062) | 0.000 (0.117)   |
| \( a_{11} \)                   | 0.431** (0.069) | 0.314** (0.041) | 0.276** (0.037) | 0.225** (0.063) | 0.143** (0.006) | 0.419** (0.033) | 0.202** (0.047) |
| Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| $a_{12}$ | 0.234** | (0.049) | 0.360** | (0.049) | 0.187** | (0.039) | -0.067 | (0.041) | -0.067** | (0.023) | 0.083** | (0.014) |
| $a_{21}$ | -0.301** | (0.093) | -0.227** | (0.030) | -0.067 | (0.061) | 0.012 | (0.067) | 0.179** | (0.026) | -0.312** | (0.056) |
| $a_{22}$ | 0.062** | (0.026) | 0.095** | (0.040) | 0.105** | (0.050) | 0.166** | (0.048) | 0.349** | (0.028) | 0.061** | (0.025) |
| $b_{11}$ | 0.921** | (0.016) | 0.907** | (0.015) | 0.939** | (0.010) | 0.993** | (0.020) | 0.932** | (0.078) | 0.930** | (0.011) |
| $b_{12}$ | -0.050** | (0.011) | -0.111** | (0.027) | -0.052** | (0.010) | 0.055** | (0.013) | -0.045** | (0.011) | -0.001 | (0.001) |
| $b_{21}$ | 0.063** | (0.020) | 0.076** | (0.013) | 0.041** | (0.019) | -0.051** | (0.023) | 0.063** | (0.016) | 0.024** | (0.008) |
| $b_{22}$ | 1.023** | (0.011) | 1.025** | (0.015) | 0.991** | (0.015) | 0.934** | (0.015) | 0.991** | (0.011) | 0.992** | (0.001) |

| Diagnostic tests |
|------------------|
| Log(L) | -1897.32 | -2391.52 | -2131.47 | -2193.29 | -2309.86 | -2252.63 | -2090.63 |
| $Q_1(32)$ | 35.04[0.326] | 32.24[0.455] | 39.67[0.165] | 32.07[0.463] | 25.90[0.766] | 25.81[0.772] | 23.23[0.870] |
| $Q_2(32)$ | 27.67[0.685] | 25.40[0.789] | 23.70[0.855] | 29.50[0.593] | 23.17[0.872] | 26.23[0.753] | 26.73[0.730] |
| $Q_3^1(32)$ | 32.75[0.420] | 24.42[0.829] | 36.43[0.269] | 32.63[0.436] | 48.23[0.033] | 28.73[0.632] | 36.30[0.274] |
| $Q_3^2(32)$ | 32.69[0.855] | 31.87[0.473] | 36.84[0.254] | 37.30[0.238] | 35.16[0.321] | 58.10[0.003] | 43.54[0.084] |

Note: Values in brackets and parentheses are p-values and standard errors, respectively. ** indicates significance at the 5% level.
The off-diagonal elements of matrices $A$ and $B$ capture cross-market effects such as shock spillover and volatility spillover effects for the four pairs. As shown in Table 5, the coefficient $a_{21}$ was negative and significant at the 5% level, providing evidence of unidirectional shock spillovers from Hong Kong, Korea, and Singapore to China. In fact, past shocks from the other Asian stock markets (except for Taiwan) impacted the current volatility of the Chinese stock market. In addition, there are strong bi-directional shock spillovers among Korea, Singapore and Taiwan.

In addition, the coefficient $b_{21}$ was significant, providing evidence of unidirectional volatility spillovers from Korea and Singapore to China (i.e., the flow of information from Korea and Singapore to China). Furthermore, there is strong bi-directional volatility spillover among Korea, Singapore and Taiwan. However, the cross-market coefficients $a_{12}$ and $b_{12}$ were significant, providing evidence of significant shock and volatility spillovers from the Chinese stock market to the other Asian stock market, except for China-Korea case. These evidences imply that the Chinese stock market was influenced by the other Asian stock markets during the pre-crisis period.

2. Volatility Spillovers in the Post-crisis Period

There is a broad consensus that linkages among stock markets are likely to strengthen after a financial crisis. In this context, we considered the post-crisis period to determine the impact of the global financial crisis of 2008 on volatility spillovers among the Asian stock markets by paying close attention to the direction of shocks and volatility spillovers between the Chinese stock market and the other four Asian stock markets.

Table 6 reports the estimation results from the VAR(1)-bivariate GARCH (1,1) model for the post-crisis period. In the VAR(1) estimation, we cannot find any typical pattern of mean spillover among the Asian stock markets. The
off-diagonal elements \((a_{12}, a_{21}, b_{12}, \text{ and } b_{21})\) capture cross-market effects such as shock spillovers and volatility spillovers. First, the off-diagonal coefficients \(a_{12}\) and \(a_{21}\) were significant, providing evidence of bidirectional shock spillovers for all pairs except for the China-Singapore and China-Taiwan pairs. Second, the off-diagonal elements \(b_{12}\) and \(b_{21}\) were significant, providing evidence of bidirectional volatility linkages for all pairs (i.e., the volatility of the Asian stock markets. The two-way shock spillovers indicate strong linkages between the Chinese stock market and the other Asian stock markets. Third, we find strong bi-directional volatility spillover effect among Korea, Singapore and Taiwan.

A comparison of the estimation results for the pre-crisis period with those for the post-crisis period indicates that before the global financial crisis, the volatility of the Chinese stock market was largely independent of the volatility of the other Asian stock markets but that after the crisis, the volatility of the Chinese stock market was closely correlated with that of the other Asian stock markets. This implies that the global financial crisis of 2008 increases the integration of Chinese stock market into Asian stock markets.

V. Conclusions

Because of China’s large economic scale and impressive economic growth, the Chinese stock market has become one of the most important sources of information in Asia. In particular, after the global financial crisis of 2008, the investment flow and financial linkages between the Chinese stock market and other emerging stock markets in Asia have strengthened dramatically.

In this study, we examined the existence and direction of effects of volatility spillovers between the Chinese stock market and four emerging stock markets in Asia (Hong Kong, Korea, Singapore and Taiwan) by using a VAR(1)-bivariate GARCH model. In addition, we investigated how the global financial
crisis of 2008 has impacted volatility transmission among the Asian stock markets.

The results of the empirical analysis indicate that in the pre-crisis period, there were unidirectional volatility spillovers from Korea, and Singapore to China, implying that the Chinese stock market was not closely related to the other Asian stock markets before the global financial crisis. In the post-crisis period, however, there were strong volatility linkages between the Chinese stock market and the other Asian stock markets, implying that the Chinese stock market became integrated with the other emerging stock markets in Asia after the crisis.

It is clear that the global financial crisis strengthened the international linkages between the Chinese stock market and the other four Asian stock markets, which may limit potential gains from international equity portfolios. Thus, investors should develop a trading strategy that takes into account signals from the volatility of various markets, especially from that of the Chinese stock market. A good understanding of the volatility spillover effect is an important ingredient for designing successful trading and hedging strategies and optimizing portfolios.
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Sang Hoon Kang

Sang Hoon Kang is a Professor of Business Administration at Pusan National University. He holds a PhD in Financial Economics from University of South Australia. His main interest is to model and forecast the volatility of financial time series. He has published several academic journal papers, in particular “Forecasting Volatility of Crude Oil Markets” (Energy Economics, 2009), “Structural Changes and Volatility Transmission in Crude Oil Markets” (Physica A, 2011).

Seong-Min Yoon

Seong-Min Yoon is a Professor of Economics at Pusan National University. He holds a PhD in Economics from Korea University. He has been a visiting scholar to the University of Washington in Seattle and the University of Colorado in Denver. His research fields include financial market dynamics, corporate finance, regional economics, and applied microeconomics. He has published over 120 academic journal papers on those fields including “Forecasting Volatility of Crude Oil Markets” (Energy Economics, 2009) and various books including Vision and Issues of Busan Industry (Asian Institute for Regional Innovation, 2009), Rediscovery of Busan Economy (Asian Institute for Regional Innovation, 2008), Regional Economy in the Age of Globalization (Sejong, 2008), Intelligent Finance (University of Ballarat, 2004), Regional Innovation and Industrial Networks in Busan (Kuyngsung University Press, 2004), Business Democracy and Corporate Governance (Baeksan Pub. Co., 2002), and Economic Policy (Pukyong National University Press, 1996).
강상훈(姜尙勳)

현재 부산대학교 경영학과에서 조교수로 재직 중이다. 남호주대학교(University of South Australia)에서 금융경제학 박사학위를 취득했다. 주요 관심분야는 금융시장 시계열의 변동성 예측과 모형화다. 주요 논문으로는 "Forecasting Volatility of Crude Oil Markets"(Energy Economics, 2009), "Structural Changes and Volatility Transmission in Crude Oil Markets"(Physica A, 2011) 등이 있다.

윤성민(尹盛民)

부산대학교 경제학부 교수로 재직 중이다. 고려대학교 경제학과에서 경제학 석사 및 박사학위를 취득하고, 위싱턴대학교(University of Washington at Seattle) 콜로라도대학교 델버캠퍼스(University of Colorado at Denver)에서 방문교수를 하였다. 주요 연구 분야는 금융시장 동학, 기업금융, 지역경제, 소비자이론 응용 등이다.『부산산업의 비전과 과제』(동북아지역혁신연구원, 2009),『부산경제의 재발견』(동북아지역혁신연구원, 2008),『세계화시대의 지역경제』(세종, 2008), Intelligent Finance(University of Ballarat, 2004),『지역혁신과 부산지역의 산업네트워크』(경성대학교 출판부, 2004),『기업민주주의와 기업 지배구조』(백산서당, 2002),『경제정책』(부경대학교 출판부, 1996) 등의 저서가 있으며, "Forecasting Volatility of Crude Oil Markets"(Energy Economics, 2009) 외에 120여 편의 학술논문을 발표하였다.
